The Potential for Biomass Production and Conversion in Iowa

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Chapter 1

Introduction

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CHAPTER 1. INTRODUCTION

A publication on biomass energy, distributed by the United States Department of Energy, highlights an agricultural community in Iowa that revitalized its markets for agricultural products by diversifying into energy crops. The response to this publication was immediate; the Department of Energy received inquiries from people across the United States and abroad who wished to visit this biomass success story in Iowa [1]. Sadly, the community exists only on paper, representing what might be achieved if biomass energy were incorporated into the rural economy. Because of Iowa's preeminence in agricultural production, there is both a national and international expectation that innovations in agriculture will emerge from Iowa. Clearly, leadership in biomass energy is among these expectations.

Biomass is the prominent renewable energy resource in Iowa, as well as for much of the rest of the midwestern United States. Unlike wind energy, it is widely distributed across the state. Unlike solar energy, the technology for collecting this energy form is technically mature and widely understood and practiced. Unlike either wind or solar energy, biomass energy comes in an easily storable form and is thus available when needed. However, despite the critical importance of agriculture in the economy of Iowa, biomass is not a prominent energy source in the state. Currently, biomass accounts for less than 3% of energy use in Iowa [2].

A number of previous studies have addressed the issue of expanding biomass energy use in the United States, with some of these studies providing specific information on Iowa. In 1980, the Office of Technology Assessment of the United States Congress released a study on the potential for biomass energy in the United States [3]. This study projected that up to 17 quads (quadrillion Btus) of biomass energy could be produced in the United States annually [3]. In comparison, the total energy consumption in the United States in 1990 was 68 quads [4]. This study went on to recommend the development of small gasifers with the capability of efficiently generating clean producer gas as the best means of using the dispersed biomass resources of the United States.

A white paper prepared as part of the 1990 National Energy Strategy examined both technical feasibility and cost of a variety of conversion technologies proposed for biomass

energy [5]. This paper includes the blunt assessment that electric power production from biomass is severely constrained by the availability of low-cost fossil fuels near load centers. Liquid fuels from biomass, on the other hand, were expected to make significant contributions to the nation's energy requirements, premised on continued tax incentives for the conversion of corn into ethanol. The study recommended intensified research and development on technologies to convert cellulose to alcohols.

In 1993 the Union of Concerned Scientists published a report called "Powering the Midwest" [2] that recognized biomass-to-electric power as the best near-term prospect for expanding renewable energy use in the midwestern United States. This conclusion concurs with a recently emerging view among many academics, government agency personnel, and industry representatives [6]. This study also provides state-by-state estimates of biomass resources available at different price thresholds. For example, this study estimates that 18 MM dry tons of wastes (predominately crop residue) and 4 MM dry tons of energy crops (assumed to be switchgrass) would be annually available in Iowa for between $40 and $50 per dry ton. Unfortunately, many of the conclusions of this study are strongly colored by the advocacy role of its writers.

In 1992, in recognition of the complex environmental and economic issues associated with biomass energy systems, the Electric Power Research Institute and the National Audubon Society established the National Biofuels Roundtable. The goal of the Roundtable was to develop consensus among stakeholders on guiding principles for adopting biomass energy systems. In a report issued in 1994 [7], the Roundtable counsels the use of waste biomass in the production of biofuels and power for the near-term to facilitate an eventual transition to biomass energy supplied from plantations of dedicated energy crops. The Roundtable acknowledges the importance of energy policy, environmental regulations, tax incentives, and agricultural policy, in addition to conventional market forces, in influencing the development of the biomass energy industry. Once established, this group suggests that energy crops might occupy up to 11% of agricultural lands in some regions, making it a significant secondary crop.

In 1994 the Iowa Department of Natural Resources released the Iowa Biomass Energy Plan, which describes its efforts to achieve energy sustainability in Iowa through greater use of biomass [8]. Although this plan includes several biomass resources, the largest contributors are projected to be ethanol from corn (69 trillion Btus per annum) and dedicated energy crops of switchgrass for the production of electricity (15 billion kWh, which is equivalent to 179 trillion Btus).

The present study is an examination of the potential for Iowa to develop biomass resources and energy systems. It is also a critical appraisal of roadblocks standing in the way of widespread use of biomass energy in Iowa. The report on this study is divided into several topics. Chapter 2 evaluates the biomass resources available in Iowa. This evaluation includes municipal solid wastes, forestry and agricultural wastes, as well as the potential for dedicated energy crops. Chapter 3 is an economic study of the cost of producing dedicated biomass crops, both woody and herbaceous. Chapter 4 assesses conversion technology options for biomass energy systems. Candidate technologies are described and capital and operating costs are estimated. Chapter 5 surveys existing infrastructure in Iowa that could support a transition to biomass-to-energy systems. Both transportation infrastructure to bring biomass to central conversion facilities and existing power plants and liquid fuel facilities are identified. Chapter 6 surveys the human resources that would be needed to support biomass-to-energy systems in the state. This chapter considers both manpower requirements for production of biomass crops and conversion of these crops to useful energy forms. Chapter 7 considers the prospects for financing biomass-to-energy systems. Chapter 8 reviews the environmental benefits and costs associated with large-scale biomass-to-energy systems. Chapter 9 examines how nonmarket factors associated with environmental and social concerns ("externalities") can be included in evaluations of competing production and conversion technologies. Chapter 10 provides recommendations, based on information in the previous chapters, for a course of action to introduce wide-scale biomass energy systems to Iowa.

Each chapter is organized in similar format. An introduction is followed by a description of methodologies and assumptions employed in the analysis of the topic. The third section of each chapter presents the results of the analysis. Each chapter closes with conclusions from the analysis.

Several people have contributed to this study. Chapter 1 was written by Robert Brown of the Mechanical Engineering Department at Iowa State University. Joe Colletti of the Forestry Department at Iowa State University prepared Chapter 2 with assistance from Andy Arends, Shabana Hameed, Steve Jungst, Dick Shultz, and Rick Hall. Arne Hallam of the Agricultural Economics Department at Iowa State University was the task leader for Chapter 3. He prepared the sections dealing with herbaceous crop economics with the assistance of Y. W. Park, K. Kondo, and E. Paterno. Joe Colletti prepared the sections on woody crop economics with assistance from Andy Arends. Robert Brown also prepared Chapter 4 with assistance from Brian Smith and Ethan Brue. Rebecca Roberts of the

Geography Department of the University of Iowa was the task leader for Chapter 5. She prepared the section on transportation infrastructure with assistance from Andrew Hoover. Robert Brown prepared the section on conversion facilities in Iowa with assistance from Ethan Brue. Rebecca Roberts prepared Chapter 6 with assistance from Andrew Hoover. Arne Hallam prepared Chapter 7. George Malanson of the Geography Department at the University of Iowa prepared Chapter 8 with assistance from David Cairns. Donn Johnson of the Economics Department at the University of Northern Iowa was task leader for Chapter 9. Murray Austin of the Geography Department at the University of Northern Iowa also contributed to Chapter 9. They were assisted by Amy Harris and Johanna Benson. Chapter 10 was prepared by Robert Brown.

Many others provided assistance in preparing this report. The task leaders are particularly indebted to Jim Majure of the Geographical Information Systems (GIS) Department at Iowa State University, who introduced us to graphical representation of data via GIS and prepared many of the state maps found in this report, and Marcia Pierson of the Engineering Research Institute's Engineering Publications and Communications Services, who provided professional editorial services during manuscript preparation.

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Chapter 2

Survey of Iowa Biomass Resources

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CHAPTER 2. SURVEY OF IOWA BIOMASS RESOURCES

INTRODUCTION

Iowa is a mosaic landscape of agricultural crops, pasture lands, native woodlands, prairie remnants, and wetlands, separated by a network of rivers, streams, and lakes. Iowa's landscape can be described as having moderate relief, no mountains, many streams and rivers, and very deep and fertile soils (see Figures 2.1 and 2.2) [1]. It is a highly modified landscape where agricultural activities dominate. Statewide, the average annual precipitation is about 32 inches with most precipitation occurring during the spring and summer months. The southeast receives more precipitation than the statewide average and the northwest receives less than average [2]. The average precipitation during the growing season is 21 inches [3]. The Iowa topography (land forms), soils, and climate make for ideal conditions for production agriculture.

Thompson [3] cites sources that estimated native prairies covered about 85% of the state at the time of settlement in the 1850s. Thomson [4] suggests that at time of settlement, there were over 6.6 million acres of forested lands representing about 18% of Iowa's land area. Over the last 140 years almost all of the natural prairies, prairie potholes (especially on the Des Moines lobe landform), and most acres of natural forestlands [4] have been converted to agricultural land use. Agricultural production, crops, and livestock have been the mainstay of economic development for Iowa for many years.

Present farming practices have resulted in the state of Iowa being ranked near the top in terms of total cash receipts (> $9.2 billion, third nationally in 1988) from total farm marketing (livestock and crops) [5] and land devoted to agricultural crops (>31.3 million acres out of 36 million acres) [6]. In 1992, total value of all marketed crops and livestock was over $10 billion, with $5.4 billion from livestock and animal products [6].

The economic and social gains from modern agricultural production of crops and livestock in Iowa do not account for unintended environmental impacts from soil erosion and agricultural chemicals (pesticides and fertilizers), which degrade the quality of surface and groundwater and affect wildlife species. Also, with specialization in corn and soybean

production, Iowa farming has less diversity of annual and perennial crops than in the 1950s and less biodiversity of plant and wildlife species. These factors of the environment have

Figure 2.1

Figure 2.2

not been included in attempts to quantify the net benefits from modern production agriculture.

The concerns about soil loss, ground and surface water contamination, farm crop diversity, rural development, and landscape fragmentation/biodiversity are being addressed by both the agricultural and nonagricultural interests in our state, the Midwest Corn Belt region, and nationwide. Optimal solutions to these environmental problems/externalities will involve farmers, nongovernmental organizations, and public entities working cooperatively with existing and improved soil and water conservation activities and programs. The agricultural activities and programs of the future need to be guided by the best scientific thought possible.

For Iowa, given the land and soil resources and the climate, a major innovative component of the statewide soil and water conservation activities could involve the establishment of perennial (woody and herbaceous) plant systems on certain soils, land forms, and rivers throughout the state. Such plant systems can help to address the concern for biodiversity, diversity and sustainability of agricultural production, nonpoint source pollution, rural development, and renewable energy feedstock production.

The use of certain lands in Iowa to produce renewable biomass for energy feedstock can help to diminish the environmental impacts from agriculture on the soil, water, and wildlife resources of the state. Additionally, perennial woody and herbaceous biomass produced in the state can have a significant impact in terms of ameliorating the carbon dioxide buildup in the atmosphere. The Department of Energy (DOE), Oak Ridge National Laboratory (ORNL) researchers indicate that for every 1 Mg of carbon produced by woody biomass, an estimated 3 Mg of carbon dioxide is sequestered. Thus a woody biomass plantation producing 9 dry Mg ha^{-1} yr^{-1} (~4 tons ac^{-1} yr^{-1}) of biomass would sequester about 14 Mg ha^{-1} yr^{-1} (6 ac^{-1} yr^{-1}) of carbon dioxide, assuming wood to be approximately 50% carbon. The DOE, ORNL [7], and the National Audubon Society [8] indicate the potential of no net increase of carbon dioxide because of biomass growth and production from woody and herbaceous perennials compared with the net increase in carbon dioxide caused by the use of fossil fuels or the use of annual crops for biofuels.

The production of renewable biomass in Iowa does not mean that there will not be environmental impacts. Because dedicated herbaceous and woody energy systems are similar to row and hay crop production, the use of pesticides and fertilizers and the establishment on erodible soils have the potential of generating nonpoint source pollution such as those from annual row crop production. Thus careful site selection and design of

the biomass systems to fit the landscape is required to minimize soil and water pollution problems. The production of renewable biomass must adhere to the goal of being sustainable and environmentally friendly (or, at minimum, environmentally neutral). Moreover, sustainable production of herbaceous and woody biomass must take a long-run, "agro-ecosystem" view.

The recovery and reuse of wastes and by-products from agricultural, municipal (residential and commercial), and industrial activities can provide additional valuable energy feedstock in an environmentally benign manner. Increasing costs (tipping fees, transportation costs, etc.) for the disposal of waste materials, limits on available sanitary landfills, and changes in state and federal laws affecting the options for disposal of residential, commercial, industrial, and agricultural wastes are factors influencing the potential of energy recovery from the various organic waste streams in Iowa.

Iowa's land (soil), forest, and water resources do play important roles in the issues of surface and groundwater pollution, soil erosion, agricultural diversification, biodiversity of plant and animal species, and energy feedstock supply. These resources are not uniformly distributed across Iowa. Land use, soils, forests, and waterways all vary in terms of location across the state and their capabilities in providing (market) goods and environmental services such as aesthetics and soil and water protection.

Goal of Task

The purpose of this survey of the Iowa biomass resources is to provide statewide estimates of the potential of biomass resources from natural and human-caused biologically based agricultural, residential, and commercial/industrial activities in the state.

Task Description

Biomass resources to be surveyed include agricultural land suitable for biomass production, municipal and yard waste, crop residues and manure, and other materials of recent biological origins. Total woodlands and croplands available for commercial use will be determined through existing databases. Soil Conservation Service (SCS) Land Capability Classifications will be employed in identifying contingent land suitable for meeting sustained fuel requirements for central-sited energy conversion facilities. The relationship of proposed biomass production to existing soil, water, and wildlife conservation plans will be determined.

In short, this chapter deals with the issues of what lands and soils are potentially available for dedicated, "green field" biomass production systems (herbaceous and woody) and where they are located within the state. The chapter also discusses what the types and quantities of biomass are that can be "collected" as residues or wastes from agricultural and nonagricultural activities across the state and where these biomass residues and wastes are concentrated?

METHODOLOGY

To complete this task, several subtasks were identified for different types of biomass resources. This organization allowed for the important data sources to be identified and analyzed for each type of biomass. Also, this classification of biomass resources will facilitate future in-depth analysis of Iowa's biomass resources supply and demand within a comprehensive decision-making model that uses economic, environmental, social, and political/institutional criteria/factors.

The methodology used for this task consisted of four major steps:

1. data collection
2. summary and description of data
3. synthesis of data
4. analysis and display of data

Data on current and historical land use (with emphasis on agricultural land use), the statewide drainage (rivers and lakes) system, and soils of the state were collected from published and unpublished sources. Likewise, data on each biomass resource type as per subtasks (see Table 2.1) were collected mainly from government documents and computerized databases. To the extent possible, the data are Iowa-specific for the period 1990–1994.

After assembly of various data for land, soil, waterways, and biomass resource types, each resource is described in terms of qualitative and quantitative characteristics. Next the data are synthesized and analyzed, given certain assumptions of factors affecting each basic resource (e.g., land use, soil, forest, and water) and each biomass resource. For example, land use is analyzed assuming continuation of soil and water conservation programs as part of the 1995 farm bill to determine the biological/physical potential of the biomass resource. In this chapter, the term "synthesized" means that new data were created from the combination of several components of particular data. The analysis of the basic

Table 2.1. Subtasks by biomass resource type, geographical elements, and general data sources to quantify the resources.

Subtask 1. Perennial Crops - (woody & herbaceous). Herbaceous crops from perennial prairie grasses. Short-rotation woody crops (SRWC). Herbaceous and woody biomass crops as dedicated "green-field" energy plantations. Woody biomass from natural forestlands.

- Geographical elements: Stream corridors, flood prone lands, HEL, native forestlands
- GIS databases - STATSGO
- USDA & state data - USDA SCS & Forest Service, IA DNR, IA DALS,
- Nongovernmental organization (NGO) reports

Subtask 2. Annual Crops. Herbaceous plants such as sorghum.

- Geographical elements: Crop acres, flood prone lands, HEL
- GIS databases - STATSGO
- USDA & state data - USDA SCS, IA DALS,
- Governmental organization reports (ISU - CARD)

Subtask 3. Waste Biomass Resources. Municipal and yard wastes from residential and commercial sources. Municipal treated sludge (biosolids). Demolition and construction wastes (organic faction). Wood wastes from the Iowa wood industry.

- Geographical elements: population distribution, forestland/timberland acres, mill locations
- USDA Forest Service, IA DNR
- Nongovernmental organization (NGO) reports

Subtask 4. Animal Manures/ Crop Wastes. Manure from livestock in feedlots. Residues from annual crops.

- Geographical elements: Crop acres, livestock feedlots
- GIS databases --> overlays
- USDA & state data, SCS, IA DALS, IA DNR,
- Nongovernmental organization (NGO) reports -
- Livestock & commodity groups

and biomass resources used biological/ecological criteria to determine the potential biomass resource by type for the state. The results are displayed in tables and, to the maximum extent possible, in graphs/figures by use of Geographical Information System (GIS) technology (Iowa State University GIS Laboratory).

For each biomass resource type, data were collected from printed public documents dealing with land use in the Midwest and Iowa, soils by county from the SCS, and crop production data from the U.S. Department of Agriculture (USDA) and the Iowa Department of Agriculture and Land Stewardship (IDALS). Additionally, governmental databases such as the State Soil Geographic Data Base (STATSGO) were used to provide a spatial representation of the various components of each biomass resource for each of the 99 counties in Iowa and the estimates of the potential by biomass type for each county. The results in this chapter are defined at the county level. However, some data are not spatially derived at the county level, meaning that it is not known exactly where in the county the data/resources occur. For example, annual crop and livestock production and CRP acres are not spatially derived. Thus only the totals for these data by county are known, not where in the county they occur in relationship to all other land uses or agricultural activities. Thus it is not known exactly where within a county acres with specific characteristics occur; only the totals and proportions are known with certainty.

A driving force in the methodology used in this chapter was to provide a spatial or geographical display of the potential for each type of biomass resource for the entire state. Figures depicting the quantity and/or location of the various produced and waste biomass types are presented in the results section of this chapter.

An accurate estimate of the production and utilization potential of biomass types requires the simultaneous consideration of biophysical, ecological, socio-economic, and institutional/political criteria. Because of the long-term nature of dedicated woody and perennial biomass production and its relationship to associated environmental and socio-economic problem/issues in the state, a special emphasis is given to assessing the potential based on multiple decision criteria. Biological suitability will be combined with an economic criterion such as land rent and an institutional factor such as the agricultural land idled under the Conservation Reserve Program (the 1985 Food Security Act and the Food and Agriculture Conservation and Trade Act of 1990) to determine geographical zones of high, medium, and low biomass production. Future research endeavors beyond this report regarding Iowa biomass resources need to model both production (supply) and utilization

(demand). Also, site-specific evaluations within the zones with the highest potential for dedicated and waste biomass types must be undertaken.

RESULTS OF ANALYSIS

This section presents the estimates of the biomass types considered in this report. Additionally, the exact steps, assumptions, and data/information sources used to obtain estimates for each biomass types will be presented.

Land Use

Iowa has 36.016 million acres of land and water. The land area totals 35.746 million acres and water areas make the balance. Most of the land area is classified as private rural land (32.4 million acres), with public (county, state, and federal) lands representing a very small ownership component. In 1992 there were approximately 27.2 million acres of cropland in Iowa [6]. Table 2.2 indicates the major agricultural crops in 1992. The two dominant annual crops are corn and soybeans with 13.2 million acres and 8.15 million acres planted in 1992, respectively [6]. Figure 2.3 through Figure 2.9 [6] give a visual representation of the 1992 county acreage harvested for the major crops grown in Iowa. The cropping pattern for soybeans in Iowa is associated with the major landforms and soil associations. The northwest, central, and north central counties (Des Moines lobe, northwest Iowa plains, and Missouri alluvial plain landforms) have the greatest number of soybean acres (produced and) harvested in 1992 (and before). Corn production and harvest is distributed across more landforms of the state, except in the south central counties (southern Iowa drift plain) where the terrain has more relief. The south central counties have greater hay and alfalfa production and livestock grazing than other regions in the state, except in the northeast where dairy and alfalfa/hay production are concentrated.

Since the mid-seventies, Iowa's farm and nonfarm economies have undergone major changes. Fewer family farms and many larger (>2,000 acre) corporate farms exist today. A boom-and-bust farm economy period in the late seventies through early eighties caused many hardships for the farming sector and had statewide economic impacts. Concomitant with these changes were changes in the nation's farm policy with heavy emphasis on soil and water conservation to address the concerns related to nonpoint source (NPS) pollution.

Table 2.2 Iowa's agricultural crops - 1992[a].

Crop	Planted (000 -acres)	Harvested (000 -acres)	Production (1,000's)
Corn	13,200	12,950	1,903,650 bu
Corn silage	-	230	4,025 tons
Soybeans	8,150	8,120	357,280 bu
Oats	859	375	25,125 bu
Wheat	70	40	1,560 bu
Alfalfa	-	1,550	5,735 tons
All hay	-	1,950	6,615 tons

[a] Source: [6].

Corn is used for animal feed, to produce a food sweetener, and for the production of ethanol. Soybeans are used for many food and nonfood products. Today nonfeed and nonfood uses of corn and soybeans are being researched and developed in the state. Likewise, research continues for Iowa's major crops on improving yields, increasing pest resistance, and enhancing field/pasture production techniques.

The latest USDA Forest Service (1990) estimate for the state indicates over 2 million acres of forestland, up nearly 500,000 from the 1974 survey [9]. The internal (within Iowa) and external forces (nation's economy) caused a reversal of forestland conversion to agricultural use, which was characteristic of the period 1950–1974. In 1974 natural hardwood forests covered 4.3% of the state. In 1990, 5.7% of the state was in forests. The greatest increase in forestland over the period since 1974 was in the southeastern unit (as defined by the USDA Forest Service), up nearly 42%. Figure 2.10 indicates the forestland by county in Iowa. Forestland is located in the northeast, southeast, and south central regions and along the major river systems in Iowa.

Timberland is defined as forests producing, or capable of producing with management, 20 cubic feet per acre per year or more of growth. These forested acres have been referred to as commercial forest lands, although there are no economic criteria used to establish the commercial profitability. The timberland distribution across the state is presented in Figure 2.11. Timberland ownership is predominately farmer (~64%), private individual (~22%), private corporation (~6%), and public (~8%). The quality hardwood

Figure 2.3

Figure 2.4

Figure 2.5

Figure 2.6

Figure 2.7

Figure 2.8

Figure 2.9

Figure 2.10

Figure 2.11

forest type (white oak, red oak, and hickory) represents about 37% of the timberland. The maple-basswood and elm-ash-soft maple associations combined represent about 50% of the timberland. Net growing stock volume has increased annually by 44 million cubic feet since 1974. See Figure 2.12 for the distribution of net growing stock volume. Growth for most forest species has exceeded removals (for land clearings and wood product use) [9].

Annual Set-aside Acres, the Conservation Reserve Program (and Wetland Reserve Program)

Annual set-aside (diverted) agricultural lands totaled over 625,000 acres in 1992. For comparison purposes, the total diverted acres in 1987 were 3.56 million [6]. This indicates the rapid shift in agricultural land use (crop production) in response to farm policy programs designed to support commodity prices and increase farm income. Currently over 2.2 million acres are enrolled in the Conservation Reserve Program (through the 12th sign-up) or Wetlands Reserve Program [10]. Figure 2.13 presents the distribution of the CRP acres across the state and the percentage of total land in each county in the CRP.

The Conservation Reserve Program (CRP) originated in the 1985 Food Security Act (FSA). It is designed to provide farmers with a ten-year conservation option to continued cropping of lands with excessive soil erosion. The Food, Agriculture, Conservation, and Trade Act (FACTA) of 1990 (under Title XIV - Conservation) amended the contract length to allow 10- and 15-year contracts and established the Wetland Reserve Program, a conservation program similar in intent to the CRP but focused on excessively wet farmland. The CRP allows farmers to enroll qualified (erodible) lands into the program in exchange for development of "permanent" grass and/or tree cover, an annual rent (determined by a bid process), and cost-share of 50% of the establishment cost. There is an upper limit of $50,000 per person per year for annual rent paid for all acres enrolled in the program. The CRP program was authorized to establish permanent grasses and trees on 45 million acres of highly erodible land (HEL), nationwide. No more than 25% of the cropland in any county can be enrolled in the CRP. The Agricultural Stabilization and Conservation Service (ASCS) administers both programs with assistance from the Soil Conservation Service (SCS), state forestry, and Extension agencies [10], [11]. The Food, Agriculture, Conservation, and Trade Act (FACTA) established an upper limit of 1 million in the WRP [11].

Figure 2.12

Figure 2.13

Through the twelfth sign-up (June 15-26, 1992), Iowa has 2,224,818 acres enrolled in the CRP. With the exception of 16,157 acres planted to trees, the Iowa CRP acres have been planted to various permanent grasses. The average rent paid for Iowa CRP lands is $82.31 per acre. The national average is $49.67 per acre. Out of the total acres enrolled in Iowa in the CRP, 1,373,831 acres represent a reduction in base acreage for several commodity crops. Eighty-seven percent of this commodity crop base acreage reduction is from corn acres [10]. One may interpret these corn acres (and all acres in CRP/WRP) to be "farmer-determined marginal" acres in terms of acceptable soil loss, yield, and economic rent. Otherwise these acres would not have qualified for the CRP, and the farmer would not have bid them into the program.

The first ten-year CRP contracts expire in 1996. Iowa will have over 334,000 acres of permanently vegetated land "coming out" of the CRP [10]. What will happen to these acres is the subject of current debate and analysis. Will all 2.2 million acres of CRP lands be converted into annual row crop production? It is unlikely. However, at the moment, it is uncertain how many acres will remain in permanent vegetative cover.

Iowa's current crop and livestock market prices are poor, and the outlook for both markets is mixed and uncertain. The agricultural crop and livestock markets (the current market price for corn is $2.14 per bushel, soybeans is $5.88 per bushel, hogs are $50 per hundred weight, and cattle are $67 per hundred weight as quoted in the *Sunday Des Moines Register*, July 17, 1994), foreign trade (e.g., North American Free Trade Agreement - NAFTA, General Agreement on Trade and Tariffs - GATT), climate/natural disasters (e.g., droughts and floods), and farm policy (e.g., the 1995 farm bill) will all impact the private decisions regarding all CRP/WRP acres.

Idle Land in the Midwest

In 1986 the cropland acres supply was estimated to be in excess of need (demand) by 44 million acres. Based on projections under fixed assumptions of demand, prices, and policy (the intermediate and low-stress scenarios), the Center for Agriculture and Rural Development (CARD) for the SCS has projected an increase for idle cropland in the U.S. [12]. This analysis was completed for the SCS as required by the Resource Conservation Act (RCA). CARD projects in the Second RCA Appraisal that the Midwest (Corn Belt, Great Lake, and Northern Great Plains regions) could have 79.6 million acres idled in the year 2000. As indicated in the Second RCA Appraisal, the excess capacity of cropland beyond the lands idled under the CRP may mean that

1. Land may be abandoned
2. Farm and trade policies will cause demand to match supply, allowing higher cropping cost farming to occur
3. Alternative land use and crops (trees/biomass) may be produced, assuming lower land prices
4. Typical crops will be produced but with an increase input of land relative to capital and labor.

As pointed out in the Second RCA Appraisal, the idle and "used" cropland projections assume a continuation of the current farming incentives over the next 50 years. As was indicated, this assumption is "unlikely false" [12]. The future farm policy is being debated and analyzed as this report is being written. It seems that there may be land available in the Midwest for conservation and energy-oriented biomass systems beyond the CRP acres.

Nonagricultural Land Use

Nonagricultural land is urban land, roads, aggregate (gravel, stone etc.) producing lands, farmsteads, strip-mines, and any other land not usable for agricultural or forestry production. In 1990 the projected acreage was 3.235 million acres. Nonagricultural land is projected to increase to 3.322 million acres in the year 2000 and to 3.435 million acres in 2030 [13]. Given the total land and water area of Iowa at nearly 36 million acres and subtracting the area in water (0.22 million acres), the theoretical upper limit of land available for agriculture, forestry, and agroforestry production could be 32.456 million acres in 2000 and 32.359 million in 2030.

A question that must be answered is: what lands are being converted to nonagricultural land? The Second RPA Appraisal indicates that 60% of the agricultural land converted to nonagricultural land comes from cropland. The balance of agricultural land converted must be pasture, hay lands, wooded pasture, and woodlands. Moreover, if by 2030 an additional 200,000 acres of agricultural land is converted to nonagricultural land, over 50% may come from prime farmland (see page 21 of reference [12] for the definition of prime farmland).

Flood-Prone Land and the 1993 Floods

Based on the 1982 National Resources Inventory, Iowa has 4.9 million acres that are classified as flood-prone rural (nonfederal) lands [12]. Given the very small percentage

of federal and state lands in Iowa, this means that nearly 14% of Iowa's rural land is prone to flooding. The risk factor for these lands is high in terms of potential economic loss and environmental damage from agricultural activities—off-site impacts from NPS pollutants. Over 7 million acres in Iowa have drainage tiles or drainage ditches facilitating excess water removal. Unknown miles of private levees have been built along Iowa's rivers and streams, allowing farming activities to occur on very fertile lands. The tiling of certain soils, the straightening of streams, and the construction of public and private levees have significantly reduced the native wetlands and riparian zones throughout Iowa. These sponge-like zones of vegetation are effective buffers against major precipitation events such as those during the summer of 1993. Moreover, the riparian forest buffer plays an important role in ameliorating nonpoint source pollution from agricultural and other sources [13].

The effects of the great floods of 1993 are still being felt, and their costs, initially estimated at $10 billion, are still being determined. The precipitation totals during the summer of 1993 for Iowa, Minnesota, Illinois, South Dakota, and North Dakota set new records. Most of Iowa had over 2 feet of rain from April through August and most of the central region of Iowa had over 3 feet of rain. Twenty-three million acres were affected by the flooding in the Midwest and Congress has authorized $5.7 billion [14].

Federal and state agencies are analyzing what happened to allow such widespread and massive destruction of crops, property, and infrastructures. The federal task force draft report (led by the U.S. Army Corps of Engineers) on the 1993 flood was just released (July 1, 1994). The draft report suggests that innovative management of the river systems in the Midwest is required to "solve" the flood problems. This likely means that changes in agricultural land use and the development of wetlands and forested riparian buffer zones will be centerpieces of an integrated, sustainable approach to flood management.

Also, the Environmental Protection Agency (EPA) is involved in analyzing alternatives to rebuilding the thousands of miles of levees that were ruined in the flood. Some of the analysis is being done at Iowa State University by CARD for the EPA [15]. Alternatives being considered for test areas include rebuilding the same levee and planting agroforestry (herbaceous and woody) systems for biomass. Wetland or riparian areas along Iowa's rivers and streams will be the focus of attention as economically viable and environmentally friendly solutions are sought.

Soils

The SCS Land Capability Classification

The SCS classifies soils based on their suitability for most types of field crop production. The system uses a broad capability class denoted by Roman numerals from I to VIII. Class I lands are soils with few limitations that restrict their use for field crops. The ascending numerals indicate increasing limitations to field crop use. The system also has capability subclasses that indicate the main type of limitation for a given class. The SCS uses small letters—e (risk of erosion), w (wet conditions interfere with crops), s (shallow, droughty, or stony soils), or c (climatic limitation) [16].

Table 2.3 indicates the breakdown of soils classified by the SCS using the LCC system. Roughly 10% of soils in Iowa have few limitations for field crops. The dominant classes are II and III. Class II soils are soils with moderate limitations to field crop species and require moderate conservation activities. Class III soils have severe limitations in terms of plant species and require special conservation practices.

Table 2.3. The Land Capability Classification (LCC) of Iowa's soils[a].

LCC	Total Area (1,000's acres)	Percentage
I	3,015	8.6%
II	16,452	46.7%
III	9,927	28.2%
IV	2,921	8.3%
V	291	0.8%
VI	1,434	4.1%
VII	1,165	3.3%
VIII	32	0.09%
Total	35,237[b]	100.09%

[a]. SCS, 1994 LCC data for Iowa. The LCC is a system used to show the suitability of soils for most field crops.

[b]Some lands are not classified by the SCS. The total represents the sum of cropland, pastureland, and forestland plus other lands. The state total land area from the 1982 National Resource Inventory is 36.016 million acres.

Because of the importance of soil erosion as an NPS pollutant and as a factor that affects the long-term economic viability of the land for crops, it is necessary to break down the LCC classes into the area in subclass "e". Table 2.4 indicates the erosion subclass area for the state by LCC. Recall that the erosion subclass acres are in crop, pasture, or forestland use. This means that some of the 20.7 million acres of erosion subclass acres are in permanent vegetation cover in pasture and forest land use. The data indicate that the overall erosion risk is great and the distribution of subclass "e" acres within the LCC system serves as the base for all governmental and private programs designed to reduce soil erosion to "a tolerable level."

Figure 2.14 and Figure 2.15 indicate the distribution of LCC 2e and LCC 3e/4e soils, respectively [17]. Note the scattered distribution of 2e lands with small clusters of counties in the northeast, north central, central, west, and northwest regions of Iowa. In Figure 2.15 it is apparent that the counties bordering the Missouri and Mississippi rivers and the bottom three tiers of Iowa counties have the greatest concentration of 3e and 4e soils with severe limitation to typical crop production.

Table 2.4 Iowa's LCC with erosion subclass areas and the relative percentage of erosion subclass land within each LCC class[a] .

LCC	"e" Subclass (acres)	Class Total (acres)	Ratio "e" subclass to Class total (%)
I	0	3,015	-
II	7,761	16,452	47.2%
III	8,372	9,927	84.3%
IV	2,380	2,921	81.5%
V	0	291	-
VI	1,301	1,434	90.7%
VII	888	1,165	76.2%
VIII	32		0.09%
Totals	20,734	35,237[b]	58.8%

[a]SCS, 1994 LCC data for Iowa. The LCC is a system used to show the suitability of soils for most field crops.

[b]Some lands are not classified by the SCS. The total represents the sum of cropland, pastureland, and forestland plus other lands. The state total land area from the 1982 National Resource Inventory is 36.016 million acres.

Figure 2.14

Figure 2.15

Iowa's Marginal (Crop) Land

The SCS defines marginal land (for agricultural crop production) as those lands in LCC IV–VII. For Iowa, based on the 1994 SCS LCC data, there are 5.811 million acres of marginal lands. Figure 2.16 presents the distribution of Iowa's marginal crop land. The Loess hills, northeast bluff region along the Mississippi river, and the southern/south central regions have the greatest concentrations of marginal crop land. Using the rural land use percentages determined by Campbell and Majerus [18] (from SCS - 1982 National Resource Inventory data), an estimated 44.5% of marginal land in Iowa is cropland, 35% is pastureland, and the balance, 20.4%, is forestland. Applying these land use percentage values to the marginal land total, an estimate for 1994 of the number of marginal acres by land use can be determined. Thus an estimated 2.86 million acres are in cropland use, 2.03 million acres are in pastureland use, and 1.19 million acres are in forestland use.

Campbell and Majerus [18] evaluated marginal land in the Great Lakes region (where Iowa was included) for conversion to permanent biomass crop production. They recommended that only LCC V and VI (crop and pasture) lands be converted to perennial energy crop production. An estimated 71,400 acres of LCC V cropland and 454,900 acres of LCC VI cropland were recommended for conversion. Additionally, they recommended that 536,500 acres of LCC VI pastureland be converted to perennial energy crops. In total, they recommend over one million acres be converted to perennial energy crops. The LCC IV marginal acres were excluded from the recommendation on the basis that the SCS does indicate these lands/soils to be acceptable for typical rows/field crop production, although very severe cropping limitations exist.

Given the expectation of continued conservation titles in the 1995 farm bill, reduced funding for the 1995 farm bill, political push for integration of rural development, and soil and water conservation policies and programs, all LCC IV–VII marginal lands in crop and pasture land use are see as potential lands available for dedicated, "greenfield" biomass (woody and herbaceous) production systems. Thus 4.89 million acres of marginal (agricultural) lands could produce perennial woody and herbaceous energy crops in Iowa. The amount of marginal land that is likely to produce biomass for energy depends on assumptions of production costs, biomass market prices, energy-oriented government biomass production incentives, and agricultural policy.

Figure 2.16

Iowa's Agricultural Land Value and Land Rent

The state's agricultural land has continued to increase in value since 1986. The average value increased by $26 from the 1992 statewide value. In 1993 the average agricultural (farmland) value for the state was $1,275 per acre. The estimates of agricultural land value are based on an Iowa State University Agricultural Extension survey (by Duffy and Gingerich [19]) of real estate brokers and people knowledgeable about the agricultural land market (see Figures 2.17 and 2.18). Survey data are combined with U.S. Census of Agriculture data to provide regional (crop reporting district) and county estimates for agricultural land of low, medium, and high quality. Agricultural land value in an assumed competitive market represents the capitalized value of land used for agricultural (cropping and livestock) production. Other land use demand, such as suburban or urban development, will cause changes (increases) in farmland that is closest in proximity to residential, commercial, and industrial development. Thus the market price for farmland will also reflect nonagricultural development factors, in addition to the value of the land used for (assumed) continued agricultural production. In the simplest terms, the 1993 farmland values represent estimates of what willing buyers are paying for farmland sold by willing sellers.

The 1993 data indicate that the south central crop reporting district has the lowest average agricultural land values considering low, medium, and high quality lands. The 1993 values for low, medium, and high quality farmland in the south central region were $1,041, $618, and $342 per acre, respectively. The weighted average farmland value for this region in 1993 was $643 per acre. This district (south central) farmland average value was more than $300 lower than the next lowest regional average value of $961 per acre from the southwest region [19].

The 1993 data indicate that farmland values in the southwest, south central and southeast crop reporting districts (basically the three lower tiers of counties in Iowa) are lowest of all crop reporting regions for the low and medium quality lands [19]. The 1993 survey indicates that 75% of farmland sales were to farmers (72% existing and 3% new). Investors were involved in 22% of the sales (representing about 22% of the farmland). The greatest percentage of investor farmland sales occurred in the southeast, southwest, and central crop reporting districts, all with 28% [19] Clearly there is competition for the farmland by nonfarmer investors. This can be either a positive or negative factor in the development of dedicated biomass production systems.

Figure 2.17

Figure 2.18

Rent for cropland represents the returns to land (as opposed to returns to labor or capital). Based on an ISU Extension survey instrument of agriculture and agribusiness professionals, including farmers, cash rents are estimated for twelve areas of the state [20]. The cash rent reporting areas are different from the nine crop reporting districts used for the land value survey. The 1994 cash rents by areas for corn, oats, hay, and pasture lands ($ per acre) reported by Edwards and Davis [20] are presented in Table 2.5.

Table 2.5. The 1994 cash rents ($ per acre) for low quality corn land and oats, grass hay, and pasture lands by Iowa rent areas.

Areas	Corn	Oats	Grass Hay	Tillable Pasture	Permanent Pasture
1	$80/ac	$73/ac	$52/ac	$61/ac	$23/ac
2	89	82	79	46	26
3	84	81	58	43	25
4	78	80	90	75	33
5	84	75	63	41	30
6	83	72	51	41	28
7	92	67	55	40	25
8	90	73	64	50	30
9	89	79	86	54	28
10	72	63	46	46	27
11	64	45	37	34	20
12	74	60	48	44	22
State Avg.	82	71	55	48	26

Rent areas 10, 11, and 12 are the bottom three tiers of counties in the state. Areas 11 and 12 have the lowest cash rental values considering all agricultural land uses in Table 2.5. It is assumed that these land use categories could shift to dedicated herbaceous and woody biomass production under certain economic, social, and political conditions related to production and utilization of renewable biomass in Iowa, the region, and the nation.

Perennial Crops

Perennial woody species ecologically suited to Iowa's land, soils, and climate include willow (*Salix* spp.), hybrid poplar (various selected *Populus* clones), eastern cottonwood (*Populus deltoides* Bartr.), silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and black locust (*Robinia pseudoacacia* L.). Perennial herbaceous species suited to Iowa include reed canarygrass (*Phalaris arundinacea* L.), switchgrass (*Panicum virgatum* L.), perennial rye (*Lolium perenne* L. var. perenne), and big bluestem (*Andropogon gerardi* Vitman). The woody and herbaceous perennials listed are limited to species for which Iowa-based biomass research has occurred.

The production of woody biomass for energy in plantations is referred to as short-rotation woody crops (SRWCs). Fast-growing tree species are planted at close spacing (0.3 m x 0.3 m to 2.4 m x 2.4 m) and harvested in 2–15 years. Most economic studies by DOE [21] and university researchers [18, 22, 23] indicate that rotations of 5 to 15 years are viable. The establishment and management of SRWC systems are similar to agricultural crops including the use of pesticides (mainly herbicides), cultivation, and fertilizers. Weed control is critical for optimal biomass growth. In Iowa, SRWC systems studied by the ISU Department of Forestry since 1975 have used fertilizers sparingly because of the relatively fertile soils across Iowa [22].

Perennial herbaceous systems are referred to as herbaceous energy crops (HECs). HECs using species such as switchgrass, big bluestem, and reed canarygrass are established with typical farm practices and require intensive management for optimal biomass yield. Management practices include the use of pesticides (mainly herbicides), cultivation, and fertilizers. Harvesting can occur (after initial establishment year) one or more times each year. The biomass can be baled using typical or special farm equipment.

Perennial herbaceous and short-rotation woody crops offer many potential environmental benefits associated with NPS pollution (soil erosion and water quality) and carbon sequestering [21]. Moreover, the DOE [24] and the Electric Power Research Institute (EPRI) [25] have developed programs or strategies for the use of biomass for electricity. Both have identified the Midwest as having potential for both woody and herbaceous biomass for energy production. Thus it is important to present a realistic and scientific basis for indicating the lands that have the greatest potential for perennial herbaceous and woody crops.

This section uses basic soil and land characteristics to depict lands within each Iowa county that would be suitable for herbaceous and/or woody biomass production. Neither

this section nor this chapter address the cost or income aspects of biomass production. The costs of woody and herbaceous biomass production will be presented and discussed in Chapter 3.

Because of differing viewpoints and assumptions used in this section relative to recent Midwest [26] and Iowa biomass assessments [27], it is necessary to discuss and compare these assessments regarding perennial woody and herbaceous biomass potential for Iowa. The Union of Concerned Scientists [26] developed an estimate of the potential biomass from SRWC for Iowa (and other Midwest states) that is based on the assumption that hybrid poplar can be grown only on the "Land Group 1" soils and "Land Group 7" soils. They cite research from Minnesota that indicates that hybrid poplar does best on good quality soils with adequate soil moisture or on soils of medium quality with a close water table. They same statement can be made for any HEC or SRWC species. Thus the set of land/site quality assumptions used for SRWC biomass led to the false appearance that SRWC can only play a minor role in Iowa regarding dedicated biomass production. From a biological/ecological viewpoint, this is not true.

Clearly, no agronomist or forest biologist considering siting an energy plantation of switchgrass or hybrid poplar (*Populus* spp.) would reject a site with a well drained, deep and rich soil (a good soil) with a gentle slope. The better the soil, the better the growth and yield of any perennial—herbaceous or woody. The flatter the slope, the easier the establishment, culture, and, especially, harvest of the biomass. But the SRWC species (poplar - cottonwood/aspen types, silver maple, willow, and green ash) being evaluated in Iowa for biomass grow well on many sites.

Biologic Decision Criteria for Determination of Perennial HEC and SRWC Suitability

Based on the literature [23] for both herbaceous and woody perennial plants used for biomass for energy, long-term SRWC research at ISU [22] and professional recommendations by forest biologists [28, 29] and an agronomist at ISU [30], the primary site limitations for herbaceous and woody biomass species are (1) where the depth to water table is deep (> 3.5 ft) and the drainage excessive or (2) where the depth to water table is shallow (< 1.5 ft) and flooding occurs frequently with long (> 7 days) duration.

If the soil and site conditions do not match these criteria, then the land would be suitable for woody or herbaceous biomass production. By carefully evaluating the actual

site and selecting tree or grass species adapted to the site, growth potential and cost-effectiveness can be achieved.

Biological decision criteria applied to perennial herbaceous and woody plants used for biomass production are flooding potential (duration and frequency) and depth to water table. Also, slope and drainage characteristics are evaluated. Steep slopes will make production and harvesting more difficult, whereas excessively drained or very poorly drained soils will present droughty or swampy conditions for the plants.

Figures 2.19 through 2.21 present the statewide distribution of low, moderate, and high (steep slopes). The counties in the Des Moines lobe, northwest Iowa plains, and the Iowa surface landforms have the greatest concentrations of low (0–5%) sloped lands. The southern counties of the state (southern Iowa drift plain) is where the moderately sloped (6%–14%) lands occur. The northeast counties bordering the Mississippi river have the steepest sloped lands.

In terms of drainage, Figures 2.22 through 2.25 indicate the statewide distribution of soils as excessively to very poorly drained. The excessively/somewhat excessively drained and very poorly drained soils would make very poor sites for herbaceous and woody biomass systems.

Schultz [28] and Hall [29] established the criteria for determining acceptable depth to water table for SRWC plantings as being those lands with other than shallow (0–1.5 feet) or deep (> 3.5 feet) depth to water table. Figures 2.26 through Figure 2.28 show the areas with shallow, deep, and acceptable (not shallow or deep) depth-to-water table.

Figure 2.29 depicts flooding potential. All lands with acceptable depth to water table and without frequent and long duration flooding are suitable for perennial herbaceous or woody biomass production.

Annual Crops

Annual energy crops include hybrid grain corn, sorghum, and specialty corn such as Tropical or Caribbean corn. These potential energy crops are produced exactly as are the typical corn and soybean crops in Iowa with intensive inputs of fertilizers, pesticides, and management. The expected positive environmental effects from perennial herbaceous and woody energy crops may not exist for this type of energy crop [21].

With over 1.9 billion bushels of corn produced in 1992 in Iowa, there is the appearance of a large resource base for utilization of corn for energy production, primarily by conversion to ethanol. Currently about 7% of Iowa's annual corn production is

Figure 2.19

Figure 2.20

Figure 2.21

Figure 2.22

Figure 2.23

Figure 2.24

Figure 2.25

Figure 2.26

Figure 2.27

Figure 2.28

Figure 2.29

converted to ethanol. In 1991, 3.75 million tons (3.4 million Mg) of corn was used to produce over 343 million gallons (1.3 billion liters) of ethanol in Iowa [27–31]. This liquid transportation fuel is used in a gasoline blend (10% ethanol) and receives a federal subsidy to promote its use and acceptance as a clean transportation fuel. There are limits to the proportion of Iowa corn that will be used for ethanol production. These limits exist because of competition with livestock feed and corn sweetener demand and from other Corn Belt states' production of ethanol from corn. As reported by the Iowa Department of Natural Resources (IDNR) [27], the Iowa Corn Promotion Board has indicated that only 26% of the current annual corn production could be converted into ethanol without affecting, in a negative way, the livestock feed and sweetener products. Moreover, the oil companies currently are applying heavy political pressure to limit the expanded use of ethanol (in various blends) in certain major U.S. cities with summer air quality problems.

Sweet sorghum and sorghum/sudangrass hybrid are two annual crops that have been investigated as energy crops for Iowa. Expected yields are substantial for these annual crops, reported to be in the range of 7 to 16 dry tons per acre [21]. Researchers at Iowa State University (Drs. I. C. Anderson, Department of Agronomy, D. Buxton, USDA- ARS, and A. Hallam, Department of Economics) have been researching the growth, yields, management, and economics of these annual crops and other annual crops such as rye and Caribbean corn. Also, several perennial herbaceous crops (switchgrass, reed canarygrass, big bluestem, and alfalfa) are being researched. Detailed production cost estimates and data on growth and yields of annual and perennial herbaceous energy crops are presented in Chapter 6.

The use of these annual crops in agroforestry systems offers an alternative to monoculture row crop production. By growing trees and herbaceous crops in 16-m (52-ft) wide strips adjacent to each other, the growth of both is expected to be enhanced, and because of the blend of perennial woody plants with the annual herbaceous crops, the negative environmental impacts from intensive "row" cropping are reduced. An alley-cropping woody and herbaceous energy system has been developed by the City of Ames, Iowa State University, and the IDNR [22]. Early results indicate compatibility between the hybrid poplar - short-rotation woody crop (SRWC) and sweet sorghum, and between SRWC and Caribbean corn. Switchgrass is also grown in this alley-cropping agroforestry energy system and seems to be quite compatible. In 1991 and 1992, the sorghum and Caribbean corn yields were 24 dry metric tons ha^{-1} (10.7 dry tons ac^{-1}) [22].

Waste Biomass Resources

Waste biomass resources includes municipal solid wastes from residential and commercial sources, municipal treated sludge (biosolids), and demolition and construction wastes (organic faction). Nationally, an estimated 3.5 pounds per person per day of municipal solid wastes (MSW) are produced [32, 33] (see Table 2.6). Nationally, MSW generation per person is estimated to be increasing at about 3% annually [34]. Demolition/construction and industrial wastes are produced at a rate of 2.62 pounds per person per day [32, 33]. This waste stream includes brick, concrete and other nonorganic materials [32]. Another potential energy waste stream is the municipal treated sludge generated by water pollution control facilities. The national average rate of treated sludge generation is 0.50 pounds per person per day [32].

Table 2.6. Components of Municipal Solid Waste (MSW), energy recovery factor, and computed potential energy MSW production [32, 33].

Component	Percentage by Weight	Energy Recovery Factor[a]	Energy MSW[b] (lbs/person/day)
Paper	37%	0.60	0.777
Wood	6%	0.60	0.126
Food	7%	0.60	0.147
Yard	18%	0.50	0.315
Plastic	8%	0.60	0.168
Nonorganics	24%	-	-
Total	100%		1.533

[a]The energy recovery factor is derived by subtracting the recyclable fraction (40% for all components except yard waste, which is 50%). The recyclable fraction goes into the production of other products.

[b]Energy MSW is determined by multiplying the component percentage (decimal form) times the Energy Recovery Factor and then times 3.5 pounds per person per day.

For Iowa, using the estimated energy MSW total of 1.533 pounds per person per year, each person produces 560 pounds of potential MSW energy feedstock each year. The 1992 population estimate for Iowa is 2,802,944 [35]. Thus there is the potential of producing 784,824 tons per year (711,992 Mg) of energy MSW (assuming no change in the population).

A graphical presentation of estimates by county of MSW, demolition/construction and industrial wastes (organic fraction only), and municipal treated sludge energy resources is desired. It is assumed that suburban and urban areas would realistically generate sufficient concentrations of these "potential energy wastes" to warrant all recovery costs. Thus, using a GIS database of Iowa's county population demographics, the rural component of each county is eliminated before the waste generation factors are multiplied times the county population.

The energy waste generation factors used are:

MSW: 1.533 pounds/person/day

Demolition/construction and industrial wastes: 0.655 pounds/person/day

(assumes only 25% organic and 100% recovery of this fraction)

Municipal Treated Sludge: 0.50 pounds/person/day

(assumes all recovered and used for biofuels)

Figures 2.30 through 2.32 present the distribution of these potential energy resources recovered from our waste streams. Of course, based on the assumptions used to generate these estimates, there are clusters of concentrations associated with Iowa's urbanized population centers [32, 33, 35].

Wood Wastes from the Iowa Wood Industry

Wood residues generated by Iowa sawmills are used more and more for livestock bedding, composting material, and landscape chips. The cost and environmental limits of disposal of wood wastes have caused the Iowa wood industry to find alternative ways to dispose of the material. In 1980, an estimated 50 sawmills produced nearly 140,000 green tons (5.4 million cubic feet) of coarse, fine, and bark residues [36]. In 1988 the Iowa primary wood industry produced 8.7 million cubic feet of coarse, fine, and bark residues [9].

The USDA Forest Service projects that growth will exceed removals from 1990 to 2020 under the high removal option, with a net increase in total growing stock volume of only 10% during this time period. What this suggests is that a higher level of sawtimber output could occur from Iowa's timberland and thus generate additional wood residue biomass for energy use (and competing uses). This higher removal scenario may or may not occur; if it does occur, however, it seems that forest growth projections suggest sustainability over the period 1990–2020 [37].

Figure 2.30

Figure 2.31

Figure 2.32

An estimate of the wood residues generated by the Iowa wood product industry that might be available for energy use is 8.7 million cubic feet per year. If market prices for the wood residue as a biofuel exceed those paid for the residue used as livestock bedding, composting, or landscape chips, then conceivably all 8.7 million cubic feet would be available.

Biofuels from Crop Residues and Animal Manures

Residues from Annual Crops

From the millions of acres of corn, oats, wheat, sorghum, and other annual crops produced in Iowa, there is an apparent large source of residue biofuels. In Iowa (and nationwide), farmers who choose to be involved with the farm program and receive price support payments (for Iowa the commodity support is for corn) must have approved conservation (for soil and water resources) plans. The SCS must approve the individual plans. One of the guidelines used in these conservation plans is a minimum requirement of retaining one ton of crop residue on the field to aid in reducing water and aid borne soil erosion and improving or maintaining the soil tilth and long-term soil productivity. Recall that Iowa has about 12 million acres classified by the SCS as highly erodible lands (HEL).

For the purposes of this report, the Iowa SCS [38] provided recommendations regarding corn, soybean, wheat, and other crop residues that could be collected for energy purposes. The recommendations are:

1) a maximum of one ton (dry weight basis) per acre of corn residue (stover) be removed only from level lands (0–3% slopes),
2) no corn residue be removed from lands with greater than 3 % slopes
3) no residue be removed from any lands producing soybeans, wheat, or other annual crops.

This set of SCS recommendations is combined with the assumption that they would be applied to all acres in annual crop production and complied with by all farmers. Using the STATSGO database, an algorithm was developed to determine the number of acres with slopes between 0 and 3% inclusive. Because there is no dataset that provides spatial information as to the location of the 1992 corn production acres with flat slopes, a decision rule was used to choose the smaller of two acreages—the number of acres in the county with flat slopes or the number of acres in corn production in 1992.

The results are presented Figure 2.33. The estimated total theoretically available corn residue is 11,547,019 tons per year. It is apparent that the counties with the greatest

Figure 2.33

proportion of flat sloped cropland or corn production acres in 1992 are the source of the corn residue biomass. No attempt was made to develop cost estimates for collecting, transporting, and storing the corn residue.

On the basis of the Iowa-specific SCS annual crop residue recommendation and the participation assumption, this estimate is unlikely to be conservative in terms of theoretically available crop residues. The Union of Concerned Scientists (UCS) has reported estimates of crop residue biomass and costs per ton in their 1993 report entitled *Powering the Midwest—Renewable Electricity for the Economy and the Environment* [26]. Given the low-weight to high-bulk nature of crop residues, the production and delivery costs of crop residues are estimated to be greater than those estimated for dedicated biomass (woody or herbaceous) [26]. The UCS report indicates that at a price of $50 per ton, an estimated 17.4 million dry tons of cereal crop residues (excluding soybeans) "might be brought to market."

The actual levels of crop residues that "might be brought to market" annually in Iowa will depend on market price, the role of future soil conservation programs in farmer decisions related to crop residues, and technology related to crop residue collection, transportation, and storage that reduce the unit cost of production.

Manure from Livestock in Feedlots

The use of animal manure for biofuels (biogas or biosolids) is an option for the Iowa farmer. The proper use of livestock manure has been the application of raw and processed wastes on various agricultural croplands (row crop, hay, and pasture land). The application of livestock manure to crops is thought by some to be the most environmentally safe use of this waste [39]. Water and air pollution concerns are driving forces today in Iowa affecting livestock production and utilization, especially related to feedlot facilities.

The potential animal manure for biogas/biofuel is a function of (1) the annual production of manure by animal type (dry total solids per animal is used as the biomass metric), (2) the number of livestock animals on feed in various types of confinement/feedlot facilities, (3) the likelihood of larger production facilities to have capital resources to afford technologically advanced manure management systems allowing for use of the wastes as biogas/biofuel, and (4) the competition for manure as a nutrient source for agricultural lands (see Table 2.7). The potential animal manure (PAM) by animal type is given by the following relationship.

PAM(i) = Manure(i) x 365 days per year x feedlot factor(i) x large facilities factor(i)

where "i" refers to all cattle and calves, swine (hogs/pigs), sheep, and all poultry; manure (i) is the daily manure production in dry pounds per day per animal; feedlot factor (i) is the fraction of production that occurs in feedlots/confinement facilities; and large facilities factor (i) is the fraction of feedlot production that occurs in large operations (generally 500 animals per year or larger). The units on PAM are dry pounds per year per animal.

Table 2.7. Estimated potential manure biomass for Iowa by animal type, 1992 [6, 32, 40].

Animal type	PAM[a]	Inventory, 1992	Annual Manure Biomass
Cattle	842	3,963,602	1,668,676 tons
			1,513,490 Mg
Hogs/Pigs	155	14,153,158	1,096,870 tons
			994,893 Mg
Sheep	21	405,354	4,256 tons
			3,860 Mg
Poultry	18	12,560,235 (chickens)	113,042 tons
			102,529 Mg
	18	3,138,512 (turkeys)	28,247 tons
			25,620 Mg

[a]Potential Animal Manure in dry lbs year^{-1} animal^{-1}.

The American Society of Agricultural Engineers has developed estimates of manure production and characteristics for various animal types [40]. Beef (all) produce 7.2 dry (total solids) pounds per day per animal, hog/pigs produce 1.12 pounds per day per animal, sheep produce 1.10 pounds per day per animal, and poultry produce 0.05 pounds per day per animal. These manure output values were verified as reliable and reasonable by faculty/staff in the Departments of Animal Science and Agricultural and Biosystems Engineering at ISU. Dairy and beef cattle and swine manures are handled as liquids with

an average total solids content ranging between 10%–13%. Sheep and poultry manures are typically handled as solids with roughly 20%–25% solids.

The key assumptions and estimates for cattle, swine, sheep, and poultry manure biomass are as follows:

Cattle

- 7.2 dry lbs day^{-1} animal^{-1} (total solids content) [40],
- 65% of cattle and calves are produced in feedlots in Iowa [6]
- 50% of feedlot production is from farms with 500 head or more [6]. These facilities are likely to use manure as biogas (methane) and use the digester effluent as a fertilizer for agricultural lands, perhaps to grow woody and herbaceous biomass.
- A production "turn" for cattle in a feedlot is 150 days. There are 2.4 turns per year.

Hogs and Pigs

- 1.2 dry lbs day^{-1} animal^{-1} (total solids content) [40]
- 50% of hogs and pigs are produced in feedlots in Iowa [32] and [6]
- 71% of feedlot production is from farms with 500 head or more [6]. These facilities are likely to use manure as biogas (methane) and use the digester effluent as a fertilizer for agricultural lands, perhaps to grow woody and herbaceous biomass.
- A production "turn" for hogs and pigs in a feedlot is 130–140 days. There are 2.7 turns per year.

Sheep

- 1.1 dry lbs day^{-1} animal^{-1} (total solids content) [40]
- 15% of sheep are produced in feedlots in Iowa [32]
- 35% of feedlot production is from farms with 300 head or more [6]
- A production "turn" for sheep in a feedlot is 150 days. There are 2.4 turns per year.

Poultry (chickens broilers/layers and turkeys)

- 0.05 dry lbs day^{-1} animal^{-1} (total solids content) [40]
- 100% are produced in confinement units in Iowa [6]
- A production "turn" for poultry on feed is 60 days. There are 6 turns per year.

Figures 2.34–2.36 depict the distribution of cattle, swine, and sheep potential manure biomass by county, respectively.

Figure 2.34

Figure 2.35

Figure 2.36

The estimated annual total potential manure biomass is 2.640 million Mg based on these four animal types and the manure production and assumed recovery factors. Beef and swine are the major livestock producers of manure-based biomass for energy. Eghball and Power [41] estimated that for beef cattle alone there would be 2.4 million Mg per year (based on 2.4 Mg total solid per animal per year in the feedlot).

Biomass Resources from Iowa's Natural Forests

Beyond the potential use of wood residues from the Iowa woody industry, the forests of the state can contribute biomass from (1) logging residues, (2) forest improvement activities, and (3) capture of natural mortality.

In 1988, the USDA Forest Service estimated that there were 2.6 billion cubic feet of total growing stock and nongrowing stock volume in Iowa (1.7 billion cubic feet from growing stock volume, which is the volume from desirable tree species used for wood products). Total removals in 1988 were 24.733 million cubic feet. Out of the total removals estimate, 11.237 million cubic feet of wood was removed for commodity products, another 2.375 million cubic feet were logging residues, and 11.121 million cubic feet were other removals (where wood was felled, piled, and burned in land clearing operations or felled and left in the forest) [9, 37].

County estimates of logging residues and forest improvement activities were obtained by multiplying a residue factor times the county net growing stock volume (in thousands of cubic feet). The residue factors for the logging residues and forest improvement activities assume that the residue potentially available for energy use is proportional to the total net growing stock volume in each county.

The logging residue factor (LRF) is obtained by the following relationship:

$$LRF = F1 \times F2 \times (0.50),$$

where F1 is the ratio of 1988 total annual removals to total growing and nongrowing stock volume (~9.5% of total removals each year are logging residues), F2 is the ratio of logging residues to total annual removals, and 0.50 is an assumed feasible recovery percentage of logging residues from the forests.

Thus

$$LRF = (0.00951) \times (0.0963) \times (0.50) = (0.000453)$$

LRF is multiplied by the total growing stock volume in each county. Figure 2.37 presents the distribution of potential logging residues. The southeast, south central, and northeast regions of Iowa have the greatest concentrations of potential logging biomass.

Forest improvement activities (FIA) include precommercial thinnings, removal of unacceptable growing stock (UGS) trees, and timber stand improvement. It is assumed that other removals totaling 11.121 million cubic feet in 1988 will be the source of this potential biomass. Thus, annual removals will not be assumed to increase; rather, greater use of those cubic feet removed will occur. The FIA estimates for each county are derived in the same manner as logging residue.

$$FIA = F1 \times F3 \times (0.50)$$

where F1 and 0.50 are as described in the LRF relationship and F3 is the ratio of other removals to total annual removals (in 1988). So

$$FIA = (0.00951) \times (0.45) \times (0.50) = (0.00214)$$

FIA is multiplied times the county growing stock volume to obtain an estimate of the biomass potential from enhanced forest improvement activities. Figure 2.38 shows the distribution of this potential biomass resource across the state.

The capture of some natural mortality was not estimated because of the concern for wildlife and aesthetics.

Land Resources

TASK CONCLUSIONS

Iowa's cropland base is 27.2 million acres. Roughly 22 million acres are planted annually to crops (mainly corn and soybeans). There are 19.46 million acres of LCC I and II in Iowa. Thus, for farmers to continue to produce 22 million acres of corn and soybeans requires some LCC III (and lower quality lands). An estimated 9.96 million acres of cropland are in LCC III and IV—soils that are defined as having severe and very severe limitations for typical row crops and require special to very special conservation practices for agriculture to occur. Moreover, about 83% of these LCC III and IV acres

Figure 2.37

Figure 2.38

(~ 8.3 million acres) are in the erosion subclass requiring special management. Considering only LCC III lands, over 84% or some 6.8 million of these acres are classified in the "e" subclass. If more agricultural land in the Midwest and Iowa is idled in the future as some predict, then LCC IIIe lands may be the lands to be idled assuming that LCC IV and poorer lands have already shifted out of cropland use. Idling LCC IIIe lands could generate sites that would benefit from perennial plant systems such as HECs and SRWCs.

The SCS defines some 5.811 million acres as marginal croplands (LCC IV–VII) in Iowa. An estimated 2.86 million acres of these marginal acres are currently in cropland use. Combining the marginal acres currently cropped with the marginal acres currently used as pastureland yields an estimated 4.89 million acres of marginal land could be devoted to dedicated HEC (perennial) and SRWC biomass-for-energy production.

In addition, there are 2.225 million acres currently enrolled in the CRP/WRP program (most in the CRP). With the first CRP contracts ending in 1996, there is an opportunity to shift these acres into perennial herbaceous and woody biomass production.

Given the acreage of erodible soils in Iowa, which is considerably more than the acreage enrolled in the CRP/WRP program, a considerable proportion of these acres could also be shifted to dedicated HEC (perennial) and SRWC biomass-for-energy production. These energy crops are expected to provide positive soil and water conservation benefits as they produce annual and periodic biomass for energy.

From a biological viewpoint there are relatively few soils/lands across Iowa where HEC and SRWC species cannot be planted and grown. Herbaceous and woody species are adapted to very wet, heavy soil conditions or to very dry, sandy soil conditions. A key consideration for productive and cost-effective herbaceous and woody crops is careful site evaluation and effective management prior to and after planting.

Land value and rent will play an important role in possible shifts in land use to HECs and SRWCs. The southern portion of Iowa (bottom three tiers of counties) has the greatest concentration of low rental values for low and medium quality agricultural land. At the margin, it is the low quality land that would shift to HECs or SRWCs first as the market price of biomass rises (assuming usage to establish demand).

Annual HECs and Crop Residue

Annual herbaceous species such as sweet sorghum, sorghum x sudangrass, and tropical corn offer very high-yield potential when grown on Iowa sites (based on research by Iowa State University by Drs. Anderson, Buxton, and Hallam). Whereas the expected

yields and unit costs are attractive, these biomass crops pose the same negative environmental impacts from NPS pollution as does hybrid corn production. Careful soil and water conservation practices are a key consideration for annual HECs.

Annual crop residue means corn residue, given the application of the Iowa SCS criteria for removal of 1 ton per acre from corn lands with 0%–3% slopes. When this corn residue criterion is applied to all counties, the result is that over 11.5 million tons of corn residue is potentially available each year.

Residential/Commercial/Industrial Wastes

The MSW, demolition/construction and industrial, and municipal treated sludge biomass types could provide an estimated, 0.785 million tons, 0.325 million tons, and 0.256 million tons, respectively. The key to recovering energy from the MSW and the demolition/construction and industrial waste streams will be the success of recycling the paper, plastic, and organic materials for other use. It is assumed that the recycling rate for the recyclables in MSW will be 40%. All three of these wastes will be available in localized, urban regions of the state.

Iowa sawmills have the potential to contribute 0.283 million tons of biomass each year. However, this limited biomass type will face stiff competition with animal bedding, landscape material, composting, and dry kiln fuel uses. Nevertheless, on a local level it may be a near-term or long-term biofuel for existing biomass-using facilities or those installed at sawmills.

Animal Wastes

Manure from livestock in feedlots could produce an estimated 2.9 million tons of biomass each year primarily from cattle and swine. Manure from cattle and swine can be used to produce methane in technically advanced systems (such as the system that Dr. Dague from Iowa State University has patented). After processing the methane, the residue can also be used as a fertilizer/soil amendment on HEC or SRWC systems associated with the large feedlot/confinement facilities. A well-designed shelterbelt agroforestry planting of HEC and SRWC species can provide an effective odor barrier as well as produce annual and period biomass yield for animal bedding or fuel to dry grain.

Natural Forest Biomass Resources

Without increasing the annual removal volume of growing stock and by increasing the use of the annual removals, it is possible for the natural forests of the state to produce 0.116 million tons of biomass. Also, by recovering logging residues associated with the annual removals, an additional 0.024 million tons could be produced each year. Wildlife, recreational, and aesthetic concerns can play a major role in the actual logging and other forest residues that are extracted from Iowa's 2 million acres of forestland.

Dedicated Herbaceous and Woody Crops for Energy

HECs and SRWCs can be planted in various agroforestry systems on selected sites to provide specialized environmental purposes, such as the disposal or land application of treated municipal sludge on nonfood crops. Iowa State University, the City of Ames, and the Iowa DNR are cooperating on a research/demonstration project where treated sludge from the new water pollution control facility is applied to an alleycropping system of switchgrass, sweet sorghum/Caribbean corn, and hybrid poplars

Riparian zones along Iowa's rivers and streams (including the lower-order streams or headwater reaches) play important roles in moderating floods, trapping overland flow of sediment and pesticides, and transforming nitrate-nitrogen and pesticides that leach into the soil and move with the groundwater. Establishing multipurpose riparian buffer zones with a mix of herbaceous and woody biomass species offers a system that can aid both in soil and water protection and wildlife and fisheries enhancement while providing biomass for on-farm and commercial energy use.

Because of the floods of 1993 in Iowa and the Midwest, a special interest exists concerning flood-prone lands and their proper land use. As part of Task 1, a case analysis was done for Story County to determine flood-prone lands, using GIS procedures. This determination, while simple in concept, is very difficult and time-consuming to complete. A procedure has been developed to identify flood-prone lands using Digital Elevation Model (DEM) data. Figure 2.39 depicts the "flood-prone" lands that are contiguous with streams in Story County. About 4.8% of all acres in the country are flood-prone as determined by digital elevations. Thus, about 17,800 acres are at risk from floods. If a strategy is adopted to establish HEC and SRWC riparian bufferstrips (20 m wide on each side of a stream) streams along 587 km (364 mi) in the headwater reaches of first-, second-, and third- order streams) in the county, then 2,357 ha (~5824 acres) could be

Figure 2.39

converted to permanent vegetative cover. The multipurpose, multispecies, riparian buffer strips would provide flood control functions and produce biomass for energy.

Dedicated HECs and SRWCs can be sited on many soils across Iowa. Earlier in this chapter Figures 2.28 and 2.29 depicted the application of the biological decision criteria-acceptable depth to water table and flooding potential—to determine lands suitable for perennial herbaceous or woody biomass production. Schultz [28] and Hall [29] devised the biological decision criteria suggesting that saturated (water-logged) soils subject to frequent and long-duration flooding are unsuitable for dedicated HECs or SRWCs. Also, they suggest that soils with deep (>3.5 feet) water tables are unsuitable because of their droughty nature. While these figures are useful in obtaining a general idea of counties with concentrations of land meeting each criterion, they do not provide enough detail to clearly visualize where the lands suitable for HECs and SRWCs are within a county.

Figure 2.40 provides a more detailed visualization of the lands suitable for HECs and SRWCs. This figure was developed using GIS procedures involving DEM (Digital Elevation Model) data and STATSGO data. The method first determined three slope classes (0–5%, 6–14%, or >14%) by using DEM data within each map unit in the state. A map unit is a collection of similar soils and does not correspond to county political boundaries. Next the biological decision criteria (acceptable depth to water table and flooding potential) were applied simultaneously to the three slope classes within each map unit. This was done for all map units in Iowa. Thus, Figure 2.40 presents a higher resolution look at the lands suitable for HECs and SRWCs across Iowa. As indicated in Figure 2.40, most of Iowa is suited for growing dedicated HECs or SRWCs to varying degrees. The legend is interpreted as follows. Using the three DEM slope classes, the darker shades of gray indicate greater percentage of land meeting the biological decision criteria within a map unit.

The production potential of perennial herbaceous or woody biomass in Iowa is a function of suitable lands (biologically), land availability and value, competition with other land uses and economic rents, and governmental policy and programs (for agriculture, energy, and the environment). Figures 2.41 and 2.42 present information as to land suitable for dedicated energy crops where SCS Land Capability Classification data are evaluated along with the biological decision criteria using the same DEM and STATSGO GIS methodology applied to generate Figure 2.40.

Figure 2.41 indicates areas of concentration where the land/soil meet all biological criteria and are classified as LCC 3e or 4–7. Clearly the figure shows the bottom three

Figure 2.40

Figure 2.41

Figure 2.42

counties in Iowa from the eastern border westward toward the Missouri River as having the greatest concentration of lands meeting all criteria simultaneously. Another moderate zone exists in the western portion of northeast Iowa.

Figure 2.41 indicates land suitable for dedicated energy crops where LCC 3e lands have been excluded. The percentage of lands within a map unit meeting all decision criteria is diminished, but the zone of concentration in southern Iowa still is evident.

Additional GIS analysis could be done which focuses on groups of counties with moderate to high concentration of lands meeting these decision criteria and other criteria or factors such as CRP acres, land rent, existing utility capacity, population centers, transmission lines, and actual 1994 agricultural land use.

Finally, Table 2.8 presents the estimated potential biomass resources "produced or recovered" each year in Iowa. The greatest potential exists for corn crop residue and dedicated HECs and SRWCs. In total, an estimated 406 trillion BTUs could be produced annually in Iowa from all biomass types. Iowa has significant potential in terms of biomass resources. The actual level of biomass production will depend on the integration of economic, social, political, and environmental factors.

Table 2.8. Iowa's potential annual biomass resources in millions of standard (short) tons and trillions of British Thermal Units (BTUs).

Biomass Type	Biomass Potential (millions tons/yr)	Energy Value (trillion BTUs/yr)
MSW (@ 4,500 Btu/dry lb)*†	0.783	7.07
Demolition/construction/industrial wastes (@ 5,000 Btu/dry lb)*	0.335	3.35
Municipal treated sludge (@ 6,000 Btu/dry lb)†	0.256	3.07
Wood industry residue (@ 8,500 Btu/dry lb)‡	0.283	4.80
Logging residues (@ 8,500 Btu/dry lb)‡	0.024	0.42
Other forest residues (@ 8,500 Btu/dry lb)‡	0.116	1.97
Corn crop residue (@ 7,500 Btu/dry lb)§	11.547	173.21
Animal manures (@ 6,000 Btu/dry lb)†		
Cow	1.669	20.02
Hogs/pigs	1.097	13.16
Poultry/sheep	0.145	1.75
Dedicated HECs on 50% CRP (switchgrass @ 7,750 Btu/dry lb)†»	5.462	84.66
Dedicated SRWCs on 50% CRP (hybrid poplar @ 8,500 Btu/dry lb)‡	5.462	92.85
Totals	27.179	406.33

Sources: *[43], †[44], ‡[45], §[46], »[30].

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Chapter 3

Costs of Producing Biomass Crops in Iowa

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CHAPTER 3. COSTS OF PRODUCING BIOMASS CROPS IN IOWA

PART 1. HERBACEOUS ENERGY CROPS

INTRODUCTION

The ultimate economic feasibility of biomass depends on its cost of production and on the cost of competing fuels. The purpose of this chapter is to evaluate the production costs of several combinations of species and management systems for producing herbaceous biomass for energy use in Iowa. Herbaceous biomass production systems have costs similar to other crop production systems such as corn, soybean, and forages. Thus the factors influencing the costs of producing dedicated biomass energy crops include technological factors such as the cultivation system, species, treatments, and soil type, and site and economic factors such as input prices and use of fixed resources. In order to investigate how these production alternatives are influenced by soil resources and climate conditions, two locations in Iowa, Ames and Chariton, with different soil types and slightly different weather patterns were selected for analysis. The choice of areas was based on a desire to represent two different parts of the state and on the fact that a five-year set of agronomic experiments relating to biomass production was recently completed at these sites. The Ames site located in central Iowa represents low erosive, highly productive soils while the Chariton site located in southeast Iowa represents more erosive, less productive soils.

Thirteen cropping systems were grown at the two sites for five years, from 1988 to 1992. Some of the systems involved multiple cropping or interplanting, using combinations of cool-season species and warm-season species, in order to meet multiple objectives of maximum biomass, minimal soil loss, reduced nitrogen fertilization, or diminished pesticide inputs. Six of the systems featured continuous monocropping of herbaceous crops with an emphasis on production. The seven other systems consisted of

similar crops, but with crop rotation and soil conservation considerations. While the erosion and other off-site effects of these systems is an important consideration in their overall evaluation, this chapter will concentrate on direct production costs only. Other chapters discuss these off-site effects.

METHODOLOGY

The practices applied in the agronomic experiments were chosen as much as possible to reflect typical field systems, but in many cases the constraints of experimental work and a desire to collect and analyze specific scientific data led to practices that would not be considered commercially viable. Thus this chapter estimates costs based on typical "best management practices" for these crops in a commercial setting.

Seven different species were used in the agronomic research and will be discussed in this chapter. Tables 3.1 and 3.2 give the characteristics of the selected energy crop species used, which include their standing life and assumed storage method, and the cropping systems employed, respectively.

The report presents a series of estimates of the net production costs of growing herbaceous biomass based on the yield data obtained from the 13 cropping systems employed in the agronomic research. The production cost estimates are estimates of the costs of producing these crops on a commercial basis in Iowa. The data from the experimental plots was used in conjunction with data on typical management practices and costs of representative Iowa producers. The costs are comparable to the annual cost estimates of the Iowa State University Extension Service for corn, soybean, and alfalfa [1]. The tillage practices assumed in this report are a composite of the ones used in the experiments and more commonly used commercial alternatives. Some judgment was used in specifying these practices and the margin of error is probably high. This is the standard practice for such technology assessments and gives a "best" estimate of potential production costs. In all cases, sensitivity of the estimates to assumptions was analyzed.

DISCUSSION OF THE CROPPING SYSTEMS

Each of the cropping systems is an alternative way to produce biomass on an acre of land. Some discussion of the technical aspects of each system is important. In a broad sense, there are five cropping systems: pure monoculture, monoculture in rotation, double

crop, double crop in rotation, and intercrop of annual crop into perennial grasses (see Table 3.2). The purpose of employing different cropping systems is twofold: first, to compare the yields of the different species, and second, to compare the soil conservation potential of different cropping systems.

Table 3.1. Characteristics of selected energy crop species.

Species	Growth Habit	Stand Life	Storage Method
Alfalfa	Perennial	5 yrs	Hay
Reed canary grass	Perennial	10 yrs	Hay
Switchgrass	Perennial	10 yrs	Hay
Big bluestem	Perennial	10 yrs	Hay
Sweet sorghum	Annual	1 yr	Silage
Sorghum x Sudan grass hybrid	Annual	1 yr	Silage
Rye	Annual	1 yr	Hay
Corn	Annual	1 yr	Grain/ Silage
Soybean	Annual	1 yr	Grain

Note: Intercrop sorghums were stored as a hay rather than silage. Corn stover was stored as silage.

Table 3.2. Cropping systems.

Cropping Systems	Remark
1. Alfalfa	Monocrop
2. Reed canary grass	Monocrop
3. Switchgrass	Monocrop
4. Big bluestem	Monocrop
5. Sweet sorghum	Monocrop
6. Sorghum x Sudan grass hybrid	Monocrop
7. Sweet sorghum/rye	Double crop
8. Sorghum x Sudan grass hybrid/rye	Double crop
9a. Sweet sorghum	Rotation 1
9b. Sweet sorghum/rye	Rotation 1
10. Corn	Rotation 1
11. Soybean	Rotation 1
12. Alfalfa/sweet sorghum Alfalfa/sorghum x Sudan grass hybrid	Intercrop
13. Reed canary grass/sweet sorghum Reed canary grass/sorghum x Sudan grass hybrid	Intercrop

Note: 1. The rotation is a three year sequence of corn, soybean with a sweet sorghum (9a), and sweet sorghum/rye (9b) double crop in the third year.

Of the thirteen cropping systems, the first six systems are pure monoculture systems while systems 7 and 8 are doublecrop systems. Of the first six systems, the first four systems involve the production of pure perennial grasses. Systems 5 through 8 involve annual crops—sweet sorghum, sorghum x Sudan grass hybrid, and rye. Each of these first eight systems are independent of one another in the sense that year after year the same crop is produced on the initially allocated land.

On the other hand, systems 9 through 11 are grown as a fixed rotation. The systems comprise a three-year rotation. Given initially allocated land, corn is produced first, then soybean followed by either sweet sorghum or rye/sweet sorghum depending on the cropping systems within the rotation. The final two systems, systems 12 and 13, represent intercropping of an annual crop into a perennial grass stand.

The first four systems consider perennial crops—two native warm-season grasses (big bluestem and switchgrass), a cool-season introduced grass (reed canary grass), and a legume (alfalfa)—that have been grown mostly for the feeding of animals. These crops provide two advantages. One is that they have excellent soil erosion control properties and can be grown productively on both highly productive land and marginal land that is unsuitable for production of row crops. All of the harvestable material can be removed without creating soil erosion because the permanent root system remains in the field after harvest, thereby protecting the soil from wind and water erosion. A second advantage is that cutting and hauling of these forage crops need not conflict with crop harvests of corn and soybean [2]. The next sections describe the various crops, the practices used in the experimental research, and the ones assumed for the cost estimation. The actual practices assumed are contained in the appropriate tables in all cases.

Alfalfa

Alfalfa is a herbaceous perennial legume, one of only a few crops that can be grown in every state in the U.S.A. Alfalfa is regularly produced in the North Central states. Alfalfa is a highly drought tolerant species. It becomes dormant for up to two years, if necessary, during periods of severe drought and resumes growth when moisture conditions become favorable [3].

Alfalfa has been produced primarily as a feedstuff for livestock because it possesses the highest feeding values among all commonly grown hay crops. It produces more protein per acre than grain or oil seed crops [3]. Alfalfa can be harvested for fuel or

chemicals, or used in a cropping rotation to provide nitrogen for other crops, thus reducing the need for expensive inputs of fossil fuel derived nitrogen [2, 3, 4].

Alfalfa has the potential to be a highly productive crop; however, the success of its production depends on the following factors: a fertile soil, adequate water, and good seedbed preparation at establishment [3, 5]. Proper fertility management is the key to optimum economic yields. Proper fertilization of alfalfa allows for good stand establishment and promotes early growth, increases both yield and quality, and improves alfalfa's winter hardiness and stand persistence. Good fertility also improves the ability of alfalfa to compete with weeds and strengthens disease and insect resistance [5]. Alfalfa is sensitive to soil acidity. Thus soil pH is a critical factor for establishment and maximum production of alfalfa. Soil pH influences symbiotic N fixation and the availability of essential and toxic elements [3]. Lime application before seeding is important to achieve and maintain proper soil pH, 6.8 or higher, for alfalfa. Benefits of liming alfalfa include ". . . increased stand establishment and persistence, more activity of nitrogen-fixing Rhizobium bacteria, added calcium and magnesium, improved soil structure and tilth, increased availability of phosphorus and molybdenum, and decreased manganese, iron and aluminum toxicity" [5].

Other nutrients commonly recommended for alfalfa production include phosphorus and potassium, which are relatively immobile nutrients when added to soil. Research has shown that maintaining yields, reducing susceptibility to certain diseases, and increasing winter hardiness and stand survival are highly dependent on an adequate potassium supply. It has also been shown that adequate soil phosphorus levels increases seeding success at establishment by encouraging root development [3, 5].

Alfalfa typically obtains enough nitrogen from its symbiotic relationship with nitrogen fixing *Rhizobia* bacteria and from soil organic matter-released nitrogen. Thus nitrogen application is not generally recommended for alfalfa, except when alfalfa is seeded on low-N soils or when alfalfa is seeded with a companion crop [3, 5].

Diseases and winter hardiness are the key factors for the persistence of an alfalfa stand. Lack of winter hardiness may result in winter injury or winterkill. Winter injury causes reduced plant density and a lower yield. Diseases may cause seedling death, reduced stand density, lower yield, and shortened stand life [5]. Choosing disease resistant cultivars and utilizing proper fertilizer management practices are two widely suggested practices to overcome diseases and lack of winter hardiness [3, 5]. The expected stand life of alfalfa is up to ten years [3]. A five-year stand life is assumed in this research.

As shown in Table 3.3, the most commonly recommended fertilizers—lime, phosphorus, and potassium—mentioned previously were applied in the agronomic research and accounted for in the cost estimation. Although some have recommended applying lime 12 months before seeding to get better results [5], in this experiment lime was applied in the fall of the year previous to establishment of alfalfa at Chariton. Lime was not applied at Ames because the soil had a pH above 7. Application time for both phosphorus and potassium during establishment is not specified. On the experimental plots, both phosphorus and potassium were applied only once in the fall of the year previous to the establishment of alfalfa. There was no annual fertilizer application beyond the establishment year.

Fertilizer application rates are usually determined by soil test. On the test plots, 160 lb/acre of phosphorus and 625 lb/acre of potassium were applied at both Ames and Chariton during the establishment year. Lime was applied only at Chariton at a rate of 5 tons per acre.

The time of alfalfa seeding is influenced by the following factors: precipitation patterns, temperature, and cropping patterns [3]. Alfalfa seeding in the U.S. generally occurs either in the early spring or in the late summer. Adequate moisture and cool temperatures at the time of seedling germination is crucial for successful establishment. Since alfalfa is extremely cold tolerant at emergence, spring seeding of alfalfa can begin as soon as the potential for damage from spring frosts has passed. This early seeding brings less weed competition and less moisture stress during germination because of cooler temperatures. For the northern states, including Iowa, spring seeding is preferred because of a greater chance of successful stand establishment for the reasons explained above [5]. Recommended seeding dates in Iowa are April for north and central Iowa and between the middle of March and April for southern Iowa [5]. Alfalfa was seeded in the middle of April at both the Ames and Chariton experimental sites.

Optimum seeding depths of alfalfa vary with soil types. Shallower depths may be used when moisture is adequate, while the deeper depths should be used for drier soil conditions. In general, alfalfa seed should be planted in a firm seedbed to a depth of 0.52 in. with a cultipacker seeder or with press wheels on a conventional drill in order to obtain good soil-seed contact [3, 5].

Optimal seeding rates are influenced by soil conditions, the method of seeding used, and weather conditions. Generally recommended seeding rates are between 12 and 15 lb/acre [5]. In this research, a grain drill was used to seed alfalfa seed at the rate

Table 3.3. Description of establishment year tillage systems for alfalfa.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizers broadcast			Fall
Phosphorus, lb	160	160	
Potassium, lb	625	625	
Chisel plow			Fall
Tandem disk			Spring
Harrow			Spring
Herbicide			Spring
Eptom, pt	3	3	
Grain drill			Spring
Seed, lb	12	14	
Cultipack			Spring
Harvest (2x in establishment year)			Summer & Fall
Mow-conditioner			
Large round bale			
Haul			

Note: For the establishment year, both monocrop and intercrop alfalfa have the same tillage systems.

12 lb/acre in Ames and 14 lb/acre in Chariton, respectively. A cultipacker was used to firm the soil (see Table 3.3).

Field preparation is important for controlling weeds and smoothing the soil. Controlling the weeds prior to seeding helps ensure a long-lasting, productive stand. As suggested by Undersander et al. [5], field preparation began in the fall before spring seeding. In the field research, a chisel plow was used to loosen the soil and help control weeds. This was followed in the spring by disking for further weed control, land leveling, and breaking up large soil clods before seeding. Harrowing was practiced as the final tillage in the spring to smooth out the soil. Eptam, a preplant incorporated herbicide for controlling annual grasses and broadleaf weeds [5], was applied at the rate of 3 pt/acre. Field preparation activities are illustrated in detail in Table 3.3.

Harvest schedules are important to provide the highest yield of high quality forage. Optimum harvest schedules for biomass use of alfalfa are different than those used for producing forage for livestock. Research shows that there exists a correlation between yield, forage quality, and harvesting time. Yields increase with longer intervals between cuttings, while forage quality for livestock rapidly declines. It also has been shown that, as the plant matures, the leaf portion, which is more nutritious than stems, decreases and the stem increases in lignin and other fibrous constituents (cellulose and hemicellulose) [5]. Thus it has been recommended, for livestock, to take an early first cutting, usually early May in Iowa, with 28-33 day intervals after the first cut [5]. However in this research, since the goal is to maximize yield and fibrous constituents content, the first cut occurred in June with longer intervals for the cuts than the suggested harvest schedule for livestock. All the following practices were employed in harvesting: mowing, mechanical conditioning, raking, and large round baling. Raking is assumed to occur on a sporadic basis, as needed, depending on rainfall. For the purpose of cost estimation, one raking per year is assumed for the three-cut system, with no raking in the establishment year. If alfalfa is harvested only twice each year, no raking is assumed. Mechanical conditioning was practiced to increase the drying rate. Despite the transportation inefficiency of large round bales, they were used because of widespread use in Iowa. Furthermore, they are easy to store and can be left near the field on a good drainage site.

Reed Canary Grass

Reed canary grass is a grass found in temperate portions of all five continents. It is well adapted to the northern half of the United States. Although its natural habitat is poorly

drained and wet areas, it is also drought tolerant. It is very tolerant of flooding and can withstand standing water for up to 35 or more days at any stage of development with no damaging effects [6].

Reed canary grass is classified as a coarse, cool-season, sod forming grass that spreads underground by short, scaly rhizomes. It forms a heavy sod under well-managed conditions but cannot tolerate continued close clipping. It is a vital part of many soil conservation programs, and can be used under irrigation with sewage effluent as a pollution control measure. Reed canary grass has a high yield capacity with good regrowth throughout the pasture season [6]. It tends to be slow in establishment, but once established it is very disease resistant and long lived [7]. In this study, the stand life of reed canary grass was assumed to be ten years.

As with alfalfa, diseases and winter hardiness are the important factors for the persistence of reed canary grass. Reed canary grass has long been identified as a good forage producing species because of its winter hardiness, adaption to a wide range of environmental conditions, good seasonal distribution of high yields, disease resistance, drought tolerance, and persistence under a wide range of management and fertilization systems [6, 7, 8]. For these reasons, it has lately been recognized as a good candidate for biomass production.

Reed canary grass can be seeded either in spring or late summer if sufficient moisture is available [6]. As with alfalfa, weed control is a key to establishment because weed competition can cause failure in establishment and, at best, slow establishment. If seed is planted in the late summer, success is often higher because weeds are less of a problem [7]. However, spring seedings are the most common for reed canary grass, and we planted it in the spring as well. The reason for spring seeding is that reed canary grass seedlings are more susceptible to killing by cold temperatures than those of most other cool-season grasses [6]; thus plants must be well developed before the start of winter. If reed canary grass is to be planted in the late summer, timely establishment and favorable soil moisture are very important.

Seed can be sown with a grain drill, broadcast, or with a band seeder equipped with press wheels. The seedbed should be well prepared and firm. Seed should not be placed deeper than 1.5 cm and should be cultipacked or rolled [9]. Reed canary grass can be seeded with or without a companion crop. An oat companion crop can be used for spring seedings. In this study, reed canary grass is seeded with a grain drill because it is a practice widely used in Iowa for forage production (see Table 3.4). Although reed canary

grass in Iowa is generally seeded with an oat companion crop, it is seeded without a companion crop in this study.

Seeding rates can be influenced by the soil conditions, seeding method applied, weather conditions, soil water available, and the use of a companion crop. The recommended seeding rate falls between 8 to 10 lb/acre for direct seeded reed canary grass and between 4 to 5 lb/acre with a companion crop [7]. Reed canary grass was seeded at a rate of 9 lb/acre in Ames and 11 lb/acre in Chariton, respectively.

Management of perennial cool-season grasses for biomass production consists of maximizing economic yield while fostering persistence of the stand [10]. Proper fertility management is the key to optimum economic yield because proper fertilization of reed canary grass allows for good stand establishment and promotes early growth, increases yield, and improves stand persistence. To maintain high productivity, fertilization with nitrogen, phosphorus, and potassium is recommended, especially nitrogen. Although reed canary grass responds mainly to nitrogen, increased yield may occur with added potassium and phosphorus [6, 7]. As mentioned for alfalfa, an adequate potassium supply is essential for maintaining yields, reducing susceptibility to diseases, and increasing winter hardiness and stand survival. To increase seeding success at establishment, adequate maintenance of phosphorus is important.

Recommended rates for nitrogen range from 80 to 240 lb/acre, depending on soil conditions and the need for forage. Split application of nitrogen is recommended when nitrogen is applied at over 120 lb/acre. Split application is also recommended during the growing season to assure more uniform production and to lengthen the productive period [6, 7]. As recommended, nitrogen was assumed to be applied twice in this research, once in spring at 100 lb/acre and again in the summer at 100 lb/acre, over the stand life. However, it was applied only once in the summer during the establishment year. Rates for phosphorus and potassium are recommended to be based on soil test results [7]. Based on the typical soil test results for Iowa, it is assumed that 32 lb of phosphorus per acre and 94 lb of potassium per acre are required, which is three-fourths of the potash applied for alfalfa.

In this experiment, four levels of nitrogen were applied to the separate plots at the experimental farms. The levels of nitrogen used were 0, 62, 125, and 250 lb/acre. See Table 3.4 for phosphorous and potassium rates.

Table 3.4. Description of establishment year tillage systems for reed canary grass.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer broadcast			Fall
Phosphorus, lb	32	32	
Potassium, lb	94	94	
Chisel plow			Fall
Tandem disk			Spring
Harrow			Spring
Grain drill			Spring
Seed, lb	9	11	
Cultipack			Spring
Fertilizer broadcast			Late Spring
Nitrogen, lb	200	200	
Herbicide			Late Spring
2,4-D, pt	2	2	
Harvest			Fall
Mow-conditioning			
Bale			
Haul			

Note: For the establishment year, both monocrop and intercrop reed canary grass have the same tillage systems.

As with alfalfa, field preparation is important for controlling weeds and smoothing the soil. The success of reed canary grass establishment depends on good field preparation. An adequate seedbed can insure good germination. In this research, field preparation began in the fall before spring seeding. Chisel plowing was practiced in the fall to loosen the soil and help control weeds. It was followed by disking in the spring for further weed control and breaking up of large soil clods. To smooth the soil, harrowing was practiced as the final tillage in the spring. See Table 3.4 for the description of tillage during the establishment year.

Infrequent harvests with high yields are desired. Reed canary grass stands were unaffected and no great difference in yield was found between a two- and four-cut harvest system [11]. Thus a two-cut harvest was practiced in this research. During the establishment year, it was harvested only once in the fall.

Harvest intervals to obtain high reed canary grass biomass yields assumed in this study are longer than those recommended for livestock forage as explained previously for alfalfa. The first harvest occurred some time in June with longer intervals for the second cut. The practices employed in harvesting were mowing, mechanical conditioning, and large round baling. Mowing is assumed to be done early in the day to allow a full day's drying. Mechanical conditioning was practiced to increase the drying rate. Large round baling was practiced because of ease of storage and widespread current use. Raking was not practiced because reed canary grass was harvested only twice each year.

PERENNIAL WARM-SEASON GRASSES

Switchgrass and big bluestem are warm-season grasses, which are native to the much of the central and lake states of the United States [12]. Switchgrass is a tall, sod forming perennial bunchgrass that grows 3 to 5 ft tall. Big bluestem is an erect, robust, perennial bunchgrass. It grows 3 to 6 ft tall. Big bluestem is a deep-rooted grass well adapted to loamy soils and is able to withstand drought conditions [13].

These warm-season perennial grasses start growing in late spring as air and soil temperatures increase. Maximum growth occurs from June through September. As temperatures cool in fall, growth slows and ceases with the first killing frost [13].

Switchgrass and big bluestem are winterhardy and will grow in all areas of Iowa. Although they are most productive on fertile and well-drained soils with a good moisture supply where corn grows best, they also grow well on less fertile and droughty soils

because they have a greater tolerance to low-available soil water than the cool-season grasses [13, 14]. These warm-season grasses also use soil nutrients more efficiently and have lower macronutrient requirements than cool-season grasses (see Tables 3.5 and 3.6) [14]. Additionally, they use nitrogen more efficiently than cool-season grasses [14, 15]. These properties make them practical choices to grow as biomass crops and for soil conservation on infertile, acid, and droughty soils.

Switchgrass is more tolerant than big bluestem to variability of soil conditions. It persists better in moderately wet soil conditions and occasional flooding. Switchgrass may also be better suited to droughty soils [13] than big bluestem.

As with the other perennial grasses, seedbed preparation and fertilization are important to have successful establishment. Research has shown that an adequate potassium supply is needed to maintain yields, reduce susceptibility to disease, and increase winter hardiness and stand survival. It has also been shown that keeping adequate phosphorus levels is important to increase seeding success at establishment by encouraging root development [3, 5].

Soil deficiencies in lime, phosphorus, and potassium should be corrected before or at seeding time. Application of lime and fertilizer should be based on soil tests. The pH levels should be at least 6.0 [13]. Soil tests at both experimental farms indicated that lime application was not needed for these grasses [16]. Phosphorus and potassium levels were low so that 32 lb of phosphorus and 94 lb of potassium per acre, respectively, were applied at both the Ames and Chariton experimental sites. Suggested phosphorus and potash application rates are at least 60 lb of each per acre [13]. It is assumed that these fertilizers are applied the fall before the spring seeding.

Experience in Iowa suggests not applying nitrogen in the seeding year because even small amounts stimulate weeds and retard warm-season grass establishment. However, applying 30 lb of nitrogen per acre in midsummer is suggested in order to stimulate more rapid switchgrass establishment if weed control has been good in the seeding year [13]. On the research plots, nitrogen was not applied during the establishment year; however, nitrogen was applied during production in later years. In estimating the budgets, 100 lb/acre of nitrogen was assumed.

As suggested, chisel plow, tandem disk, and harrowing were practiced for field preparation. The first two of these activities are practiced to loosen soil, help weed control, and break up large soil clods in spring before seeding. Harrowing was practiced in the spring to smooth out the soil.

Table 3.5. Description of establishment year tillage systems for switchgrass.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer broadcast			Fall
Phosphorus, lb	32	32	
Potassium, lb	94	94	
Chisel plow			Fall
Tandem disk			Spring
Harrow			Spring
Grain drill			Spring
Seed, lb	8	8	
Cultipack			Spring
Herbicide			Late Spring
Atrazine 4L, pt	2.5	2.5	
Harvest			Fall
Mow-conditioning			
Bale			
Haul			

Table 3.6. Description of establishment year tillage systems for big bluestem.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer broadcast			Fall
Phosphorus, lb	32	32	
Potassium, lb	94	94	
Chisel plow			Fall
Tandem disk			Spring
Harrow			Spring
Grain drill			Spring
Seed, lb	12	12	
Cultipack			Spring
Herbicide			Late Spring
Atrazine 4L, pt	2.5	2.5	
Harvest			Fall
Mow-conditioning			
Bale			
Haul			

These grasses can be seeded alone or as a mixture; however, seeding a single grass species is recommended because mixed species are more difficult to manage [13]. Warm-season grasses can be seeded from late April to mid-June [13], but better germination, establishment, and seedling development often occur during mid-to-late April or May when precipitation patterns are more favorable. Successful stand establishment is possible with later seeding dates if adequate precipitation occurs, but first-year forage yield is reduced [17]. Since early seeding provides more time for these grasses to become well established before winter [13], both switchgrass and big bluestem are assumed to be seeded in early May.

Switchgrass can be seeded with a grain drill or other standard forage seeding equipment. The use of a grain drill with packing over the row to get better results is recommended. If possible, grasses should be drilled into mulched seedbeds, which helps control erosion and conserve soil water [13]. Switchgrass was seeded with a grain drill at a rate of 8 lb/acre at both Ames and Chariton.

Big bluestem is difficult to seed without a special grassland drill because big bluestem seeds are light weight and “bearded.” Seed conditioning equipment has been developed to remove the “beard” or the long hairy appendages from big bluestem, making it free flowing and more easily seeded with standard forage seeders [13]. A grain drill was used to seed big bluestem, and seeding rate was 12 lb/acre at both Ames and Chariton. To firm the soil, cultipacking is usually used immediately after seeding.

Switchgrass and big bluestem often establish slowly and compete poorly with weeds. When established under heavy weed infestation, plants grow slowly and may take two to three years for production of good yields [13]. Thus effective weed control is a key to the success of warm-season grass establishment. There is no herbicide currently registered for use in establishing switchgrass or big bluestem. Old supplies of labeled "atrazine" were used in the field practice of the study, and these were applied at about 2 lb/acre before the germination of summer annual weeds. To control broadleaved weeds, if this is a serious problem, 2,4-D application at about 0.5 lb/acre is suggested. Mowing at a height of 3–4 in. in early spring during the seeding year can also reduce competition by weeds [13].

Summer mowing should be restricted to 6 in. to avoid removing any of the desired grass. Clipping should be discontinued after August 1. 2,4-D can also be used to control broadleaf weeds, once the grasses have reached the 3 to 4 leaf stage [13].

Activities employed in harvesting were the same as for alfalfa and reed canary grass.

Sorghum

Sorghums have been used primarily for forage or grain in the U.S.; however, there has been increased interest in production of sorghum for biomass. Sorghum production is concentrated in the southwestern United States. Sorghum is a coarse, erect grass. Although sorghums grow better with more adequate moisture, sorghums are known to be more drought tolerant than corn and soybeans. During the drought period, sorghum has the capability to become dormant, then resume growth when water becomes available. The drought-tolerance capability of sorghum and its versatility make it a practical choice in conventional crop rotations and conservation-tillage programs [18, 19]. This characteristic may be useful for production in southern Iowa during relatively dry summers.

Recommended seeding temperatures for sorghums are soil temperatures of 65–70° F because adequate germination of sorghums takes place at this level [18, 19]. If sorghum must be planted before the soil temperature reaches 65° F, use of a starter fertilizer is recommended to provide critically needed N and P and to enhance early season growth [18].

The planting depth of sorghum depends on the soil type. The planting depth is important because the sorghum seedling does not emerge from the soil as easily as a corn seedling. Planting depth in general should not exceed 1–2 in. For good emergence, the recommended depth is 3/4–1 in. in clay soils and 1.5–2 in. in sandy soils. Although sorghum can be planted in a dry soil if rain is expected or if irrigation water can be applied within two weeks after planting, sorghum growth and seedling development are usually better when the seed is planted in a moist soil [18].

Seeding rates of sorghum are extremely important for economical yields. If plant populations are too high, the plants tend to compete with each other for nutrients and moisture. In addition, high population often results in slender and weak stalks [18]. The recommended normal seeding rates for silage are 6–8 lb/acre [18]. Seeding rates used in this research are 7 lb/acre for all sorghum cropping systems.

Sorghums can be drilled, broadcast, or sown in rows [19]. Narrow rows, 30 in. or less, are suggested because weed control and moisture conservation may be more difficult in wider rows. With wider row spacing, sorghum has difficulty producing a

closed canopy that will help control weeds and reduce water losses caused by evaporation [18]. For this study, it is assumed that a 30-in. narrow row planter will be used.

Although sorghums will grow on low-fertility and/or moderately acid soils, good fertility management is necessary for optimum yields in sorghum. The fertility program should be based on soil test results. The recommended fertilization is as follows: 80–100 lb of N/acre for dry land and 100–120 lb of N/acre for irrigated land; 60, 40, 0 lb of P per acre for low, medium, and high levels of P-containing soil, respectively, and 80, 60, 0 lb of K per acre for low, medium, and high levels of K-containing soil, respectively [18].

Phosphorus should be applied preplant or at planting while potassium may be applied before or after planting. Nitrogen should generally be applied in split applications, with about a third of the requirement applied as a preplant or starter fertilizer. The remainder should be applied in one application approximately 20-25 days after emergence (about a month after planting) or at 10-in. plant height [18].

Relative to other major row crops such as corn or soybeans, chemical weed control choices for sorghum are somewhat limited. The herbicide most widely used for sorghum production in Iowa and elsewhere in the U.S. is Dual. Dual is registered for application to sorghum either as a preplant soil incorporated treatment or a preemergence treatment. Dual is recommended for use on sorghum grown from "Concep" treated seed. Concep acts as a safener, herbicide antidote, which reduces the potential for Dual injury to the crop. Suggested application rates are 1.5 to 2 pt. For the doublecrop sorghums, paraquat provides good to excellent control of both the annual grass in the doublecrop and broadleaf weeds. The recommended application rates depend on the height of the grass or broadleaf weeds. For control of grass and broadleaf weeds 2 in. in height or less, 1 pt/acre is suggested. For control of grass and broadleaf weeds 2 to 3 in. in height, 2 pt/acre are suggested [18].

In this research, the dry matter yield of sorghums was investigated under different cropping systems. Two sorghum cultivars, sweet sorghum and a sorghum x Sudan grass hybrid, were planted. The cropping systems used for sorghums are as follows: monocrop, doublecrop with winter rye, rotation following corn and soybeans, doublecropping with winter rye following corn and soybean rotation, and intercrop with alfalfa or reed canary grass.

Monocrop Sorghums

Monocrop sorghum systems were fertilized before planting in the middle of May. Both sites, Ames and Chariton, received 58 lb of phosphorus, 47 lb of potassium, and 100 lb of nitrogen.

Monocrop sorghum fields were disked, followed by field cultivation and harrowing in the middle of the spring to control weeds, break up large soil clods, and smooth the soil. A narrow-row planter was used to plant sorghum seeds in the spring. Post-planting cultivation was practiced to control weeds in summer. For weed control, Dual was applied at the rate of 2 pt/acre at the time of disking in spring.

Monocrop sorghums were harvested with a silage harvester in the late fall. Table 3.7 describes the tillage systems for monocrop sorghums.

Doublecrop Sorghums with Rye

Phosphorus and potassium were applied in the fall before planting winter rye. Both sites, Ames and Chariton, received 58 lb/acre of phosphorus and 47 lb/acre of potassium. A split application of nitrogen was used. About one-third of the nitrogen was applied in late March for the doublecrop rye/sorghum systems. The remainder was applied in late May at the time of sorghum planting.

The doublecrop sorghum/winter rye systems were disked, followed by harrowing in the fall before planting the winter rye. Rye was planted by grain drill in the winter and the sorghum was planted no-till into the rye stubble immediately after the rye was harvested as forage in May. Winter rye was seeded at 100 lb/acre in Ames and 120 lb/acre in Chariton, respectively. Sorghum was seeded at 7 lb/acre at both sites.

Winter rye was harvested as hay in late May while sorghums were harvested as silage in the fall. See Table 3.8 for a description of the tillage systems.

Sweet Sorghum and Sweet Sorghum/Rye in Rotation

These systems are very much like the other sorghum systems except for the use of nitrogen. For the sorghum/rye in rotation with corn and soybean, no nitrogen was applied in the early spring because soybean is a nitrogen fixer. Nitrogen was applied only once in late spring, at the time of sorghum planting.

Monocrop sweet sorghum in rotation with corn and soybean was fertilized in the spring. The amount of phosphorus and potassium applied for this system was the same as

Table 3.7. Description of tillage systems for monocrop sweet sorghum silage and sorghum Sudan grass.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer application			Spring
Phosphorus, lb	58	58	
Potassium, lb	47	47	
Anhydrous ammonia, lb	100	100	
Disk and herbicide			Spring
Dual, pt	2	2	
Field cultivate			Spring
Harrow			Spring
Plant			Spring
Seed, lb	7	7	
Cultivate			Summer
Harvest			Fall
Haul			
Forage blower			

Note: Sorghum was harvested for silage.

Table 3.8. Description of tillage systems for doublecrop rye/sweet sorghum and sorghum x Sudan grass hybrid.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer application			Fall
Phosphorus, lb	58	58	
Potassium, lb	47	47	
Tandem disk			Fall
Harrow			Fall
Grain drill			Fall
Rye seed, lb	100	120	
Anhydrous nitrogen, lb	63	63	Spring
Harvest rye			Spring
Mow-condition			
Large round bale			
Haul			
Plant			Spring
Sorghum seed, lb	7	7	
Anhydrous nitrogen, lb	100	100	Spring
Herbicide			Spring
Paraquat, pt	2	2	
Harvest			Fall
Haul			
Forage blower			

Note: Sorghum was harvested as silage.

the amount used for the other systems involved with sorghum, except the intercrop sorghum systems. Nitrogen applied for this system was less than for the other systems involved with sorghum because sweet sorghum in this system was planted after soybean, which is a nitrogen fixer. Nitrogen was applied at 50 lb/acre in spring before the sorghum planting.

Tables 3.9 and 3.10 give the tillage systems practiced for the sorghums in rotation with corn-soybean.

Intercrop Sorghum/Alfalfa Systems

For the establishment year, the intercrop sweet sorghum/alfalfa and sorghum x Sudan grass hybrid/alfalfa systems have the same tillage practices as for monocrop alfalfa. The difference in tillage practices appears only during the production years of alfalfa following the establishment year. During the standing years, sorghums are intercropped into the established alfalfa. Sorghums, both sweet sorghum and sorghum x Sudan grass hybrid, are planted in the late spring right after the first harvest of alfalfa. A custom made "slot tiller" was used at the experimental farm to till the soil for the sorghum rows in the established alfalfa before planting the sorghum into alfalfa. However, in description of tillage systems and estimation of production costs, use of a no-till planter was assumed since a "slot tiller" is not commercialized. As with all other sorghum systems, sorghum seeding rates were 7 lb/acre at both Ames and Chariton.

After planting the sorghum and before emergence, paraquat was sprayed at a rate of 2 pt/acre around sorghum slots to suppress the foliage of established alfalfa to reduce competition for the emerging sorghum.

For the description of the tillage systems, see Table 3.11. This is the tillage systems for both sweet sorghum/alfalfa and sorghum x Sudan grass hybrid/alfalfa.

Intercrop Sorghum/Reed Canary Grass System

For the establishment year, this system has the same tillage practices as for the monocrop reed canary grass. Both sweet sorghum and sorghum x Sudan grass are interplanted into the established reed canary grass.

In the fall of each year, maintenance rates of phosphorus and potassium were applied to both of the experimental sites at a rate of 32 lb/acre and 94 lb/acre, respectively.

Table 3.9. Description of tillage systems for sweet sorghum in rotation with corn-soybean.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer application			Spring
Phosphorus, lb	58	58	
Potassium, lb	47	47	
Anhydrous ammonia, lb	50	50	
Disk and herbicide			Spring
Dual, pt	2	2	
Harrow			Spring
Plant			Spring
Seed, lb	7	7	
Harvest			Fall
Haul			
Forage blower			

Note: Sorghum was harvested for silage.

Table 3.10. Description of tillage systems for doublecrop sweet sorghum/rye in rotation with corn-soybeans.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilizer application			Fall
Phosphorus, lb	58	58	
Potassium, lb	47	47	
Tandem disk			Fall
Harrow			Fall
Grain drill			Fall
Rye seed, lb	100	100	
Harvest			Spring
Mow-condition			
Large round bale			
Haul			
Plant			Spring
Sorghum seed, lb	7	7	
Fertilization			Spring
Anhydrous ammonia, lb	50	50	
Harvest			Fall
Silage harvester			
Haul			
Forage blower			

Note: Sorghum was harvested for silage.

Table 3.11. Description of tillage systems for intercrop sorghum/alfalfa.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Harvest (alfalfa)			Spring
Mow-conditioning			
Rake			
Large round bale			
Haul			
No-till plant			Spring
Sorghum seeds, lb	7	7	
Herbicide			Spring
Paraquat, pt	0.4	0.4	
Harvest (sorghum/alfalfa)			Summer
Mow-conditioning			
Large round bale			
Haul			
Harvest (sorghum/alfalfa)			Fall
Mow-conditioning			
Large round bale			
Haul			

This intercrop system received half of the nitrogen in mid-April, with the remainder applied in late July before the second harvest.

As for the intercrop sorghum/alfalfa, a slot tiller was used to till the soil to plant the sorghum into established reed canary grass. Sorghum was planted with a no-till planter in early June after the first harvest of reed canary grass. Seeding rates were the same as monocrop sorghum systems, 7 lb/acre. Paraquat was applied at a rate of 2 pt/acre to the foliage of established reed canary grass to reduce competition for the emerging sorghum after planting and before emergence in the middle of June.

Table 3.12 illustrates in detail the tillage schedule and the tillage practice for this system.

Corn and Soybean Rotation

The primary purpose of considering corn and soybeans in this research was to compare sorghum yields in a crop rotation system with the sorghum yields in the other systems. An additional purpose was to consider the effects of growing biomass on farms where corn and soybeans are the major crops.

For corn production in Iowa, the conventional tillage systems typically include the following activities: chisel plow, tandem disk, N application, field cultivation, planting, cultivation, and spraying. Chisel plowing is usually omitted for the crop rotation systems such as corn following soybeans [1]. As indicated by the short description of tillage systems above, fertilizers are applied before planting while herbicides are applied after sufficient growth of corn.

As shown in Table 3.13, the tillage systems practiced in this research are somewhat different than what has been conventionally practiced in Iowa for corn production. Chisel plowing and field cultivation activities were not practiced in this research because the soil was loose enough even without plowing, and preplant herbicides were applied instead of field cultivation. Thus the field was tandem disked followed by harrowing.

To control weeds during field preparation, herbicides were applied before planting in the spring. By attaching the sprayer on the tandem disk, disking and herbicide application activities were practiced simultaneously. The post-planting weed problems were controlled entirely by the cultivation in the summer.

Fertilizers were applied in the spring before planting. Both sites, Ames and Chariton, received the same amount of P and K, 58 lb of P per acre and 47 lb of K per acre, respectively. Four levels of fertilizer nitrogen, 0, 62, 125, and 250 lb/acre, were

Table 3.12. Description of tillage systems for intercrop sorghum/reed canary grass.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilization			Fall
Phosphorus, lb	32	32	
Potassium, lb	94	94	
Nitrogen, lb	100	100	
Harvest			Spring
Mow-conditioning			
Large round bale			
Haul			
No-till plant			Spring
Sorghum seeds, lb	7	7	
Herbicide			Spring
Paraquat, pt	0.4	0.4	
Fertilization			Summer
Nitrogen, lb	100	100	
Harvest			Summer
Mow-conditioning			
Large round bale			
Haul			
Harvest			Fall
Mow-conditioning			
Large round bale			
Haul			

Table 3.13. Description of tillage systems for corn.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilization			Spring
Phosphorus, lb	58	58	
Potassium, lb	47	47	
Nitrogen, lb	125	125	
Tandem disk & herbicide			Spring
Bladex 4L, pt	5	5	
Lasso, pt	5	5	
Harrow			Spring
Plant			Spring
Corn seed, thou k	30	30	
Cultivator			Summer
Harvest			Fall
Combine with corn head			
Flail chopper			
Rake			
Large round bale			
Haul stover			

applied to subplots at both sites. However, in estimating net production costs, 125 lb of N per acre was chosen. Although yields increased as more N was applied, the highest net return was obtained at this level of N.

Corn was planted with a John Deere MaxEmerge2 planter in early May. The seeding rate was 30,000 kennels per acre. This rate allows an approximate final population of 26,506 plants per acre.

Grain and stover were harvested separately. Grain was harvested first. A corn head was attached to the combine to harvest corn grain. Stover was harvested by a flail chopper. Then, raking, large round baling, and hauling activities were followed in order on the stover.

Field preparation activities for soybean in Iowa include chisel plow, tandem disk, and field cultivation (see Table 3.14). Field preparation is practiced in the spring before planting. Soybean planting is done in the spring at a rate of 60 lb/acre. After sufficient growth of the soybean, cultivation and herbicide applications are used to control weeds. Harvesting was done by combining in the fall [1].

Fertilizers were applied in the early spring. Phosphorus was applied at a rate of 40 lb/acre, and potassium was applied at a rate of 75 lb/acre at both sites. Nitrogen was not used because soybeans are a nitrogen fixer. The field was harrowed and then tandem disked in the spring. By attaching a sprayer to the tandem disk, disking and herbicide application were done simultaneously. Lasso was applied at a rate of 6 pt/acre at both sites to control weeds.

Soybean was planted with a John Deere MaxEmerge2 planter in the spring at a rate of 60 lb/acre. After sufficient growth of soybeans, cultivation was practiced to control weeds in the summer. Soybeans were harvested using a combine with a soybean platform in the fall.

DISCUSSION ON YIELD

Average total dry-matter yield and yield response to nitrogen treatments in the experiments are shown in Tables 3.15 through 3.21. These are the average of dry-matter yields under various nitrogen treatments over the experimental period, 1988-1992.

Most cropping systems were treated with four different levels of nitrogen (0, 62, 125, 250 lb/acre) to compare yield response to nitrogen. Sorghum intercropped with alfalfa and reed canary grass, and sweet sorghum and sweet sorghum/rye systems in

Table 3.14. Description of tillage systems for soybean.

Field Operation	Rate/Acre Ames	Rate/Acre Chariton	Time of Year
Fertilization			Spring
Phosphorus, lb	40	40	
Potassium, lb	75	75	
Tandem disk & herbicide			Spring
Lasso, pt	6	6	
Harrow			Spring
Plant			Spring
Soybean seed, unit	1	1	
Cultivator			Summer
Harvest			Fall
Combine with soybean platform			

Table 3.15. Average dry-matter yield for monocrop perennial grasses and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Alfalfa				
2 cut	3.76		3.35	
3 cut	4.21		3.47	
Reed canary grass				
0 lb N/a	1.65		2.47	
62.5 lb N/a	2.47	0.82	3.64	1.17*
125 lb N/a	3.33	0.86*	4.41	0.77
250 lb N/a	4.58	1.25	4.73	0.32
Switchgrass				
0 lb N/a	2.46		3.14	
62.5 lb N/a	4.50	2.04*	3.76	0.62
125 lb N/a	4.50	0.00	4.69	0.93*
250 lb N/a	4.73	0.23	4.92	0.23
Big bluestem				
0 lb N/a	3.30		2.20	
62.5 lb N/a	3.74	0.44*	3.29	1.09*
125 lb N/a	3.84	0.10	3.55	0.26
250 lb N/a	4.17	0.33	3.74	0.19

Note: * indicates the highest yield response to nitrogen use. To determine the highest yield response to nitrogen use, both the absolute and the marginal change in yield at different level of nitrogen application were examined. However, the marginal change in yield is the decisive factor determining the highest yield response. Although the highest level may be at 250 lb/acre, for example, the highest marginal change is always denoted by *.

Table 3.16. Average dry-matter yield for monocrop sorghum and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Sweet sorghum				
0 lb N/a	5.04		5.92	
62.5 lb N/a	6.68	1.64*	7.07	1.16*
125 lb N/a	7.08	0.40	7.29	0.22
250 lb N/a	6.81	-0.27	7.18	-0.11
Sorghum x Sudan grass				
0 lb N/a	5.03		5.62	
62.5 lb N/a	5.79	0.76*	6.35	0.73*
125 lb N/a	6.47	0.68	6.36	0.01
250 lb N/a	6.48	0.01	6.97	0.61

Note: * indicates the highest yield response to nitrogen.

Table 3.17. Average dry-matter yield for intercrop systems and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Sweet sorghum/alfalfa				
62.5 lb N/a	6.11		4.29	
125 lb N/a	6.19	0.08	4.71	0.42
Sorghum x Sudan grass/alfalfa				
62.5 lb N/a	5.60		4.86	
125 lb N/a	6.03	0.43	5.16	0.30
Sweet sorghum/reed canary grass				
62.5 lb N/a	3.36			
125 lb N/a	4.41	1.05		
Sorghum x Sudan grass/reed canary grass				
62.5 lb N/a	3.44			
125 lb N/a	4.49	1.05		

Table 3.18. Average dry-matter yield for doublecrop sorghum/rye and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Sweet sorghum/rye				
sweet sorghum				
0 lb N/a	3.26		2.97	
62.5 lb N/a	4.25	0.99*	3.73	0.76*
125 lb N/a	5.22	0.97	4.48	0.75
250 lb N/a	5.53	0.31	5.49	1.01
Rye				
0 lb N/a	1.19		1.50	
62.5 lb N/a	1.80	0.61*	1.72	0.22*
125 lb N/a	2.12	0.32	1.85	0.13
250 lb N/a	2.40	0.27	1.92	0.07
Total				
0 lb N/a	4.22		4.47	
62.5 lb N/a	5.69	1.47*	5.45	0.98*
125 lb N/a	6.92	1.23	6.33	0.88
250 lb N/a	7.45	0.53	7.41	1.08
Sorghum x Sudan grass/rye				
sorghum x Sudan grass				
0 lb N/a	2.78		2.94	
62.5 lb N/a	4.15	1.38*	3.66	0.72
125 lb N/a	4.89	0.74	4.47	0.81*
250 lb N/a	6.06	1.17	5.20	0.73
Rye				
0 lb N/a	1.11		1.17	
62.5 lb N/a	1.59	0.48*	1.72	0.55*
125 lb N/a	1.90	0.31	1.80	0.09
250 lb N/a	2.20	0.29	2.03	0.23
Total				
0 lb N/a	3.67		4.10	
62.5 lb N/a	5.42	1.76*	5.37	1.27*
125 lb N/a	6.41	0.99	6.27	0.90
250 lb N/a	7.82	1.41	7.23	0.96

Note: * indicates the highest yield response to nitrogen use.

Table 3.19. Average dry-matter yield for sorghum and sorghum/rye in rotation and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Sweet sorghum				
62.5 lb N/a	6.68		7.15	
125 lb N/a	7.18	0.51	7.32	0.17
Sweet sorghum/rye				
sweet sorghum				
62.5 lb N/a	5.46		5.61	
125 lb N/a	5.76	0.31	6.85	1.23
Rye				
62.5 lb N/a	2.32		1.93	
125 lb N/a	2.35	0.03	1.98	0.05
Total				
62.5 lb N/a	7.31		7.55	
125 lb N/a	7.64	0.33	8.83	1.28

Table 3.20. Average dry-matter yield for corn and yield response to nitrogen fertilization.

Cropping System	Yield	Change in Yield	Yield	Change in Yield
	(ton/acre)			
	Ames		Chariton	
Corn				
Grain				
0 lb N/a	1.37		1.83	
62.5 lb N/a	2.45	1.08*	2.09	0.26*
125 lb N/a	3.00	0.55	2.23	0.14
250 lb N/a	3.31	0.31	2.23	0.00
Stover				
0 lb N/a	2.41		2.29	
62.5 lb N/a	2.70	0.28	2.24	-0.05
125 lb N/a	3.16	0.47*	2.69	0.45*
250 lb N/a	3.38	0.21	2.87	0.18
Total				
0 lb N/a	3.78		4.12	
62.5 lb N/a	5.15	1.37*	4.33	0.21
125 lb N/a	6.17	1.02	4.91	0.58*
250 lb N/a	6.69	0.52	5.09	0.18

Note: * indicates the highest yield response to nitrogen use.

Table 3.21. Average dry-matter yield for soybean.

Cropping System	Ames	Chariton
	(ton/acre)	
Soybean		
Grain	0.76	1.10
Stover	0.60	0.99
Total	1.36	2.09

rotation with corn and soybean had only two different levels of nitrogen treatments (62 and 125 lb/acre). Monocrop alfalfa and soybean received no nitrogen treatments.

It is generally believed that yields on productive land are higher than those on marginal land under the same management systems. As shown by the data from the Iowa experiment on biomass production, this research reaches the same conclusion with a few noticeable exceptions. For example, reed canary grass yields on marginal land in Chariton are higher than on productive land in Ames, as shown by Table 3.15. Yields of the pure monocrop sorghum and sweet sorghum in rotation with corn and soybean are also higher in Chariton than in Ames. This may be due to a regional difference in weather conditions during the experimental periods, 1988 to 1992. Chariton is located in southern Iowa so it is usually warmer than Ames, which is located in central Iowa. In general, reed canary grass grows better under cool and moist weather conditions [6], while sorghum is a warm-season crop [20]. Thus the warmer conditions in Chariton might be a reason for the higher yields.

Yield response to nitrogen use is measured by comparing the marginal productivity of nitrogen, which is defined as the change in yield in response to a small change in nitrogen. In this study, the highest rate of yield increase response was achieved at a rate of 62.5 lb/acre with very few exceptions. Although total yield increases at nitrogen rates above 62.5 lb/acre, the yield increases at a decreasing rate.

Perennial Forages

As mentioned before, alfalfa had two harvesting systems, two cuts and three cuts per year. Reed canary grass was harvested twice per year. Switchgrass and big bluestem were harvested once per year. Table 3.15 shows the yield response of the perennials at both Ames and Chariton to different levels of nitrogen use.

For alfalfa, the three-cut system had higher yields than the two-cut system at both locations. However, not much yield improvement was achieved by the three-cut system at Chariton as compared to Ames.

Reed canary grass at Ames showed consistent improvement in yield in response to increases in nitrogen use compared to the yield response at Chariton. The highest yield response is observed at 125 lb of nitrogen per acre at Ames and 62.5 lb of nitrogen per acre at Chariton, respectively.

Switchgrass produced more dry matter on average per year than the other perennial forages selected for this research at both the Ames and Chariton experiment sites

(Table 3.15). The largest increase in yield is observed at the nitrogen levels of 62.5 lb/acre at Ames and 125 lb/acre at Chariton, respectively. Switchgrass yield at Ames shows almost no response to the additional nitrogen use beyond 62 lb/acre.

Big bluestem shows the largest yield response to nitrogen use at 62.5 lb/acre at both Ames and Chariton. The yield response at Chariton at this level is much larger than at Ames.

In short, the maximum yield responses to nitrogen are observed at the nitrogen level of 62.5 lb/acre, except reed canary grass at Ames and switchgrass at Chariton. Among the perennial grasses, switchgrass is the highest dry matter producing energy crop.

Sweet Sorghum and Sorghum x Sudan Grass Hybrid

The sorghums are high-yielding annual crops. Table 3.16 shows the yields of the sorghum crops used in this study at different levels of nitrogen.

Sweet sorghum produced more dry matter than sorghum x Sudan grass hybrid at both locations for all nitrogen levels. The yields of sweet sorghum ranged from 5.04 to 7.08 tons/acre at Ames and from 5.92 to 7.29 tons/acre at Chariton for different nitrogen levels. The yields of sorghum x Sudan grass hybrid ranged from 5.03 to 6.48 tons/acre at Ames and from 5.62 to 6.97 tons/acre at Chariton.

Sweet sorghum produced about 15% more dry matter at Ames and about 11% more at Chariton, respectively, than sorghum x Sudan grass hybrid at the 62.5 lb nitrogen level per acre. At 125 lb nitrogen per acre, it produced about 9% more at Ames and about 15% more at Chariton, respectively. At 250 lb/acre, it produced about 5% more at Ames and about 3% more at Chariton.

The largest yield response to nitrogen was achieved at the rate of 62.5 lb/acre for both sorghums at both sites. Dry-matter yield for sweet sorghum at Ames increased by about 33% per acre and that at Chariton increased by about 20% per acre when nitrogen input use changed from 0 to 62.5 lb/acre.

Sorghum x Sudan grass hybrid had the most yield response to nitrogen at 62.5 lb/acre at both sites. Sorghum x Sudan grass hybrid at Ames produced about 15% more dry matter at 62.5 lb nitrogen per acre than 0 lb nitrogen per acre. At Chariton, yields increased about 13% at 62.5 lb nitrogen per acre as compared to 0 lb nitrogen per acre.

Two things should be noted from Table 3.16. First, contrary to the general notion that yield on productive land is higher, dry-matter yield was higher on the marginal land in

Chariton than on the productive land in Ames. As explained in the beginning of this section, this may be primarily due to the regional difference in weather conditions during the experimental period. Secondly, sweet sorghum showed negative yield response to nitrogen at 250 lb/acre at both locations. Reasons for this are not totally obvious, given that the dry-matter yield of doublecrop sweet sorghum with winter rye (Table 3.18) shows a continuous increase in total yield as more nitrogen is applied. One possible explanation for the negative response of monocrop sweet sorghum to nitrogen at 250 lb/acre is higher crop losses during harvest.

Sorghum Interseeded with Alfalfa or Reed Canary Grass

These systems were harvested three times per year. Sorghum, in this system, was harvested together with the perennial grasses. As a result, sorghum in this system is assumed to be harvested as hay.

Sorghum intercropped into the reed canary grass system was not initiated at Chariton because of the weather conditions in 1988. Reed canary grass was seeded on 13 April, 1988, at Chariton; however, the reed canary grass did not establish and reseeding was done in late August. The reed canary grass emerged but winter killed when unusually warm weather initiated growth and then an arctic cold front dropped temperatures below 30° F, killing the grass. Reseeding was done in April 1989 without tillage of the plots, and establishment was weak but successful. No harvest was taken until 1990. As a result, the sorghum/reed canary grass system was not initiated at Chariton.

As shown in Table 3.17, sorghum intercropped into alfalfa at Ames produced much higher dry-matter yield than sorghum intercropped into reed canary grass. Sweet sorghum/alfalfa produced about 82% more dry matter at the nitrogen rate of 62.5 lb/acre and about 40% more at 125 lb/acre, respectively, than sweet sorghum/reed canary grass at the same levels of nitrogen. Sorghum x Sudan grass hybrid/alfalfa produced about 63% more at 62.5 lb/acre and about 34% more at 125 lb/acre than sorghum x Sudan grass hybrid/reed canary grass.

As expected, dry-matter yield was higher on the productive land in Ames for both sorghums intercropped into alfalfa. At 62.5 lb/acre of nitrogen, yields at Ames were about 18% higher for sweet sorghum/alfalfa and about 15% higher for sorghum x Sudan grass hybrid/alfalfa, respectively, than at Chariton.

By comparing Table 3.17 to Tables 3.15 and 3.16, we observe that the dry-matter yield of these systems is greater than the monocrop alfalfa and reed canary grass systems,

but lower than the monocrop sorghum systems. The same results have been observed in other experiments [21, 22].

In short, under the same management systems, sorghum intercropped into alfalfa is more suitable for energy crop production because this system has higher yields than sorghum intercropped into reed canary grass.

Sorghum Doublecropped with Winter Rye

Table 3.18 shows average dry-matter yields and yield response to nitrogen fertilization for sorghum doublecropped with winter rye.

Rye dry-matter yields were much lower than other crops in this research. Rye yields were influenced by previous nitrogen applications to sorghum with consistent yield increases in response to nitrogen fertilizer, although the response at Chariton was small beyond 62.5 lb/acre. Rye dry-matter yields responded the most to nitrogen fertilizer application at 62.5 lb/acre at both sites. At this level, dry-matter yield increased by more than 40% except in the case of the rye doublecropped with sweet sorghum, which showed about a 15% increase at Chariton.

Like monocrop sweet sorghum, sweet sorghum doublecropped with rye produced, overall, slightly higher dry-matter yield than the sorghum x Sudan grass hybrid at both locations. As expected, dry-matter yield was lower on the marginal land. Unlike monocrop sorghum, consistent yield increases with nitrogen application were evident at both sites.

Noticeable differences in yield between monocrop sorghum and doublecrop sorghum was observed. Dry-matter yield of doublecrop sorghum was much lower than that of monocrop sorghum. Even total dry-matter yield of doublecrop sorghum, which is the sum of the dry-matter yield of sorghum and rye, was lower overall than the yield of monocrop sorghum. Thus the intercrops must find their advantage, if any, in soil conservation properties, not yields.

Sweet Sorghum in Rotation with Corn and Soybean

Two rotation systems were employed. One was sweet sorghum following corn and soybean and the other was sweet sorghum/rye doublecrop following corn and soybean. Both are in a three-year rotation.

As shown by Table 3.19, sweet sorghum in rotation with corn and soybean produced higher dry-matter yield than sweet sorghum/rye in rotation, if we compare just

the dry-matter yield of sorghum itself. However, if we compare the total dry-matter yield of sweet sorghum/rye, which is the sum of the yield of both sorghum and rye, to sorghum in rotation, sweet sorghum/rye in rotation produced higher dry-matter yield.

As with the monocrop sorghum in Table 3.16, the dry-matter yield of sorghum in rotation on the marginal land was higher than that on the productive land. As explained before, this is probably due to climate differences.

Corn and Soybeans

As expected and shown in Table 3.20, corn yield responds positively to nitrogen use. The largest corn grain yield response to nitrogen occurred at 62.5 lb/acre of nitrogen at both Ames and Chariton. As the nitrogen level increases beyond 62.5 lb/acre while all other input levels stay the same, additional yields on corn grain increase at a decreasing rate. At Chariton, no yield response to nitrogen is observed at 250 lb/acre. Corn grain yields of this rotation system are slightly higher than the estimated grain yields of corn following soybean in Iowa under a similar management system as suggested by extension service budgets. It is also slightly higher than the actual average annual corn grain yields in Iowa from 1988 through 1991. Estimated yields of corn grain in Iowa are 115 bushels/acre with 138 lb/acre of nitrogen using extension budgets [1], while the actual average annual corn grain yields in Iowa are 111 bushels/acre [23, 24]. The average yield in the experiments was 118 bushels/acre at a nitrogen level of 125 lb/acre.

As expected, yields on corn stover steadily increase as the level of nitrogen use increases. Unlike corn grain, however, the largest yield response to nitrogen is observed at 125 lb/acre of nitrogen at both Ames and Chariton. One thing that should be noticed is that yield on stover decreases at nitrogen level 62.5 lb/acre at Chariton compared to the yield with no nitrogen use. This inconsistency in stover yields on nitrogen use might have been caused by harvest loss.

No nitrogen was used in soybean production since soybean is a nitrogen fixer. Yields of soybean are shown in Table 3.21. Compared to the estimated yields of soybean in rotation with corn (50 bushel/acre) for a similar management system in Iowa [1], soybean yields (28 bushels/acre in Ames and 40 bushels/acre in Chariton) in our experiment are much lower.

The actual average annual yield for soybean in Iowa during the 1988-1991 time period was 38 bushels/acre [23, 24]. This was higher than the yields at Ames, but lower than the yields at Chariton.

Summary of Yield Responses

Overall, sweet sorghum and sorghum x Sudan grass hybrids in different cropping systems produced higher yields than any other annual and perennial species grown in this experiment.

As shown in Tables 3.16 through 3.19, among the cropping systems involved with sorghum, sweet sorghum in both the pure monocrop system and monoculture in the rotation system produced the highest dry matter. When we just compare sorghum yield itself in the mixed cropping systems to the monocrop sorghum systems, including sweet sorghum in rotation, sorghum yield in the mixed cropping systems is lower than that of monocrop sorghum. However, if we compare the total yield of the mixed systems themselves (e.g., sorghum/rye in doublecrop or in doublecrop rotation) to the monocrop systems, there is not much difference in dry-matter yields.

Sorghum intercropped into the perennial forages, alfalfa and reed canary grass, also produced lower dry-matter yields than the monocrop sorghum systems. However, if we consider the objective of soil conservation, the sorghum/alfalfa intercrop system might be a good system to consider as an energy crop production system since it has relatively high dry-matter yields.

Among the perennial grasses, switchgrass produced the highest dry-matter yields at both Ames and Chariton. In Ames, big bluestem produced relatively higher dry-matter yields than reed canary grass. On the other hand, big bluestem was less productive than reed canary grass in Chariton.

Given the objective to find a biomass crop(s) and a biomass production system(s) that has sustainable high productivity and serves conservation purposes, the results are encouraging.

Recent research shows that sorghum yields may decrease if continuous production of sorghum is practiced on the same land [22]. This is the problem inherent in monoculture and doublecrop sorghum [22]. Pure monoculture sorghum also has a soil erosion problem because it has no groundcover after harvest. However, by practicing the crop rotation system over continuous cropping of a monoculture sorghum, we can avoid some pest and disease problems [22], which will result in less use of chemicals, and soil erosion problems without losing high productivity. Thus the intercrop sorghums show some promise as an environment-friendly biomass crop.

Switchgrass is another excellent choice as a biomass energy crop in Iowa, particularly where soil erosion is an important concern. Although its yield is lower than

sorghum, it is the most productive among the perennial grasses and, once established, it provides good soil control [22].

So far we have discussed yields of each species and cropping system and their responses to the nitrogen use. We have also looked at the most productive nitrogen level for each species. Furthermore, we have identified the most productive cropping systems within the perennial grasses and the annuals and among the different systems. Now we turn to the production costs of each cropping system. This will help in selecting an economically feasible biomass cropping system(s).

ASSUMPTIONS USED IN ESTIMATING PRODUCTION COSTS FOR THE BIOMASS SYSTEMS

Production of the biomass crops considered in this study is most likely to occur on farms that are already producing forage, since production of biomass crops involves high fixed costs to maintain forage machinery. In some areas, an active custom market for forage operations may allow producers to add these biomass crops at a reasonable cost, even without machinery ownership.

Two types of cost estimates are developed in this study. One type is a good approximation of the costs for producers who custom hire the planting and harvesting operations or for those who already own and effectively utilize forage equipment. For producers who already grow other forages, if the biomass crops provide a better return to the fixed machinery and labor resources, the biomass crops can be easily substituted for the currently grown forage crops. The other set of costs are based on lower annual use of forage equipment by farmers who primarily grow row crops such as corn and soybean and are considering adding biomass crops.

The net production costs presented in this report provide a detailed breakdown of variable production costs for both marginal and high productivity land. The Mississippi State Budget Generator (MSBG) is used as a tool to estimate the net production costs for each of the cropping systems with modification on input data to incorporate Iowa conditions and these specific crops.

Equipment and Annual Hours of Use

It is assumed that the equipment required to perform the various tillage, planting, and harvest operations is owned by the farm operator. Table 3.22 presents the annual hours of use and performance rate for each piece of equipment used in the production of the

Table 3.22. Performance rate of implements and annual hours of use.

Description	Annual Use (A)	Annual Use (B)	Performance Rate
	(hours)		(a/hr)
Fertilization			
Bulk fertilizer, 25 ft		30	10.2
NH3 applicator, 15 ft		60	5.7
Tillage			
Chisel plow, 15 ft		80	7.4
Tandem disk, 17 ft		100	9.2
Disk with sprayer, 21 ft		100	7.8
Peg-tooth harrow, 7 section	9	40	18.0
Field cultivator, 21 ft		40	10.2
Planting			
Grain drill, 13 FT	28	40	5.7
Planter, 4 row NR		67	4.9
No-till planter, 6 row NR	24	60	6.7
Cultipacker, 15 ft	23	120	7.1
Weed control			
Sprayer, 40 ft		50	11.8
Cultivator, 4 row		80	7.4
Harvesting			
Mower-conditioner, 12 ft	27	120	5.9
Flail chopper, 10 ft	35	80	4.6
Rake, 9 ft	34	100	4.7
Large round baler, 14 ft	21	120	7.5
Silage harvester, 3 row	100	200	1.6
Forage blower, 14 ft	27	50	6.0
Combine, corn head, 4 row NR		110	2.3
Combine, soybean platform, 13 ft		80	2.7
Haul hay, 15 ft trailer	40	80	4.0
Haul grain, 300 bu wagon		150	4.0
Haul silage, 7.17 ft	80	140	2.0
Haul stover, 7.17 ft	80	140	2.0

Source: ISU Cooperative Extension Service, "Estimating Field Capacity of Farm Machines," January 1986.
Note: (A) 160 acres biomass production is assumed.
(B) Estimated based on average Iowa equipment use.

biomass crops in this research. The performance rate is the rate at which an implement performs its primary function; e.g., the number of acres that can be plowed per hour. The implied annual hours of use for each implement is estimated by dividing the number of land acres used in crop production by the performance rate.

Two sets of the annual hours of use for each implement are listed under annual use column (A) and (B) in Table 3.22. The first one (A) assumes that only 160 acres of farm land are allocated to the production of energy crops. Only those implements used in the forage production are in this set. Thus the annual use of the forage equipment is rather low. The second set (B) is based on the average annual hours of use of implements by Iowa farmers. This set is from survey data collected by the Iowa State University Extension Service. Although the first set is estimated by assuming that 160 acres of land is allocated for the biomass production, this does not necessarily mean that the 160 acres represents total farm land devoted to energy crop production. It is just a yardstick. For example, if a representative farmer decides to allocate 320 acres for production of energy crops (160 acres for switchgrass and 160 acres for sweet sorghum) and a bulk fertilizer spreader is used in both crops, then the annual hours of use for bulk fertilizer spreading would be the number in the annual use column of Table 3.22 multiplied by 2, which is 32 hours per year. In short, the annual hours of use of implements are directly related to the acres of land allocated to the biomass crop production.

The tillage systems used in estimation of the biomass crop production costs are ones typically practiced by Iowa farmers and not necessarily the ones used in the experimental trials. A list of equipment used in estimating production costs of biomass crops is shown in Tables 3.23 and 3.24. Implements used in the production of each biomass cropping system are listed in Tables 3.25 through 3.28 along with their field capacity and annual hours of use. For the systems involved with perennial grasses, implements used during the establishment year and implements used during the standing years are presented separately in Tables 3.25 and 3.26, respectively. Annual hours of use of implements shown in Tables 3.25 through 3.28 are estimated by the same method used in Table 3.22.

Division of Costs

By the construction of the MSBG, the cash costs of variable factors of production such as operating inputs, labor, fuel, repairs and maintenance, and interest on operating capital are itemized under direct expenses. On the other hand, the noncash costs of owning

Table 3.23. Implements used in production of perennial grasses and intercrop sorghum.

Description	AL	RC	SWG	BB	ALI	RCI
Fertilization						
Bulk fertilizer, 25 ft	x	*	*	*	x	*
Tillage						
Chisel plow, 15 ft	x	x	x	x	x	x
Tandem disk, 17 ft	x	x	x	x	x	x
Peg-tooth harrow, 7 section	x	x	x	x	x	x
Planting						
Grain drill, 13 ft	x	x	x	x	x	x
No-till planter, 6 row NR					#	#
Cultipacker, 15 ft	x	x	x	x	x	x
Weed control						
Sprayer, 40 ft	*	x	x	x	*	*
Harvesting						
Mower-conditioner, 12 ft	*	*	*	*	*	*
Rake, 9 ft	+					
Large round baler, 14 ft	*	*	*	*	*	*
Haul hay, 15 ft	*	*	*	*	*	*

Note: AL=alfalfa; RC=reed canary grass; SWG=switchgrass; BB=big bluestem; x = establishment year practices only; ALI=alfalfa/sorghum intercrop; RCI=reed canary grass/sorghum intercrop.
* = activities used in both establishment year and maintenance year; + = maintenance year practice only;
# = activities used in intercrop sorghum production only throughout the standing year except establishment year.

Table 3.24. Implements used in production of annual crops.

Description	1	2	3	4	5	6
Fertilization						
Bulk fertilizer, 25 ft	x	x	x	x	x	x
NH3 applicator, 15 ft	x	x	x	x	x	
Tillage						
Tandem disk, 17 ft		x		x		
Disk with sprayer, 21 ft	x		x		x	x
Peg-tooth harrow, 7 section	x	x	x	x	x	x
Field cultivator, 21 ft	x					
Planting						
Grain drill, 13 FT		x		x		
Planter, 4 row NR	x	x	x	x	x	x
Weed control						
Cultivator, 4 row	x				x	x
Harvesting						
Mower-conditioner, 12 ft		x		x		
Flail chopper, 10 ft					x	
Rake, 9 ft					x	
Large round baler, 14 ft		x		x	x	
Silage harvester, 3 row	x	x	x	x		
Forage blower, 14 ft	x	x	x	x		
Combine, corn head, 4 row NR					x	
Combine, soybean platform, 13 ft						x
Haul hay, 15 ft		x		x		
Haul grain, 300 bu					x	
Haul silage, 7.17 ft	x	x	x	x		
Haul stover, 7.17 ft					x	

Note: 1 = monocrop sorghum; 2 = sorghum/rye double crop; 3 = sweet sorghum in rotation; 4 = sweet sorghum/rye in rotation; 5 = corn; 6 = soybeans.

Table 3.25. Field capacity and annual use of implements used in production of perennial including intercrop alfalfa and reed canary grass during the establishment year.

Description	Annual Use (A)	Annual Use (B)	Field Capacity	Crops a	b	c	d
	(hours)		(a/hr)				
Fertilization							
Bulk fertilizer, 25 ft		30	10.2	x	x	x	x
Tillage							
Chisel plow, 15 ft		80	7.4	x	x	x	x
Tandem disk, 17 ft		100	9.2	x	x	x	x
Peg-tooth harrow, 7 sect	9	40	18.0	x	x	x	x
Planting							
Grain drill, 13 ft	28	40	5.7	x	x	x	x
Cultipacker, 15 ft	23	120	7.1	x	x	x	x
Weed control							
Sprayer, 40 ft		50	11.8	x	x	x	x
Harvesting							
Mower-conditioner, 12 ft	27	120	5.9	x	x	x	x
Large round baler, 14 ft	21	120	7.5	x	x	x	x
Haul hay, 15 ft	40	80	4.0	x	x	x	x

Note: a = alfalfa in both mono- and inter-crop; b = reed canary grass in both mono- and inter-crop; c = switchgrass; d = big bluestem.
(A) 160 acres biomass production is assumed.
(B) Estimated based on average Iowa equipment use.

Table 3.26. Field capacity and annual use of implements used in production of perennial including sorghum intercropped into alfalfa and reed canary grass for the standing years.

Description	Annual Use (A)	(B)	Field Capacity	Crops a	b	c	d	e	f
	(hours)		(a/hr)						
Fertilization									
Bulk fertilizer, 25 ft	30		10.2	0	3	0	3	2	2
Planting									
No-till planter, 6 row NR	24	60	6.7	0	0	1	1	0	0
Weed control									
Sprayer, 40 ft	50		11.8	2	0	1	1	0	0
Harvesting									
Mower-conditioner, 12 ft	27	120	5.9	3	2	3	3	1	1
Rake, 9 ft	34	100	4.7	1	0	1	1	0	0
Large round baler, 14 ft	21	120	7.5	3	2	3	3	1	1
Haul hay, 15 ft	40	80	4.0	3	2	3	3	1	1

Note: a = alfalfa; b = reed canary grass; c = intercrop alfalfa; d = intercrop reed canary grass; e = switchgrass; f = big bluestem.
(A) 160 acres biomass production is assumed.
(B) Estimated based on average Iowa equipment use.
The numbers appearing in the last six columns on the table indicate the number of times of the implement is used per year.

Table 3.27. Field capacity and annual use of implements used in production of monocrop sorghum and doublecrop sorghum/rye.

Description	Annual Use (A)	Annual Use (B)	Field Capacity	Systems a	Systems b
	(hours)		(a/hr)		
Fertilization					
Bulk fertilizer, 25 ft		30	10.2	x	x
NH3 applicator, 15 ft		60	5.7	x	x
Tillage					
Tandem disk, 17 ft		100	9.2		x
Disk with sprayer, 21 ft		100	7.8	x	
Peg-tooth harrow, 7 sect	9	40	18.0	x	x
Field cultivator, 21 ft		40	10.2	x	
Planting					
Grain drill, 13 FT	28	40	5.7		x
Planter, 4 row NR		67	4.6	x	x
Weed control					
Cultivator, 4 row		80	7.4	x	
Harvesting					
Mower-conditioner, 12 ft	27	120	5.9		x
Large round baler, 14 ft	21	120	7.5		x
Silage harvester, 3 row	100	200	1.6	x	x
Forage blower, 14 ft	27	50	6.0	x	x
Haul hay, 15 ft	40	80	4.0		x
Haul silage, 7.17	80	140	2.0	x	x

Note: a = monocrop sorghum; b = sorghum/rye double crop
(A) 160 acres biomass production is assumed.
(B) Estimated based on average Iowa equipment use.

Table 3.28. Field capacity and annual use of implements used in production of corn, soybean, and sweet sorghum or sorghum/rye in rotation.

Description	Annual Use (A)	Annual Use (B)	Field Capacity	Crops a	Crops b	Crops c	Crops d
	(hours)		(a/hr)				
Fertilization							
Bulk fertilizer, 25 ft		30	10.2	x	x	x	x
NH3 applicator, 15 ft		60	5.7	x		x	x
Tillage							
Tandem disk, 17 ft		100	9.2				x
Disk with sprayer, 21 ft		100	7.8	x	x	x	
Peg-tooth harrow, 7 sect	9	40	18.0	x	x	x	x
Planting							
Grain drill, 13 ft	28	40	5.7				x
Planter, 4 row NR		67	4.6	x	x	x	x
Weed control							
Cultivator, 4 row		80	7.4	x	x		
Harvesting							
Mower-conditioner, 12 ft	27	120	5.9				x
Flail chopper, 10 ft	35	80	4.6	x			
Rake, 9 ft	34	100	4.7	x			
Large round baler, 14 ft	21	120	7.5	x			x
Combine, corn head, 4 row NR		110	2.3	x			
Combine, soybean platform		80	2.7		x		
Silage harvester, 3 row	100	200	1.6			x	x
Forage blower, 14 ft	27	50	6.0			x	x
Haul grain, 300 bu		150	4.0	x	x		
Haul stover, 7.17 ft	80	140	2.0	x			
Haul silage, 7.17 ft	80	140	2.0			x	x
Haul hay, 15 ft	40	80	4.0				x

Note: a = corn; b = soybean; c = sorghum; d = sorghum/rye.
(A) 160 acres biomass production is assumed.
(B) Estimated based on average Iowa equipment use.

durable factors such as depreciation and interest on investment for machines are treated as fixed expenses. The land cost, which is not directly related to field operations, is itemized under the allocated cost heading. For the perennial grasses, the prorated establishment costs are treated as other durable inputs and categorized under establishment costs in estimating annual net production costs of the perennial.

Input prices used to estimate energy crop production costs are listed in Table 3.29. All prices in Table 3.29 are in nominal dollars for 1993. Price data were collected from many different sources. Price data for fertilizers, fungicides, and herbicides were obtained from the local Co-op in Nevada, Iowa. Corn and soybean seed prices are cited from Iowa State University publication, *Estimated Costs of Crop Production in Iowa, 1993* [1]. Other seed prices were collected from an extension agronomist, Dr. S. K. Barnhart, who is Extension Forage Specialist in the College of Agriculture at Iowa State University.

Tables 3.3 through 3.14 in the previous section listed the amounts of fertilizer, herbicide, and seed applied to each cropping system. The fertilizer rates are based on soil tests and discussions with agronomists Dr. D. R. Buxton and Dr. I. C. Anderson at Iowa State University.

Transportation costs to a conversion plant are assumed to be $4.15/ton of dry matter for all crops. This cost is estimated by using the biomass product transportation cost formula developed by Baht et al. [25]. The assumed distance is a 30-mile round trip. It is also assumed that a semi-truck hauling 15.42 tons of hay is used.

Currently there is no active market for biomass crops. Thus we arbitrarily chose $40/dry ton as a presumed selling price for all establishment year grown biomass crops for this research. This is necessary in order to allocate the returns for this year to the other production years. This is arbitrary, but not entirely fictional. This price is within the required selling price of biomass crops to break-even with corn, and to break-even with the production costs of biomass crops in the Midwest [21]. The break-even prices for each biomass cropping system in this research is presented later (see tables in Break-even Price and Gross Margin Analysis section). The assumed price, $40/dry ton, is lower than the market price for hay, $77/dry ton in Iowa and $70.70/dry ton U.S. average in 1991 [23], although this price for hay is for good quality alfalfa.

Nitrogen Levels and Management Systems

As mentioned before, four different levels of nitrogen were applied (0, 62.5, 125, 250 lb/acre) while all other inputs were applied in the same amount to each biomass

Table 3.29. List of input prices.

Item	Unit	Price
		(dollars)
Fertilizers		
Phosphorus	lb	0.25
Potash	lb	0.17
Nitrogen (bulk)	lb	0.21
Anhydrous	lb	0.12
Lime	lb	
Fungicides		
Eptom	pt	2.81
Herbicides		
Atrazine	pt	1.58
Bladex	pt	3.07
Dual	pt	7.88
Lasso	pt	3.28
Lorsban 4E	pt	1.81
Paraquat	pt	4.46
2, 4D	pt	2.31
Seed		
Alfalfa	lb	2.50
Reed canary grass	lb	4.50
Switchgrass	lb	3.50
Big bluestem	lb	9.00
Sweet sorghum	lb	0.50
Sorghum x Sudan grass	lb	0.35
Rye	lb	0.31
Corn	1000 kernels	0.90
Soybean	unit	14.00
Interest	%	10.00
Labor	hour	6.00
Diesel fuel	gal.	0.83
Land	acre	115.00
		80.00

cropping system to see the yield response to nitrogen use. We treat each level of nitrogen application within the same cropping system as a different management system. This means that there are four different management systems for each biomass cropping system.

For the simplicity and convenience, just one management system from each biomass cropping system was chosen to estimate the net production costs (budgets). Each cropping system has two estimated budgets: one is the table number affixed with letter A and the second is the table number affixed with letter B. The difference between the two tables is the assumption on the annual hours of use for implements, given years of ownership and performance rate. The tables with the letter A assume that the annual hours of use are based on 160 acres of biomass production (numbers in the use column below the letter A in Table 3.22), while the tables with the letter B assume that the average annual hours of use of implements is similar to the average of Iowa farmers (numbers in the use column below the letter B in Table 3.22).

As shown in Table 3.22, the annual hours of use of implements assumed by this study for farmers who grow biomass as a sideline are much lower than that of typical Iowa forage farmers because of the difference in assumption on acres of land for which implements are used. Consequently, the budgets estimated with the annual hours of use of implements in the use column below letter A of Table 3.22 (tables with letter A) are higher than the budgets estimated with the annual hours of use of implements in the use column below letter B of Table 3.22 (tables with letter B).

The amount of nitrogen used in estimation of the net production cost for each biomass cropping system is not the same as the nitrogen level actually applied during the experiment period. It is an "optimum" amount recommended by the two agronomists, Dr. I. C. Anderson and Dr. D. Buxton. This nitrogen level is also consistent with the economically optimum level of nitrogen selection at the assumed dry matter price, $40/ton.

In principle, a farmer seeking a maximum net return, under the competitive market system, would choose the input level at which the contribution of each input used in production equals the cost of each input used—i.e., a profit-maximizing farmer will determine the nitrogen input level where the marginal revenue product of nitrogen (MRPN) equals the marginal factor cost of nitrogen (MFCN). Under the competitive market system, MRPN is defined as the market price of the output (dry matter) multiplied by the marginal product of nitrogen, and the MFCN is the market price of nitrogen itself. The MRPN is the benefit from an additional amount of nitrogen, and the MFCN is the cost of an additional amount of nitrogen. Therefore, a profit-maximizing farmer will increase use of nitrogen if

MRPN is greater than MFCN; otherwise, he will reduce nitrogen use. For example, as shown in Table 3.30, if we compare the marginal revenue product of nitrogen (MRPN) and the marginal factor cost of nitrogen (MFCN) in big bluestem production in the table, MRPN is greater than MCN at 62.5 lb of nitrogen and MRPN is less than MNC at 125 lb. This means that a profit-maximizing farmer producing big bluestem should use nitrogen input more than 62.5 lb but less than 125 lb/acre. Thus the recommended nitrogen level, 100 lb/acre, used in the production cost estimation for big bluestem is in accordance with economic theory.

Table 3.30 shows the MRPN and the MFCN for each crop. As mentioned above, the MFCN is the market price of nitrogen, $0.21/lb of bulk nitrogen in 1993. To estimate the MRPN in Table 3.30, we made some assumptions. First, it is assumed that the production function is a piece-wise linear concave function in the output and nitrogen input space. It means that the production function is linear over the given range of inputs; e.g., linear over 0 to 65 lb/acre nitrogen level, 65 to 125 lb/acre, and so on. As a result, the total revenue function is also a piece-wise linear concave function in money and nitrogen space. This automatically leads to our second assumption that the MRPN is constant over the given range of nitrogen levels. Thus the MRPN is estimated by dividing the change in total revenue by the change in the amount of nitrogen input. Third, as mentioned before, market price for the dry matter is assumed to be $40/dry-matter ton. Thus, given the output level, the MRPN will change as the price of dry matter changes.

Table 3.30 indicates that the optimal nitrogen input level should be less than 250 lb/acre for almost all of the biomass crop systems used in this research because the MRPN is less than the MFCN at the nitrogen level of 250 lb/acre, except for the following crops: reed canary grass at Ames, doublecrop sweet sorghum/rye at Chariton, and doublecrop sorghum x Sudan grass hybrid/rye at both Ames and Chariton. For all cropping systems at both Ames and Chariton, the MRPN is much greater than the MFCN at a nitrogen level of 62.5 lb/acre. At the nitrogen level of 125 lb/acre, the MRPN for some systems is less than the MFCN; e.g., big bluestem at both Ames and Chariton, switchgrass at Ames, both monocrop sorghum at Chariton, sweet sorghum in rotation at Chariton, doublecrop sweet sorghum/rye in rotation at both Ames and Chariton, and the intercrop alfalfa/sweet sorghum at Ames.

It should be noted that the MRPN listed in Table 3.30 for each biomass cropping system will change as either the price of dry-matter changes or dry matter yields change.

Table 3.30. Marginal revenue product and marginal cost of nitrogen.

Crop System and Change in Nitrogen Use	Change in Revenue	MRPN	Change in Revenue	MRPN	MFCN
(lb/acre)	(dollars)		(dollars)		
	Ames		Chariton		
Reed canary grass					
62.5	32.80	0.52	46.94	0.75	0.21
62.5	34.40	0.55	30.76	0.49	0.21
125.0	50.12	0.40	12.95	0.10	0.21
Big bluestem					
62.5	17.73	0.28	43.84	0.70	0.21
62.5	3.87	0.06	10.25	0.16	0.21
125.0	13.20	0.11	7.55	0.06	0.21
Switchgrass					
62.5	81.60	1.31	24.82	0.40	0.21
62.5	0.00	0.00	37.23	0.60	0.21
125.0	9.20	0.07	9.17	0.07	0.21
Sweet sorghum					
62.5	65.60	1.05	46.30	0.74	0.21
62.5	16.00	0.26	8.74	0.14	0.21
125.0	-10.80	-0.09	-4.53	-0.04	0.21
Sorghum x Sudan grass					
62.5	30.40	0.49	29.14	0.47	0.21
62.5	27.20	0.44	0.65	0.01	0.21
125.0	0.40	0.00	24.28	0.19	0.21
Sweet sorghum/rye1					
62.5	58.92	0.94	39.17	0.63	0.21
62.5	49.21	0.79	35.29	0.56	0.21
125.0	21.04	0.17	43.06	0.34	0.21
Sorghum x Sudan grass/rye1					
62.5	70.25	1.12	50.83	0.81	0.21
62.5	39.50	0.63	35.94	0.57	0.21
125.0	56.33	0.45	38.20	0.31	0.21
Sweet sorghum2					
62.5	20.23	0.32	6.80	0.11	0.21
Sweet sorghum/rye2					
62.5	13.27	0.20	51.39	0.82	0.21
Corn					
62.5	54.71	0.88	8.42	0.13	0.21
62.5	40.79	0.65	23.31	0.37	0.21
125.0	20.72	0.17	7.12	0.06	0.21

Table 3.30. (Continued).

Crop System and Change in Nitrogen Use	Change in Revenue	MRPN	Change in Revenue	MRPN	MFCN
(lb/acre)	(dollars)		(dollars)		
Alfalfa/sweet sorghum					
62.5	3.20	0.05	17.00	0.27	0.21
Alfalfa/sorghum x Sudan grass hybrid					
62.5	17.20	0.28	12.14	0.19	0.21
Reed canary grass/sweet sorghum					
62.5	42.00	0.67			
Reed canary grass/sorghum x Sudan grass hybrid					
62.5	42.00	0.67			

Note: 1 Double crop systems. 2 Rotation.
a. The numbers listed in the first column below the crop system indicates the changes in the amount of nitrogen use in the following manner: 0 to 62.5 lb/acre; 62.5 to 125 lb/acre; and 125 to 250 lb/acre in turn.
b. The second and fourth columns are the difference in total income at different levels of nitrogen use.
c. The third and fifth columns are estimated by dividing the change in revenue by the change in nitrogen use.
d. The changes in nitrogen level for the following systems are the changes from 62.5 to 125 lb/acre: sweet sorghum and sweet sorghum/rye in rotation and in intercrop systems.

The purpose of this table is merely to show some economic selection criteria for the amount of nitrogen use in production.

RESULTS OF ANALYSIS

Establishment Year and Annual Costs

For the perennial forages, the net production costs for both establishment year and annual production are developed. In the next section, the net production costs for the establishment of perennial grasses are first presented. This is followed by a discussion of the annual net production costs for all cropping systems. The tables in the text contain summary information on costs of production. More complete tables giving quantities as well as prices are contained in Appendix A. These are only reported for average Iowa equipment use.

Establishment Costs for Perennial Forages

Once established, perennial grasses have a long-lasting productive life, so that the cost incurred at the establishment should be prorated over the useful life of perennial grasses. As shown in Table 3.1, the stand for perennial grasses is assumed to be five years for alfalfa and ten years for reed canary grass, switchgrass, and big bluestem, respectively. With careful stand management, it is possible to have longer stand life.

In principle, when establishment costs are prorated, interest payments made on the establishment costs over the useful life of perennial grasses must be counted at the on-going market interest rate. In other words, opportunity costs should be considered. However, for simplicity, the net establishment year costs for each perennial grass in this research were prorated evenly over the remaining years of the stand. For example, the net establishment year costs for switchgrass are prorated over the remaining nine years of the stand.

It is assumed that the perennial grasses will be harvested and sold in the establishment year. As a result, the net establishment year costs (total establishment year costs minus the income from sales) are prorated and these prorated net establishment costs are entered into the annual production cost estimation for the perennial grasses rather than the total establishment year production cost itself.

Perennial grasses are harvested as hay. This involves mowing-conditioning, raking, baling, hauling in the field, and transportation to the conversion plant. It is assumed that switchgrass and big bluestem are harvested once a year while alfalfa and reed canary grass are harvested three times a year. The perennial grasses are assumed to be field dry. Thus, no raking is assumed for the perennial grasses, except the first harvest of alfalfa and reed canary grass. It is assumed that raking is applied to the first harvest of alfalfa and reed canary grass because of typical rainy weather conditions in Iowa in the spring.

Despite transportation inefficiency inherent in the large round bales [26], it is assumed that hay is baled into large round bales of 1,200 lb. The round bale system has relatively low capital investment and modest labor requirement. It can be a one-person operation. The bales can be stored in any open, well-drained area. This eliminates the need for storage facilities [26].

For switchgrass and reed canary grass, machinery costs are the highest among the total specified establishment costs, which accounts for all costs but land cost involved in the production process (Tables 3.31 and 3.32). Machinery costs include fuel, repair and maintenance, and depreciation and interest on average investments in machines, tractors, and implements. Fertilizer costs and seed costs are the second and the third largest costs of production, respectively.

For alfalfa, fertilizer cost is the largest because it is assumed that the total amount of fertilizer required for alfalfa production over the assumed standing life, five years, is applied at once during the establishment year. The second largest costs for alfalfa production are the machinery costs. Seed cost is the third largest establishment cost of alfalfa production.

The rankings of production costs for big bluestem are as follows: seed cost is the highest followed by the machinery costs and fertilizer cost. For big bluestem, seed cost is exceptionally high because, as shown in Table 3.29, big bluestem seed price is much higher per pound ($9) than the other perennial seeds—$2.50 for alfalfa, $4.50 for reed canary grass, and $3.50 for switchgrass. This high input price for seed is the sole reason for the high seed cost for big bluestem. (Note that although the market price of big bluestem seed had decreased to $8/lb in 1994 [27], in estimation of the establishment costs the market price of big bluestem seed in 1993 ($9/lb) is used to be consistent with other input data.)

The lowest cost for all perennial grasses is the cost of controlling weeds.

Switchgrass has both the lowest establishment cost and the lowest net establishment cost per acre while alfalfa has both the highest establishment cost and net establishment cost per acre among the perennial grasses at both Ames and Chariton. With higher land allocation to biomass crop production, total establishment cost and net establishment cost for reed canary grass are unambiguously lower than for big bluestem at both locations (Tables 3.31B and 3.32B); however, the cost comparison between reed canary grass and big bluestem is somewhat complex with lower land allocation (Tables 3.31A and 3.32A). The lower operating costs and higher dry-matter yields are the key factors contributing to the lowest establishment cost and net establishment cost for switchgrass.

As expected, when we compare the establishment year production costs of perennial grasses, switchgrass has the least prorated establishment cost while alfalfa has the largest. Between reed canary grass and big bluestem, there is almost no difference on the prorated establishment cost (Tables 3.31A/B and 3.32A/B).

From this establishment cost analysis, we make the following observations. Machinery costs could be reduced by relying on custom hiring or by renting of equipment. These would reduce the need for large capital outlays. A no-till system could be employed to reduce machinery costs and soil erosion. Soil testing before establishment might enable the producer to fine-tune application of fertilizer.

Annual Production Costs for Perennial Grasses

As explained in the description of the tillage systems, maintenance and harvesting costs are the only ones involved in production of the monocrop perennial biomass crops following the establishment year. Tables 3.33A (3.33B) and 3.34A (3.34B) show the annual production costs of monocrop perennial grasses at Ames and Chariton, respectively.

Once a good stand has been established for perennial grasses, maintaining a healthy, vigorous, and productive stand of these perennial grasses is very important for continued production and long-lasting stand life. Thus good production management practices, which include monitoring soil nutrients and controlling weeds and insects, are important for the production of perennial grasses. Good management practices will result in continued high annual yields and longer stand life. Continued high annual yields will reduce the net production cost per ton given per acre production costs. Longer stand life is crucial in reducing the prorated establishment cost. For example, the prorated establishment cost of alfalfa in Ames could be reduced to $59.97 from $74.96

(Table 3.31B) (or to $69.35 from $89.21 [Table 3.31A]) if stand life was six years instead of five years.

Table 3.31A. Estimated per acre cost of establishing alfalfa, reed canary grass, switchgrass, and big bluestem in Ames (160 acres of biomass production is assumed).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Seed	30.00	40.50	24.50	108.00
Phosphorus	40.00	8.00	8.00	8.00
Potassium	106.25	15.98	15.98	15.98
Nitrogen		26.25		
Fungicide	8.43			
Herbicide	1.81	4.62	3.95	5.78
Machinery fuel	7.13	7.21	4.99	4.99
Repair and maintenance	29.80	29.80	18.01	18.01
Labor	13.73	13.87	9.38	9.38
Interest	18.31	7.15	4.76	8.27
Fixed expenses on machinery	66.30	67.35	43.35	43.35
Total operating cost	321.76	220.73	132.92	221.76
Transportation cost	10.42	9.59	13.78	10.58
Total specified establishment cost	332.17	230.31	146.70	232.35
Land	115.00	115.00	115.00	115.00
Total establishment cost	447.17	345.31	261.70	347.35
Income from crop	100.40	92.40	132.80	102.00
Net establishment cost	346.77	252.91	128.90	245.35
Prorated Establishment cost	86.69	28.10	14.32	27.26

Note: Establishment cost of alfalfa is prorated over 4 years and establishment costs of the other perennial are prorated over 9 years.

Table 3.31B. Estimated per acre cost of establishing alfalfa, reed canary grass, switchgrass, and big bluestem in Ames (estimate based on average Iowa equipment use).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Seed	30.00	40.50	24.50	108.00
Phosphorus	40.00	8.00	8.00	8.00
Potassium	106.25	15.98	15.98	15.98
Nitrogen		26.25		
Fungicide	8.43			
Herbicide	1.81	4.62	3.95	5.78
Machinery fuel	7.13	7.21	4.99	5.37
Repair and maintenance	16.82	16.82	11.23	11.23
Labor	13.73	13.87	9.38	9.87
Interest	18.07	6.92	4.68	8.23
Fixed expenses on machinery	32.60	33.64	23.58	23.58
Total operating cost	274.84	173.81	106.29	196.04
Transportation cost	10.42	9.59	13.78	10.58
Total specified establishment cost	285.26	183.40	120.07	206.62
Land	115.00	115.00	115.00	115.00
Total establishment cost	400.26	298.40	235.07	321.62
Income from crop	100.40	92.40	132.80	102.00
Net establishment cost	299.85	206.00	102.27	219.62
Prorated establishment cost	74.96	22.89	11.36	24.40

Note: Establishment cost of alfalfa is prorated over 4 years and establishment costs of the other perennial are prorated over 9 years.

Table 3.32A. Estimated per acre cost of establishing alfalfa, reed canary grass, switchgrass, and big bluestem in Chariton (160 acres of biomass production is assumed).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Seed	35.00	49.50	25.20	108.00
Phosphorus	40.00	8.00	8.00	8.00
Potassium	106.25	15.98	15.98	15.98
Lime	30.00			
Nitrogen		26.25		
Fungicide	8.43			
Herbicide	2.72	4.62	3.95	5.78
Machinery fuel	7.52	7.21	4.99	4.99
Repair and maintenance	30.60	29.80	18.01	18.01
Labor	14.42	13.87	9.38	9.38
Interest	21.76	7.61	4.78	8.24
Fixed expenses on machinery	68.60	67.35	43.35	43.35
Total operating cost	365.30	230.19	133.64	221.73
Transportation cost	8.55	10.25	13.03	7.06
Total specified establishment cost	373.85	140.44	146.68	228.79
Land	80.00	80.00	80.00	80.00
Total establishment cost	453.85	320.44	226.68	308.79
Income from crop	82.40	98.80	125.60	68.00
Net establishment cost	371.45	221.64	101.08	240.79
Prorated establishment cost	92.86	24.63	11.23	26.75

Note: Establishment cost of alfalfa is prorated over 4 years and establishment costs of the other perennial are prorated over 9 years.

Table 3.32B. Estimated per acre cost of establishing alfalfa, reed canary grass, switchgrass, and big bluestem in Chariton (estimate based on average Iowa equipment use).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Seed	35.00	49.50	25.20	108.00
Phosphorus	40.00	8.00	8.00	8.00
Potassium	106.25	15.98	15.98	15.98
Lime	30.00			
Nitrogen		26.25		
Fungicide	8.43			
Herbicide	2.72	4.62	3.95	5.78
Machinery fuel	7.52	7.21	4.99	5.37
Repair and maintenance	17.72	16.82	11.23	11.23
Labor	14.42	13.87	9.38	9.87
Interest	21.52	7.37	4.70	8.20
Fixed expenses on machinery	34.89	33.64	23.58	23.58
Total operating cost	318.47	183.26	107.01	196.01
Transportation cost	8.55	10.25	13.03	7.06
Total specified establishment cost	327.02	193.51	120.04	203.07
Land	80.00	80.00	80.00	80.00
Total establishment cost	407.02	273.51	200.04	283.07
Income from crop	82.40	98.80	125.60	68.00
Net establishment cost	324.62	174.71	74.44	215.07
Prorated establishment cost	81.16	19.41	8.27	23.90

Note: Establishment cost of alfalfa is prorated over 4 years and establishment costs of the other perennial are prorated over 9 years.

Table 3.33A. Estimated per acre annual production cost of alfalfa, reed canary grass, switchgrass, and big bluestem in Ames (160 acres of biomass production is assumed).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Phosphorus		8.00	8.00	8.00
Potassium		15.98	15.98	15.98
Nitrogen		42.00	21.00	21.00
Herbicide	3.62			
Machinery fuel	6.69	4.82	2.60	2.60
Repair and maintenance	36.53	24.47	12.68	12.68
Labor	13.94	9.66	5.18	5.18
Interest	2.06	6.25	3.85	3.82
Fixed expenses on machinery	70.88	50.29	26.29	26.29
Total operating cost	133.72	161.47	95.58	95.55
Transportation cost	18.26	13.82	18.97	15.89
Establishment cost	86.69	28.10	14.32	27.26
Total specified cost	238.67	203.39	128.87	138.70
Land	115.00	115.00	115.00	115.00
Total cost	353.67	318.39	243.87	253.70
Income from crop1	176.00	133.20	182.80	153.20
Net return	-177.67	-185.19	-61.07	-100.51
Cost per ton2	80.38	95.61	53.36	66.24

Note: 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 4.4 ton for alfalfa, 3.33 ton for reed canary grass, 4.57 ton for switchgrass, and 3.83 ton for big bluestem. Negative net return means loss and positive means profit.

Table 3.33B. Estimated per acre annual production cost of alfalfa, reed canary grass, switchgrass, and big bluestem in Ames (estimate based on average Iowa equipment use).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Phosphorus		8.00	8.00	8.00
Potassium		15.98	15.98	15.98
Nitrogen		42.00	21.00	21.00
Herbicide	3.62			
Machinery fuel	6.69	4.82	2.60	2.60
Repair and maintenance	17.37	12.08	6.49	6.49
Labor	13.94	9.66	5.18	5.18
Interest	1.52	4.78	3.80	3.77
Fixed expenses on machinery	27.86	22.43	12.36	12.36
Total operating cost	71.00	119.75	75.41	75.38
Transportation cost	18.26	13.82	18.97	15.89
Establishment cost	75.96	22.89	11.36	24.40
Total specified cost	164.22	156.46	105.74	115.67
Land	115.00	115.00	115.00	115.00
Total cost	279.22	271.46	220.74	230.67
Income from crop1	176.00	133.20	182.80	153.20
Net return	-103.22	-138.26	-37.94	-77.47
Cost per ton2	63.46	81.52	48.30	60.23

Note: 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 4.4 ton for alfalfa, 3.33 ton for reed canary grass, 4.57 ton for switchgrass, and 3.83 ton for big bluestem. Negative net return means loss and positive means profit.

Table 3.34A. Estimated per acre annual production cost of alfalfa, reed canary grass, switchgrass, and big bluestem in Chariton (160 acres of biomass production is assumed).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Phosphorus		8.00	8.00	8.00
Potassium		15.98	15.98	15.98
Nitrogen		42.00	21.00	21.00
Herbicide	3.62			
Machinery fuel	6.69	4.82	2.60	2.60
Repair and maintenance	36.53	24.47	12.78	12.78
Labor	13.94	9.66	5.18	5.18
Interest	2.00	5.03	3.85	3.81
Fixed expenses on machinery	70.88	50.29	26.29	26.29
Total operating cost	133.66	160.25	95.68	95.64
Transportation cost	14.40	19.63	19.46	14.73
Establishment cost	92.86	24.63	11.23	26.75
Total specified cost	240.92	204.51	126.37	137.12
Land	80.00	80.00	80.00	80.00
Total cost	320.92	284.51	206.37	217.12
Income from crop1	138.80	189.20	187.60	142.00
Net return	-182.12	-95.31	-18.77	-75.12
Cost per ton2	92.48	60.15	44.19	61.16

Note: 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 3.47 ton for alfalfa, 4.73 ton for reed canary grass, 4.69 ton for switchgrass, and 3.55 ton for big bluestem. Negative net return means loss and positive means profit.

Table 3.34B. Estimated per acre annual production cost of alfalfa, reed canary grass, switchgrass, and big bluestem in Chariton (estimate based on average Iowa equipment use).

Item	Alfalfa	Reed Canary Grass	Switch-grass	Big-bluestem
		-dollars-		
Phosphorus		8.00	8.00	8.00
Potash		15.98	15.98	15.98
Nitrogen		42.00	21.00	21.00
Herbicide	3.62			
Machinery fuel	6.69	4.82	2.60	2.60
Repair and maintenance	17.37	12.08	6.49	6.49
Labor	13.94	9.66	5.18	5.18
Interest	1.46	4.83	3.80	3.76
Fixed expenses on machinery	27.85	22.43	12.36	12.36
Total operating cost	70.93	119.80	75.41	75.37
Transportation cost	14.40	19.63	19.46	14.73
Establishment cost	81.16	19.41	8.27	23.90
Total specified cost	166.49	158.84	103.14	114.00
Land	80.00	80.00	80.00	80.00
Total cost	246.49	238.84	183.14	194.00
Income from crop1	138.80	176.40	187.60	142.00
Net return	-107.69	-62.44	4.46	-52.00
Cost per ton2	71.03	50.49	39.05	54.65

Note: 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 3.47 ton for alfalfa, 4.73 ton for reed canary grass, 4.69 ton for switchgrass, and 3.55 ton for big bluestem. Negative net return means loss and positive means profit.

Applying proper amounts of fertilizer, especially nitrogen, phosphorus, and potassium, each year is an important management practice for continued high yields. The amount of each necessary fertilizer application will vary slightly from year to year. It will also differ in different regions because of differences in soil conditions. Soil testing will help to determine proper amounts needed each year in different regions. Annual use of fertilizers for all perennial grasses, except alfalfa, over the standing years is assumed to be 32 lb/acre for phosphorus and 94 lb/acre for potash, respectively, at both Ames and Chariton. These are the amounts determined by the soil test performed during the experiment period. For alfalfa, there is no annual fertilizer cost because both phosphorus and potash are assumed to be applied once in the establishment year.

Weed control is also an important factor for high yields. The decision to use herbicides for weed control in established perennial grasses should be based on the degree of the weed infestation, the type of weeds present, and, most importantly, the density of the existing stand [5]. However, to keep treatment economical, annual weed control measures after establishment were kept at a minimum for the following reasons: first, because of the ability of these species to out-compete weeds in general; second, the density of existing stand for all perennials in this research was reasonably good; and third, nutrition quality was not an important concern for the purpose of this research, the use of biomass crops for energy use.

Switchgrass has both the lowest annual production costs and the lowest net annual production costs among perennial grasses at both Ames and Chariton (Tables 3.33A/3.33B and 3.34A/3.34B). Big bluestem has the second lowest annual production costs and net annual production costs at both locations. Alfalfa has the highest annual production costs and its annual production costs are higher than that of reed canary grass at both locations. However, when we compare the net production costs between alfalfa and reed canary grass, the results are not consistent with that of production costs. The annual net production costs for alfalfa at Ames are lower than those of reed canary grass while reed canary grass has much lower net production costs at Chariton than alfalfa, because the dry-matter yields of reed canary grass at Chariton are much higher than those of alfalfa (Tables 3.33A/3.33B and 3.34A/3.34B).

Productivity, machinery costs, and establishment costs are the primary factors contributing to differences in production costs and net production costs among the perennial grasses. Although switchgrass and big bluestem have the same crop management practices, the costs of production are different because of the difference in the prorated

establishment cost. Big bluestem has a higher prorated establishment cost (almost twice as much) than switchgrass. In addition to lower production costs, higher productivity of switchgrass also contributes to lower net production costs for switchgrass. For alfalfa and reed canary grass, the differences in the production costs come largely from differences in prorated establishment costs and machinery costs. The prorated establishment cost of alfalfa is about three times larger than that of reed canary grass. Alfalfa and reed canary grass have higher machinery costs because of the differences in the number of harvests: three times for alfalfa, two times for reed canary grass, and one for both switchgrass and big bluestem.

Annual Costs for Intercrop Systems

Tables 3.35A/3.35B and 3.36A/3.36B show annual production costs for the intercrop systems at Ames and Chariton, respectively. Since sorghum is an annual crop, sorghum is interplanted every year into the established alfalfa and reed canary grass for the intercrop systems. Thus the annual production costs of intercrop systems—sorghum/alfalfa and sorghum/reed canary grass—are higher than monocrop alfalfa and reed canary grass production costs by the seed and planting costs of sorghum.

For these cropping systems, fertilizer costs, especially nitrogen, and productivity are the factors making differences in production costs and net production costs between systems. Annual production costs of the intercrop sorghum/alfalfa systems are lower than those of the sorghum/reed canary grass systems. The primary cost difference between these systems is the use of nitrogen. Since alfalfa is a nitrogen fixer, nitrogen is not applied in alfalfa production while reed canary grass requires nitrogen application for high yield. Higher dry-matter yields of the sorghum/alfalfa systems at Ames along with the lower production costs, contributes to the lower net production costs. At Chariton, sorghum/reed canary grass systems were not established because of weather conditions. Thus we are not able to compare the production costs.

Within the sorghum/alfalfa systems, there are almost no differences in net production costs at Ames; however, the sorghum x Sudan grass/alfalfa system at Chariton has almost 50% lower net annual production costs than the sweet sorghum/alfalfa system. This was due to the differences in dry-matter yield. Sorghum x Sudan grass/alfalfa had higher yield than sweet sorghum/alfalfa at Chariton.

Table 3.35A. Estimated per acre annual production cost of intercrop sorghum/alfalfa and sorghum/reed canary grass, in Ames (160 acres of biomass production is assumed).

Item	A	B	C	D
	-dollars-			
Seed	3.50	2.45	3.50	2.45
Phosphorus			8.00	8.00
Potassium			15.98	15.98
Nitrogen			42.00	42.00
Herbicide	1.78	1.78	1.78	1.78
Machinery fuel	6.91	6.91	8.06	8.06
Repair and maintenance	38.51	38.51	41.21	41.21
Labor	14.42	14.42	16.49	16.49
Interest	2.10	2.05	6.79	6.75
Fixed expenses on machinery	77.82	77.82	84.71	84.71
Total operating cost	145.04	143.94	228.52	227.43
Transportation cost	25.73	25.32	18.05	18.30
Establishment cost	86.69	86.69	28.10	28.10
Total specified cost	257.46	255.95	274.67	273.83
Land	115.00	115.00	115.00	115.00
Total cost	372.46	370.95	389.67	388.83
Income from crop1	248.00	244.00	174.00	176.40
Net return	-124.46	-126.95	-215.67	-212.43
Cost per ton2	60.07	60.81	89.58	88.17

Note: A = Sweet sorghum/alfalfa; B = Sorghum x Sudan grass/alfalfa; C = Sweet sorghum/reed canary grass; D = Sorghum x Sudan grass/reed canary grass. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 6.2 ton for A, 6.1 ton for B, 4.35 ton for C, and 4.41 ton for D.

Table 3.35B. Estimated per acre annual production cost of intercrop sorghum/alfalfa and sorghum/reed canary grass, in Ames (estimate based on average Iowa equipment use).

Item	A	B	C	D
	-dollars-			
Seed	3.50	2.45	3.50	2.45
Phosphorus			8.00	8.00
Potassium			15.98	15.98
Nitrogen			42.00	42.00
Herbicide	1.78	1.78	1.78	1.78
Machinery fuel	6.91	6.91	8.06	8.06
Repair and maintenance	18.06	18.06	20.77	20.77
Labor	14.42	14.42	16.49	16.49
Interest	1.56	1.51	6.30	6.26
Fixed expenses on machinery	30.54	30.54	37.42	37.42
Total operating cost	76.77	75.67	160.30	159.21
Transportation cost	25.73	25.32	18.05	18.30
Establishment cost	74.96	74.96	22.88	22.88
Total specified cost	177.46	175.95	201.23	200.39
Land	115.00	115.00	115.00	115.00
Total cost	292.46	290.95	316.23	315.39
Income from crop1	248.00	244.00	174.00	176.40
Net return	-44.46	-46.95	-142.23	-138.99
Cost per ton2	47.17	47.70	72.70	71.52

Note: A = Sweet sorghum/alfalfa; B = Sorghum x Sudan grass/alfalfa; C = Sweet sorghum/reed canary grass; D = Sorghum x Sudan grass/reed canary grass. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 6.2 ton for A, 6.1 ton for B, 4.35 ton for C, and 4.41 ton for D.

Table 3.36A. Estimated per acre annual production cost of intercrop sweet sorghum/alfalfa and sorghum x Sudan grass/alfalfa in Chariton (160 acres of biomass production is assumed).

Item	A	B
	-dollars-	
Seed	3.50	2.45
Herbicide	1.78	1.78
Machinery fuel	6.91	6.91
Repair and maintenance	38.51	38.51
Labor	14.42	14.42
Interest	2.04	2.02
Fixed expenses on machinery	77.82	77.82
Total operating cost	144.98	143.91
Transportation cost	17.80	21.41
Establishment cost	92.86	92.86
Total specified cost	255.64	258.18
Land	80.00	80.00
Total cost	335.64	338.18
Income from crop1	171.60	206.40
Net return	-164.04	-131.79
Cost pre ton2	78.23	65.54

Note: A = Sweet sorghum/alfalfa; B = Sorghum x Sudan grass/alfalfa. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 4.29 ton for sweet sorghum/alfalfa and 5.16 ton for sorghum x Sudan grass hybrid/alfalfa.

Table 3.36B. Estimated per acre annual production cost of intercrop sweet sorghum/alfalfa and sorghum x Sudan grass/alfalfa in Chariton (estimate based on average Iowa equipment use).

Item	A	B
	-dollars-	
Seed	3.50	2.45
Herbicide	1.78	1.78
Machinery fuel	6.91	6.91
Repair and maintenance	18.06	18.06
Labor	14.42	14.42
Interest	1.49	1.48
Fixed expenses on machinery	30.54	30.54
Total operating cost	76.70	75.64
Transportation cost	17.80	21.41
Establishment cost	81.15	81.15
Total specified cost	175.65	178.20
Land	80.00	80.00
Total cost	255.65	258.82
Income from crop1	171.60	206.40
Net return	-84.05	-51.80
Cost per ton2	59.59	50.16

Note: A = Sweet sorghum/alfalfa; B = Sorghum x Sudan grass/alfalfa. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 4.29 ton for sweet sorghum/alfalfa and 5.16 ton for sorghum x Sudan grass hybrid/alfalfa.

Annual Production Costs of Annual Biomass Crops

Annual biomass crops include sweet sorghum, sorghum x Sudan grass, and rye. Rye was used as a winter crop in both the doublecrop sorghum system and the doublecrop sorghum in rotation. Corn and soybean were produced primarily to compare yield response and production costs of monocrop sorghum and doublecrop sorghum/rye systems with monocrop and doublecrop sweet sorghum systems in rotation with corn and soybean. Tables 3.37A/3.37B through 3.40A/3.40B show annual production costs of the different annual biomass crop systems.

For all annual crops, machinery costs are the highest, as shown in Tables 3.37A/ 3.37B through 3.39A/3.39B. These costs include repair and maintenance of tractors and implements used in seed bed preparation, planting, fertilization, herbiciding, and harvesting activities. They also include fuel costs. In addition to these direct operating costs of machinery, these costs include fixed expenses of owning machinery, such as depreciation and interest on investment.

Fertilization costs are the second largest production cost for all annual crops. Interest payments are the smallest cost in production of annual biomass crops.

By comparing the annual production costs in Tables 3.37A/3.37B through 3.39A/3.39B, we observe that both monocrop sweet sorghum systems—the pure monocrop systems and the monocrop system in rotation with corn and soybean—have the least net production costs among the different sorghum production systems. At the Chariton location, monocrop sorghum x Sudan grass has lower net production costs than sweet sorghum at Ames.

The monocrop sweet sorghum system at Chariton has a positive net return at the assumed market price of dry matter, $40.00/ton (Tables 3.37A/3.37B). Both sweet sorghum and sweet sorghum/rye systems in rotation at Chariton also show positive net returns (Table 3.39B).

Although the sorghum production management systems at both Ames and Chariton are the same, there is a significant difference in net production costs. The differences in yields and land costs are the primary reasons for this difference in net production costs between the two sites.

Monocrop sweet sorghum systems in rotation require less nitrogen input use. (Compare nitrogen costs in Tables 3.37 through 3.39.) If we adopt doublecrop sorghum/rye systems solely based on economic profitability without considering

Table 3.37A. Estimated per acre annual production cost of monocrop sorghum (160 acres of biomass production is assumed).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	3.50	2.45	3.50	2.45
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	12.00	12.00	12.00	12.00
Herbicide	15.76	15.76	15.76	15.76
Machinery fuel	9.44	9.44	9.44	9.44
Repair and maintenance	24.61	24.61	24.61	24.61
Labor	15.39	15.39	15.39	15.39
Interest	6.70	6.39	9.04	8.62
Fixed expenses on machinery	46.23	46.23	46.23	46.23
Total operating cost	156.12	154.76	158.46	156.99
Transportation cost	29.38	26.81	30.21	26.39
Total specified cost	185.50	181.57	188.67	183.38
Land	115.00	115.00	80.00	80.00
Total cost	300.50	296.57	268.67	263.38
Income from crop1	283.20	258.40	291.20	254.40
Net return	-17.30	-38.17	22.53	-8.98
Cost per ton2	42.44	45.91	36.91	41.41

Note: A = Sweet sorghum; B = Sorghum x Sudan grass hybrid. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 7.08 and 7.28 ton for sweet sorghum, and 6.46 and 6.36 ton for sorghum x Sudan grass hybrid at Ames and Chariton, respectively.

Table 3.37B. Estimated per acre annual production cost of monocrop sorghum (estimate based on average Iowa equipment use).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	3.50	2.45	3.50	2.45
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	12.00	12.00	12.00	12.00
Herbicide	15.76	15.76	15.76	15.76
Machinery fuel	9.44	9.44	9.44	9.44
Repair and maintenance	22.08	22.08	22.08	22.08
Labor	15.39	15.39	15.39	15.39
Interest	6.67	6.37	8.79	8.38
Fixed expenses on machinery	40.57	40.57	40.57	40.57
Total operating cost	147.90	146.55	150.02	148.56
Transportation cost	29.38	26.81	30.21	26.39
Total specified cost	177.28	173.36	180.23	174.95
Land	115.00	115.00	80.00	80.00
Total cost	292.28	288.36	260.23	254.95
Income from crop1	283.20	258.40	291.20	254.40
Net return	-9.32	-30.20	30.97	-0.55
Cost per ton2	41.28	44.63	35.75	40.09

Note: A = Sweet sorghum; B = Sorghum x Sudan grass hybrid. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 7.08 and 7.28 ton for sweet sorghum, and 6.46 and 6.36 ton for sorghum x Sudan grass hybrid at Ames and Chariton, respectively.

Table 3.38A. Estimated per acre annual production cost of doublecrop sorghum/rye (160 acres of biomass production is assumed).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	34.50	33.45	40.70	39.65
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	34.02	34.02	34.02	34.02
Machinery fuel	10.74	10.74	10.74	10.74
Repair and maintenance	35.01	35.01	35.01	35.01
Labor	18.77	18.77	18.77	18.77
Interest	8.94	8.86	9.76	9.43
Fixed expenses on machinery	69.28	69.28	69.28	69.28
Total operating cost	233.75	232.62	240.77	239.39
Transportation cost	29.13	26.89	25.73	25.69
Total specified cost	262.88	259.51	266.50	265.08
Land	115.00	115.00	80.00	80.00
Total cost	377.88	374.51	346.50	345.08
Income from crop1	280.80	259.20	248.00	247.60
Net return	-97.08	-115.31	-98.50	-97.48
Cost per ton2	53.83	57.80	55.84	55.75

Note: A = Sweet sorghum/rye; B = Sorghum x Sudan grass hybrid/rye. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 7.02 and 6.20 ton for sweet sorghum/rye and 6.48 and 6.19 ton for sorghum x Sudan grass hybrid at Ames and Chariton, respectively.

Table 3.38B. Estimated per acre annual production cost of doublecrop sorghum/rye (estimate based on average Iowa equipment use).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	34.50	33.45	40.70	39.65
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	34.02	34.02	34.02	34.02
Machinery fuel	10.74	10.74	10.74	10.74
Repair and maintenance	26.12	26.12	26.12	26.12
Labor	18.77	18.77	18.77	18.77
Interest	8.68	8.60	9.49	9.17
Fixed expenses on machinery	48.60	48.60	48.60	48.60
Total operating cost	203.92	202.79	210.93	209.56
Transportation cost	29.13	26.89	25.73	25.69
Total specified cost	233.05	229.68	236.66	235.25
Land	115.00	115.00	80.00	80.00
Total cost	348.05	344.68	316.66	315.25
Income from crop1	280.80	259.20	248.00	247.60
Net return	-67.25	-85.48	-68.66	-67.65
Cost per ton2	49.58	53.19	51.07	50.93

Note: A = Sweet sorghum/rye; B = Sorghum x Sudan grass hybrid/rye. 1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 7.02 and 6.20 ton for sweet sorghum/rye and 6.48 and 6.19 ton for sorghum x Sudan grass hybrid at Ames and Chariton, respectively.

Table 3.39A. Estimated per acre annual production cost of sweet sorghum and sweet sorghum/rye in corn-soybean rotation (160 acres of biomass production is assumed).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	3.50	34.50	3.50	40.70
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	6.00	21.00	6.00	21.00
Herbicide	15.76		15.76	
Machinery fuel	8.60	10.35	8.60	10.35
Repair and maintenance	23.94	34.11	23.94	34.11
Labor	13.73	18.08	13.73	18.08
Interest	6.26	8.57	8.80	9.17
Fixed expenses on machinery	42.06	66.99	42.06	66.99
Total operating cost	142.34	216.09	144.88	222.89
Transportation cost	27.72	33.74	29.67	36.44
Total specified cost	170.06	249.83	174.55	259.33
Land	115.00	115.00	80.00	80.00
Total cost	285.06	364.83	254.55	339.33
Income from crop1	267.20	325.20	286.00	351.20
Net return	-16.86	-39.63	32.55	11.87
Cost per ton2	42.67	44.87	35.60	38.65

Note: A = Sweet sorghum; B = Sweet sorghum/rye.
1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 6.68 and 7.15 ton for sweet sorghum and 8.13 and 8.78 ton for sweet sorghum/rye at Ames and Chariton, respectively.

Table 3.39B. Estimated per acre annual production cost of sweet sorghum and sweet sorghum/rye in corn-soybean rotation (estimate based on average Iowa equipment use).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	3.50	34.50	3.50	40.70
Phosphorus	14.50	14.50	14.50	14.50
Potassium	7.99	7.99	7.99	7.99
Nitrogen	6.00	21.00	6.00	21.00
Herbicide	15.76		15.76	
Machinery fuel	8.60	10.35	8.60	10.35
Repair and maintenance	20.40	25.22	20.40	25.22
Labor	13.73	18.08	13.73	18.08
Interest	6.23	8.31	8.56	8.91
Fixed expenses on machinery	36.41	46.31	36.41	46.31
Total operating cost	133.12	186.26	135.45	193.06
Transportation cost	27.72	33.74	29.67	36.44
Total specified cost	160.84	220.00	165.12	229.50
Land	115.00	115.00	80.00	80.00
Total cost	275.84	334.75	245.12	309.50
Income from crop1	267.20	325.20	286.00	351.20
Net return	-8.64	-9.80	40.88	41.70
Cost per ton2	41.29	41.21	34.28	35.25

Note: A = Sweet sorghum; B = Sweet sorghum/rye.
1 Estimated at $40/dry ton. 2 Estimated by dividing total cost by average annual yields per acre: 6.68 and 7.15 ton for sweet sorghum and 8.13 and 8.78 ton for sweet sorghum/rye at Ames and Chariton, respectively.

Table 3.40A. Estimated per acre annual production cost of corn and soybean (160 acres of biomass production is assumed).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	27.00	14.00	27.00	14.00
Phosphorus	14.50	10.00	14.50	10.00
Potassium	7.99	12.75	7.99	12.75
Nitrogen	15.00		15.00	
Herbicide	31.75	19.68	31.75	19.68
Machinery fuel	10.04	5.28	10.04	5.28
Repair and maintenance	27.85	12.97	27.98	13.11
Labor	17.73	8.83	18.29	9.38
Interest	7.89	3.80	6.68	3.96
Fixed expenses on machinery	54.77	28.85	54.88	28.96
Total operating cost	214.52	116.16	214.11	117.12
Transportation cost	13.11		11.08	
Total specified cost	227.63	116.16	225.19	117.12
Land	115.00	115.00	80.00	80.00
Total cost	342.63	231.16	305.19	197.12
Income from crop1	403.94	152.16	313.11	220.29
Net return	61.31	-79.00	7.92	23.17

Note: A = Corn; B = Soybean

1 Estimated at $2.35 bu. for corn grain, $5.45 bu. for soybean grain, and $40/dry ton for corn stover. Yields for corn grain were 118.10 bu per acre and 87.79 bu per acre at Ames and Chariton, respectively. For corn stover, 3.16 ton and 2.67 ton per acre at Ames and Chariton, respectively. For soybeans, 27.92 bu and 40.42 bu per acre, respectively.

Table 3.40B. Estimated per acre annual production cost of corn and soybean (estimate based on average Iowa equipment use).

Item	A	B	A	B
	-dollars-			
	Ames		Chariton	
Seed	27.00	14.00	27.00	14.00
Phosphorus	14.50	10.00	14.50	10.00
Potassium	7.99	12.75	7.99	12.75
Nitrogen	15.00		15.00	
Herbicide	31.75	19.68	31.75	19.68
Machinery fuel	10.04	5.28	10.04	5.28
Repair and maintenance	23.36	12.77	23.40	12.91
Labor	17.73	8.83	18.29	9.38
Interest	7.84	3.79	6.63	3.95
Fixed expenses on machinery	42.77	26.74	42.88	26.84
Total operating cost	197.98	113.84	197.57	114.79
Transportation cost	13.11		11.08	
Total specified cost	211.09	113.84	208.65	114.79
Land	115.00	115.00	80.00	80.00
Total cost	326.09	228.84	288.65	194.79
Income from crop1	403.94	152.16	313.11	220.29
Net return	77.85	-76.68	24.46	25.50

Note: A = Corn; B = Soybean.
1 Estimated at $2.35 bu. for corn grain, $5.45 bu. for soybean grain, and $40/dry ton for corn stover. Yields for corn grain were 118.10 bu per acre and 87.79 bu per acre at Ames and Chariton, respectively. For corn stover, 3.16 ton and 2.67 ton per acre at Ames and Chariton, respectively. For soybeans, 27.92 bu and 40.42 bu per acre, respectively.

soil conservation, these systems are the worst among the different sorghum production systems. These systems have the largest net production costs because of the high seed costs and nitrogen costs.

Break-even Price and Gross Margin Analysis

A break-even price and gross margin analysis is the easiest way of testing the economic viability of biomass production. Break-even prices for each cropping system in this research are listed in Tables 3.41A and 3.41B.

In the previous section, production costs for each of the 13 biomass cropping systems were presented. Since they are the costs of producing the biomass dry matter, the production costs are divided by the given average dry-matter yields of each cropping system to estimate the break-even prices shown in Tables 3.41A/3.41B. These are the prices that make [(yield x price) - cost] even, where yield is assumed to be given in these tables. Thus if market price for biomass is greater than the break-even price, there is a profit; otherwise, a loss.

The break-even price estimated in this study is the price derived from the specific production management systems described in the previous sections and biomass yield associated with those management systems. Thus the break-even price can be changed as yield changes or as production cost changes by employing different crop management systems. Since break-even price estimates are based on the current state of technology, it can also be changed with better biomass production technology; e.g., the development of weather and disease resistance hybrid seeds or cost saving and resource conserving technology.

The break-even prices listed in Tables 3.41A and 3.41B are different because, as explained previously, of the differences in annual hours of use of implements, which are directly related to acres of land allocated to the biomass energy crop production. The assumed annual hours of use are smaller for Table 3.41A than those of 3.41B. As a result, the break-even prices in Table 3.41A are greater than those of Table 3.41B.

Total cost (TC) is defined as total specified costs (TSC) plus land cost. TSC includes all costs except land. TSC also includes the prorated establishment costs. Average cost (AC) is TC divided by the total biomass yield. Thus, AC represents the break-even price of producing biomass crops. Notice that the biomass yields for perennial forages in Tables 3.41A/3.41B do not include the yields in the establishment year. These

Table 3.41A. Costs and break-even prices of the crop production systems (160 acres of biomass production is assumed).

Crop Systems	Yield	TSC	TC	ASC/ton	AC/ton
	(ton)	(dollar/ton)			
		Ames			
Alfalfa	4.40	238.67	353.67	54.24	80.38
Reed canary grass	3.33	203.39	318.39	61.08	95.61
Switchgrass	4.57	128.87	243.87	28.20	53.36
Big bluestem	3.83	138.70	253.70	36.21	66.24
Sweet sorghum	7.08	185.50	300.50	26.20	42.44
Sorghum x Sudan grass	6.46	181.57	296.57	28.11	45.91
Sweet sorghum/rye	7.02	262.88	377.88	37.45	53.83
SS/rye	6.48	259.51	374.51	40.05	57.80
Sweet sorghum 1	6.68	170.06	285.06	25.46	42.67
Sweet sorghum/rye 1	8.13	249.83	364.83	30.73	44.87
Sweet sorghum/alfalfa	6.20	257.46	372.46	41.53	60.07
SS/alfalfa	6.10	255.95	370.95	41.96	60.81
Sweet sorghum/RC	4.35	274.67	389.67	63.14	89.58
SS/reed canary grass	4.41	273.83	388.83	62.09	88.17
		Chariton			
Alfalfa	3.47	240.92	320.92	69.43	92.48
Reed canary grass	4.73	204.51	284.51	43.24	60.15
Switchgrass	4.69	126.37	206.37	26.94	44.19
Big bluestem	3.55	137.12	217.12	38.63	61.16
Sweet sorghum	7.28	188.67	268.67	25.92	36.91
Sorghum x Sudan grass	6.36	183.38	263.38	28.83	41.41
Sweet sorghum/rye	6.20	266.50	346.50	42.98	55.89
SS/rye	6.19	265.08	345.08	42.82	55.75
Sweet sorghum 1	7.15	174.55	254.55	24.41	35.60
Sweet sorghum/rye 1	8.78	259.33	339.33	29.54	38.65
Sweet sorghum/alfalfa	4.29	255.64	335.64	59.59	78.23
SS/alfalfa	5.16	258.18	338.18	50.03	65.54

Note: 1 Sweet sorghum and sweet sorghum/rye in rotation with corn and soybean. SS = sorghum x Sudan grass. RC = reed canary grass

Table 3.41B. Costs and break-even prices of the crop production systems (estimate based on average Iowa equipment use).

Crop Systems	Yield	TSC	TC	ASC/ton	AC/ton
	(ton)	(dollar/ton)			
		Ames			
Alfalfa	4.40	164.22	279.22	37.32	63.46
Reed canary grass	3.33	156.46	271.46	46.98	81.52
Switchgrass	4.57	105.74	220.74	23.14	48.30
Big bluestem	3.83	115.67	230.67	30.20	60.23
Sweet sorghum	7.08	177.28	292.28	25.03	41.28
Sorghum x Sudan grass	6.46	173.36	288.36	26.83	44.63
Sweet sorghum/rye	7.02	233.05	348.05	33.20	49.58
SS/rye	6.48	229.68	344.68	35.44	53.19
Sweet sorghum 1	6.68	160.84	275.84	24.07	41.29
Sweet sorghum/rye 1	8.13	220.00	335.00	27.06	41.21
Sweet sorghum/alfalfa	6.20	177.46	292.46	28.62	47.17
SS/alfalfa	6.10	175.95	290.95	28.84	47.70
Sweet sorghum/RC	4.35	201.23	316.23	46.26	72.70
SS/reed canary grass	4.41	200.39	315.39	45.44	71.52
		Chariton			
Alfalfa	3.47	166.49	246.49	47.98	71.03
Reed canary grass	4.73	158.84	238.84	33.58	50.49
Switchgrass	4.69	103.14	183.14	21.99	39.05
Big bluestem	3.55	114.00	194.00	32.12	54.65
Sweet sorghum	7.28	180.23	260.23	24.76	35.75
Sorghum x Sudan grass	6.36	174.95	254.95	27.51	40.09
Sweet sorghum/rye	6.20	236.66	316.66	38.17	51.07
SS/rye	6.19	235.25	315.25	38.00	50.93
Sweet sorghum 1	7.15	165.12	245.12	23.09	34.28
Sweet sorghum/rye 1	8.78	229.50	309.50	26.14	35.25
Sweet sorghum/alfalfa	4.29	175.65	255.65	40.94	59.59
SS/alfalfa	5.16	178.20	258.82	34.53	50.16

Note: 1 Sweet sorghum and sweet sorghum/rye in rotation with corn and soybean. SS = sorghum x Sudan grass. RC = reed canary grass

are the average yields of the standing years. For the annuals, the yields are the average of the experimental period, 1988-1992.

Even though AC represents the break-even price, biomass producers may produce biomass crops in the short run, if the gross margin—the difference between total income and total variable costs—is positive. Any positive gross margin represents a contribution of the biomass crops to fixed cost, which is just the land cost in this study. Thus we estimated average specified cost (ASC), TSC divided by yield, to look at whether biomass production makes any contribution to fixed costs in the short run at the assumed dry-matter price. If ASC is greater than or equal to the market price for dry matter, biomass crop producers may engage in biomass production in the short run; otherwise, they will stop biomass production. Notice that ASC in this report is different from the widely used concept of average variable cost (AVC) frequently used in the economic profession in the following sense. While AVC excludes any fixed costs involved in capital investment, ASC excludes only land costs. Thus ASC includes fixed expenses, such as interest payment on and depreciation of machinery, and on capital investments.

At present, the production of biomass crops as an energy substitute for fossil fuels is not economically feasible in most cases. However, biomass energy crops may have long-run economic feasibility due to the environmental concerns related to fossil fuels and exhaustibility of fossil fuels. For this reason, comparing average specified costs to the market price of dry matter is especially important in the biomass production decision-making process.

As shown in Table 3.41B, the break-even price of biomass crops range from $34.28/dry-matter ton to $81.52/dry-matter ton. Sweet sorghum and sweet sorghum/rye in rotation have the least break-even price at both Ames and Chariton, $41.29/dry ton for sweet sorghum and $41.21/dry ton for sweet sorghum/rye at Ames, and $34.28/dry ton for sweet sorghum and $35.25/dry ton for sweet sorghum/rye at Chariton. On the other hand, with Table 3.41A, the break-even prices range from $35.60 for sweet sorghum in rotation at Chariton to $95.51 for reed canary grass at Ames.

Among the perennial grasses, monocrop reed canary grass at Ames has the highest AC per dry-matter ton, $81.52 ($95.61). At Chariton, alfalfa has the highest AC per dry-matter ton, $71.03 ($92.48). Higher AC means a higher market price for biomass dry matter to break even. Switchgrass has the lowest breakeven price, $48.30 ($53.36)/ton at Ames and $39.05 ($44.19)/ton at Chariton. See Table 3.41A/3.41B.

Compared to AC, ASC is much lower because land cost is excluded. ASC ranges from $21.99/dry ton for switchgrass at Chariton to $47.98/dry ton for alfalfa, also at Chariton. Switchgrass has the lowest ASC among all the cropping systems used in this research at both sites. Sweet sorghum in rotation has the second largest ASC (Table 3.41B). The results are different in Table 3.41A. The ASC ranges from $24.41/dry ton for sweet sorghum in rotation at Chariton to $69.43/dry ton for alfalfa at Chariton. Switchgrass at Chariton is the next least ASC, $26.94/dry ton.

In the short run, biomass energy crop producers will participate in biomass production as long as the market price for biomass dry matter equals to ASC. At this price, all the costs (except land cost) incurred from biomass crop production will be recovered.

By comparing Tables 3.41A and 3.41B, the existence of economies of scale can be clearly observed. As annual hours of use of implements increase, the production costs decrease and so do the break-even prices. Thus there is greater incentive for current forage producers to engage in biomass production.

As expected, systems involving sorghum have the highest dry-matter yields. Sweet sorghum/rye in rotation produced the largest dry matter at all levels of nitrogen use. Among the perennial grasses, switchgrass produced the largest dry matter for all levels of nitrogen, even on the marginal land at Chariton. Generally, annual energy crops produced more dry matter than perennial grasses.

In Iowa, biomass energy crops can be produced at $34.28 ($35.60) to $81.52 ($95.61)/ton of dry matter depending on species, production system, the acres of land allocated to biomass crop production, and location. These estimates of unit production cost change as yield, management systems, and input costs change.

Switchgrass has the lowest cost per ton among the perennial crops while sweet sorghum and sweet sorghum/rye in rotation have the lowest cost among all systems.

Since we are also interested in the environmental impact, primarily soil erosion, of the species and of different cropping systems, both switchgrass and sweet sorghum and sweet sorghum/rye in rotation serve as good choices as biomass energy crops.

CONCLUSIONS

By combining experimental and typical management practice data, this report has considered the costs of producing herbaceous biomass crops in Iowa. Representative sites in central (Ames) and southern (Chariton) Iowa were considered. Costs of production

were based on a careful delineation of appropriate practices for biomass production by typical producers. The practices are carefully specified so that changes in practice can be easily analyzed. Cost estimates are presented based on average Iowa use of machinery and equipment and on lower annual use for producers who grow biomass as a sideline enterprise. The lower cost estimates should not be routinely used as typical since many currently proposed systems for producing biomass involve the use of CRP acres, stream banks, waterways, or other less than full-scale sites. All estimates given in this summary refer to costs based on 160 acres of biomass per producer with the lower full-scale costs given in parentheses.

Costs of production were generally lower in southern Iowa, primarily because of lower land costs. The sorghum species grown singly or in rotation were the least expensive way to produce biomass. Costs of production in southern Iowa for sweet sorghum as a monocrop are $36.91 ($35.75)/ton. Costs in central Iowa for monocrop sweet sorghum are $42.44 ($41.28)/ton. The costs of sweet sorghum in rotation with corn and soybean are marginally lower in southern Iowa and marginally higher in central Iowa. Given some of the problems of monocrop sorghum, production in rotation seems preferred. Costs for forage sorghum (sorghum x Sudan grass) are $3–$5 higher in both locations. In central Iowa, the sweet sorghum/rye doublecrop in rotation has similar costs with the monocrop of $44.87 ($41.21)/ton. Thus the costs of adding the soil conservation benefits of winter rye are small or nonexistent using central Iowa data. Winter rye, however, adds significantly to the costs in southern Iowa. Yields of this doublecrop in the experiments were lower, probably based on reduced soil moisture following the winter rye. More research on this issue seems in order. Intercropped sweet sorghum in alfalfa costs $60.07 ($47.17) per ton as opposed to the monocrop cost of $42.44 ($41.28) in the central Iowa location. The costs of intercropped sorghum in alfalfa are higher in southern Iowa. Per ton cost was $78.23 ($59.59). Again, this may be due to dry conditions during the study period. Costs for intercropped sorghum x Sudan grass are similar in central Iowa and slightly lower in southern Iowa as compared to intercropped sweet sorghum. Costs for sorghum intercropped into reed canary grass as compared to alfalfa are much higher at the central Iowa site and were not computed for the southern Iowa site because of the failure of the stand establishment. With respect to the use of sorghums for biomass production, doublecropped sweet sorghum with rye in rotation with corn and soybean seems the logical choice in areas where spring moisture is adequate. Where moisture is a concern, the soil conservation benefits of the rye must be balanced against the potential of

lower sorghum yields. The intercrop sorghums were higher in cost than single or double crops ($6–$14) but would have significant soil conservation effects.

Among the perennial grasses, switchgrass has the lowest costs at both sites. Big bluestem is less expensive to produce than reed canary grass in central Iowa but more expensive in southern Iowa. Alfalfa is the most expensive crop in southern Iowa, while reed canary grass is the most expensive in central Iowa. Thus the ranking from least to most expensive is switchgrass, reed canary grass, big bluestem, and alfalfa in southern Iowa and switchgrass, big bluestem, alfalfa, and reed canary grass in central Iowa. Costs of switchgrass in southern Iowa are $44.19 ($39.05), while with higher land costs they are $53.36 ($48.30) in central Iowa. Thus the costs of the cheapest perennial grasses are $7–$10/ton more than the costs of the annual sorghums. The costs of switchgrass are higher than intercropped or doublecropped sorghum in central Iowa, but lower than intercropped sorghum in southern Iowa. The sweet sorghum/rye rotation is cheaper than switchgrass in southern Iowa. The costs of big bluestem are around $10–$15/ton more than switchgrass, primarily because of higher establishment costs. Reed canary grass is about $15/ton higher than switchgrass in southern Iowa and much higher still in central Iowa. Alfalfa is not competitive with switchgrass at either location. Of the perennial crops, switchgrass is clearly the lowest in cost.

In determining optimal cropping patterns for biomass use, many factors must be considered. Based on costs alone, the annual sorghums dominate the perennial grasses in all locations. The use of rye as a winter crop with sorghum is also less expensive than the grasses. The results for the intercropped sorghums are mixed. If the producer has sufficient acres to fully use forage and grain equipment, then the intercropped sorghums are cheaper than switchgrass at the central Iowa location. With lower equipment use, switchgrass is cheaper than the intercropped sorghum in central Iowa. In southern Iowa, switchgrass dominates the intercropped sorghum. Thus the use of intercrops depends critically on location, equipment use, and climate conditions. Soil conservation considerations clearly favor the perennial grasses or the intercrops. Thus decisions must be made on a case-by-case basis, using the information presented here as a benchmark.

PART 2. SHORT-ROTATION WOODY CROPS
INTRODUCTION

Field research with short-rotation woody crops (SRWCs) in Iowa has centered on determination of production potential, management technique, and estimation of production costs of hybrid poplar (various selected *Populus* clones including aspen types), eastern cottonwood (*Populus deltoides* Bartr.), silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), willow (*Salix* spp.), and black locust (*Robinia pseudoacacia* L.).

Starting in 1986, field-sized research plots of 0.2 ha and larger have been established in several locations in central Iowa and one near Amana, Iowa, but research on SRWCs in Iowa predates the field-sized plantings. Since the mid-1970s, the Department of Forestry at Iowa State University has conducted research on genetic selection of fast-growing tree species (mainly hybrid poplar) that could be harvested on short-rotations (5-10 years). Disease and pest resistance screening was and continues to be a major component of this research. Also, economic models were developed early on for hypothetical short-rotation woody crop (SRWC) systems that were to produce biomass for energy.

The first field-sized research project involving SRWC research was started at Hickory Grove County Park in central Iowa. There a 10-acre SRWC biofuels research/demonstration project was established using hybrid poplar, willow, and silver maple. This SRWC research/demonstration project has been a cornerstone in determining the costs of establishing and managing systems.

In 1988, ISU researchers used funding from the DOE's ORNL short-rotation woody crops program (SRWCP) to undertake development of a large-scale "biomass for energy" plantation using silver maple. The project site was an abandoned crop/pastureland field located on the banks of the Iowa river just south of Amana, Iowa on US 151. This six-year project was jointly sponsored by the Amana Society, the Department of Forestry at Iowa State University, and the Forestry Division of the Iowa Department of Natural Resources. The project goals were to evaluate risks associated with a scale-up SRWC system, to determine production costs, and to estimate biomass yields at the end of the

seven-year rotation. This plantation of silver maple was established during the drought years of 1988 and 1989. Each of the three compartments totaling 20 ha (~53 acres) was planted several times given the extreme (>50%) mortality that occurred during the droughty years. Long-duration (> 4 weeks) flooding in 1990, 1992, and 1993 caused by the Coralville reservoir downstream have caused this site to be abandoned. This plantation also has served as a source of cost data and risk information for SRWC systems in Iowa.

Also, in 1988, an on-farm wood-fired furnace project using trees thinned from native forests was started at the ISU McNay Research farm near Chariton, IA. The project has demonstrated on-farm woody biomass use and provided valuable cost information relating to the boiler system.

In 1990, an "agroforestry biofuels system" combining SRWC and HECs was started. A 16 ha (~40 acre) woody-herbaceous biofuels project was started with the City of Ames at their Water Pollution Control (WPC) facility. This alleycropping agroforestry system was designed so that the trees and herbaceous crops would use treated municipal sludge as a fertilizer input and produce biomass that could then be used as feedstock in a gasifier to supply electrical power to the WPC facility. Because the SRWC and HECs produce fiber not food, higher loadings of treated sludge can be applied. This provides the City of Ames more flexibility in the timing and quantity of sludge that is applied to the perennial switchgrass and hybrid poplar crops. The goals of the project are to determine biomass yields of and interactions between the woody and herbaceous species; to monitor and determine sludge effects on plants, soils, and water; and to estimate production costs. By using treated sludge as a fertilizer on the biomass system, "value" is derived from the sludge and more costly disposal methods are avoided. Moreover, the use of the biomass as feedstock for the production of low-Btu gas to generate electricity to power the facility provides a closed-loop use for sludge and biomass for energy.

An innovative agroforestry riparian best management practice (BMP) project was started in 1990 using woody and herbaceous plants in a buffer strip system to protect a stream from agricultural nonpoint source (NPS) pollutants. The system is designed to use trees and perennial grasses as biofuels for on-farm use while protecting the water resources and enhancing the environment. This system has been established on a small private farm on Bear Creek just north of Roland, Iowa. Cost of establishment and management are being determined along with the efficacy of the constructed bufferstrip related to NPS pollution.

Finally, in 1992 and 1994, two SRWC biofuels shelterbelt projects have been started on two private farms near Odgen, Iowa. These projects are designed to improve annual row crop yields (from the protected crop fields), improve the environment (sequester carbon and provide wildlife habitat), and provide a renewable biofuels resource for on-farm use. Biomass yields, tree-crop interactions, and costs are being determined.

The 1990 estimated cost to produce, harvest, and transport a dry ton of woody biomass is $50 [28]. One-half of the cost ($25/ton) is associated with the growing of the biomass. Land and taxes are estimated at $10/ton. This suggests the importance of selecting the best site for SRWC production with the lowest rent possible.

Ranney et al. [29] report that the cost to produce one million Btus from SRWC range from $2.25 to $3.25. Assuming an energy value of 8,500 Btu per dry lb, these energy costs translate into a total production, harvesting, and transporting cost of $38.25 to $55.25 per dry short ton. Also, they report that SRWC biomass yields range from 4–8 dry tons per acre per year. The DOE has established a target range of cost for biomass of between $2.35 and $2.50 per million Btus [28]. Biomass produced (harvested and transported) within this range is expected to be competitive with certain fossil fuels and supply feedstock for the next generation of biomass conversion technologies.

The Electric Power Research Institute (EPRI) has been evaluating biomass for several years. A recently published "white paper" on "Strategies for Achieving a Sustainable, Clean and Cost-Effective Biomass Resource" [28] has suggested that by the year 2010 the SRWC biomass cost could drop to $35 per dry ton from the current (1990) cost of $50 per dry ton (for production, harvesting, and transporting).

The cost per ton of $35 serves as a future target for Iowa SRWC biomass systems. The twenty-year growth target is 5 to 7 dry tons per acre per year. The near-term target (for the next decade) is $40 to $45 per dry ton with sustainable biomass growth of 4 dry tons per acre per year.

METHODOLOGY FOR SILVER MAPLE ANALYSIS

This section focuses on results from an economic assessment of the silver maple SRWC energy plantation in Amana, Iowa [30]. Three production cost scenarios were evaluated: base-actual cost, technical efficiencies, and technical efficiencies and cost-sharing. Scenario I (base-actual cost) used the activity costs that actually occurred at the plantation. In scenario II, technical efficiencies were assumed to consider the technological innovation. In scenario III (technical efficiencies and cost-sharing), the most probabilistic

costs and expected revenues for a desirable energy plantation were used by considering the ongoing technological advances and improving market conditions for woody biomass fuel within the next 5 to 10 years. In all three scenarios, the same cost items were included. These cost items are land rent, site preparation, planting (including planting stock), cultural management (weed control), fertilization, and harvesting. The harvesting cost was derived from similar plantations. These scenarios were based on Twarok [31] for the Amana SRWC project. Tables 3.42–3.44 present the activities and costs associated with each scenario evaluated.

First a break-even analysis was performed on the scenarios. This method seeks the minimum biomass yield priced at a given market price that will produce income that equals the costs of establishment, culture, rent, and harvest of the biomass. The break-even analysis determined minimum required yields (MRYs) for the biomass used as fiber and as a feedstock for energy. Thus, the MRY was determined by means of a break-even analysis based on the cost to produce one dry metric ton of fiber and one Gj of energy.

Next the net present values (NPVs) and internal rate of returns (IRR) for the three scenarios were determined. A sensitivity analysis of the economic criteria yielded NPVs, IRR, and MRYs (for fiber and energy) for each scenario using several combinations of different energy prices, fiber prices, discount rates, and biomass yields.

The analysis assumed an investment period of 30 years with a five-year rotation and used five different real discount rates of 3%, 5%, 7%, 9%, and 11%. The energy prices used ranged from $1/Gj to $8/Gj with intervals of $1/Gj. The fiber prices considered ranged from $15/Mg to $85/Mg with intervals of $10/Mg. QUICKSILVER, a PC computer software program for forestry investment analysis, was used to calculate the NPV and IRR.

The break-even formula developed by Rose [32] was used to determine the MRY in terms of energy and fiber. The mathematical models are presented as follow:

$$MRY_e = \frac{C_A}{HC \times Y \times AR}$$

$$MRY_f = \frac{C_A}{Z \times AR}$$

where

AR is the average rotation length of n harvests,

C_A is average yield ($) that must be recovered each harvest to pay

Table 3.42. Silver maple SRWC activities, year of occurrence, and costs—scenario I.

Activities	Year	Values ($ per unit)	Comments
Land rent	1-30	- $143.32/ha	actual land rent Amana Society
Site preparation	0	- $237.71/ha	chemical & mechanical
Machine planting	1	- $355.38/ha	labor @$0.039 per plantlet -planting of 3361 trees/ha -machine rate $224.30/ha
Plants	1	- $420.02/ha	$0.125 per plantlet,
Cultural Management	1,2	- $147.97/ha	post-plant, pre-emergent application of herbicides
Fertilization	3	- $150.00/ha	100 kg/ha N
Harvest cost	5-yr rotation	- $26/Mg	includes transportation cost, ~40 km one-way. Expected yield = 10 Mg/ha/yr

Table 3.43. Silver maple SRWC activities, year of occurrence, and costs—scenario II.

Activities	Year	Values ($ per unit)	Comments
Land rent	1-30	- $143.32/ha	actual land rent Amana Society
Site preparation	0	- $209.51/ha	chemical and mechanical
Machine planting	1	- $283.96/ha	labor @$0.029 per plantlet -planting of 3361 trees/ha -machine rate $185.19/ha
Plants	1	- $420.02/ha	$0.125 per plantlet,
Cultural management	1,2	- $95/ha	post-plant, pre-emergent application of herbicides
Fertilization	3	- $150.00/ha	100 kg/ha N
Harvest cost	5-yr rotation	- $19/Mg	includes transportation cost, ~40 km one-way. Expected yield = 10 Mg/ha/yr

Table 3.44. Silver maple SRWC activities, year of occurrence, and costs—scenario III.

Activities	Year	Values ($ per unit)	Comments
Land rent	1-30	- $29.63/ha	actual land rent Amana Society
Site preparation	0	- $209.51/ha	chemical and mechanical
Machine planting	1	- $259.26/ha	labor @$0.022 per plantlet -planting of 3361 trees/ha -machine rate $185.19/ha
Plants	1	- $336.05/ha	$0.10 per plantlet,
Cultural management	1,2	- $95/ha	post-plant, pre-emergent application of herbicides
Fertilization	3	- $150.00/ha	100 kg/ha N
Harvest cost	5-yr rotation	- $18/Mg	includes transportation cost, ~40 km one-way. Expected yield = 10/Mg/ha/yr

for the investment (equivalent to average compounded costs/acre),

HC is heat content in Gj per Mg of fiber,

MRY_e is minimum required yield to produce one Gj of energy at a price/cost of $Y,

MRY_f is minimum required yield to produce one Mg of fiber at a price/cost of $Z.

A heat content (HC) of 18.5 Gj/Mg for silver maple and a 10% energy loss in conversion were assumed.

RESULTS OF SILVER MAPLE ANALYSIS

The curves of minimum required yield in terms of fiber production MRY_f are presented in Figures 3.1 to 3.3 for the three scenarios, respectively. The MRY_f was calculated for the various combinations of the real discount rate and the cost to produce one metric ton of fiber. The discount rate used varied from 3% to 11% by 2% increments. The cost to produce one ton of fiber ranged from $15/Mg to $85/Mg by $10/Mg increments.

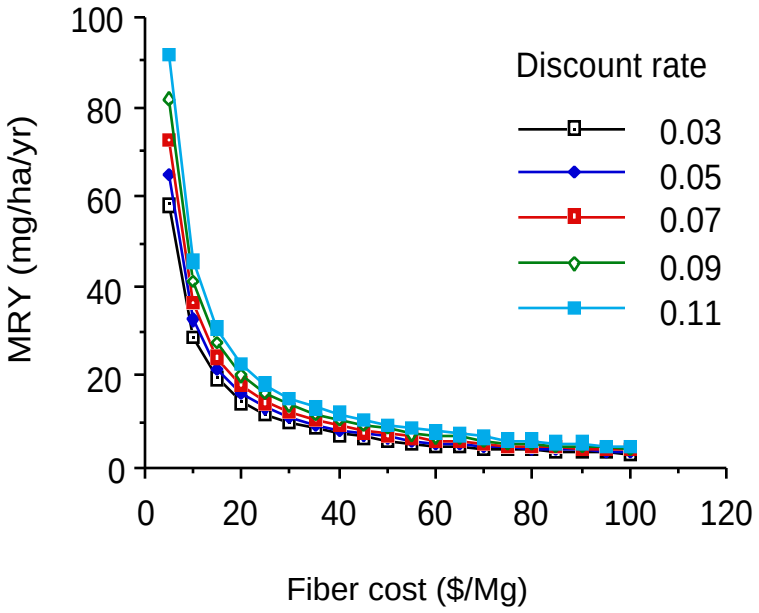

Figure 3.1. MRY_f versus fiber cost at varying discount rates in scenario I.

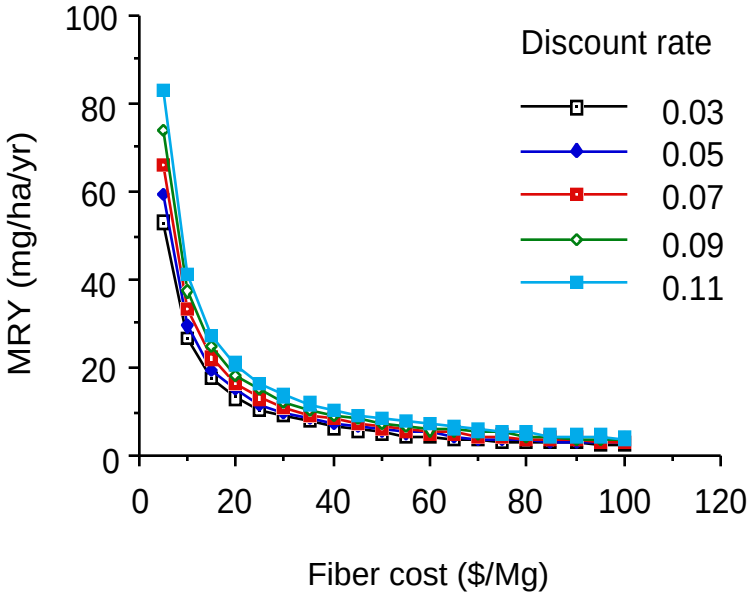

Figure 3.2. MRY_f versus fiber cost at varying discount rates in scenario II.

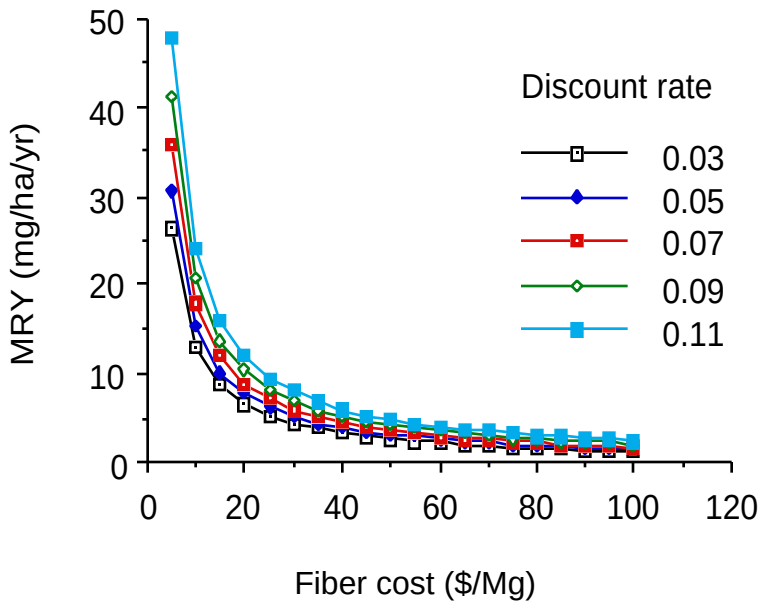

Figure 3.3. MRY_f versus fiber cost at varying discount rates in scenario III.

The curves of MRY versus fiber price are convex to the origin. MRY and the price of one metric ton of fiber are negatively related. When the price of one metric ton of fiber is relatively low, for example, less than $20/Mg, the market price of fiber is crucial in determining the MRY_f. But as the price per ton of fiber decreases, the marginal effect of the fiber production cost on the MRY_f diminishes rapidly. The discount rate and MRY_f are also negatively related. When the price per ton of fiber is low, the discount rate has a significant impact on the MRY_f. As the price of fiber increases, the impact of the discount rate on the MRY_f diminishes.

Figures 3.4–3.6 depict the MRY for the biomass used as an energy feedstock. The curves of MRY_e versus the energy cost are similar to those of MRY_f versus the fiber cost. When the price of one Gj of energy is relatively low, MRY_e is very sensitive to a price change in the market value of energy. However, as the market price of one Gj of energy goes up beyond $4/Gj, its marginal effect on the MRY_e diminishes rapidly. The MRY_f and MRY_e are largest for scenario I, smaller for scenario II, and smallest for scenario III. For instance, in the case where the fiber cost is $25 Mg^{-1} and real discount rate is 5%, the MRY_f is 13.0 Mg/ha/yr, 11.9 Mg/ha/yr, and 6.1 Mg/ha/yr under scenarios I, II, III,

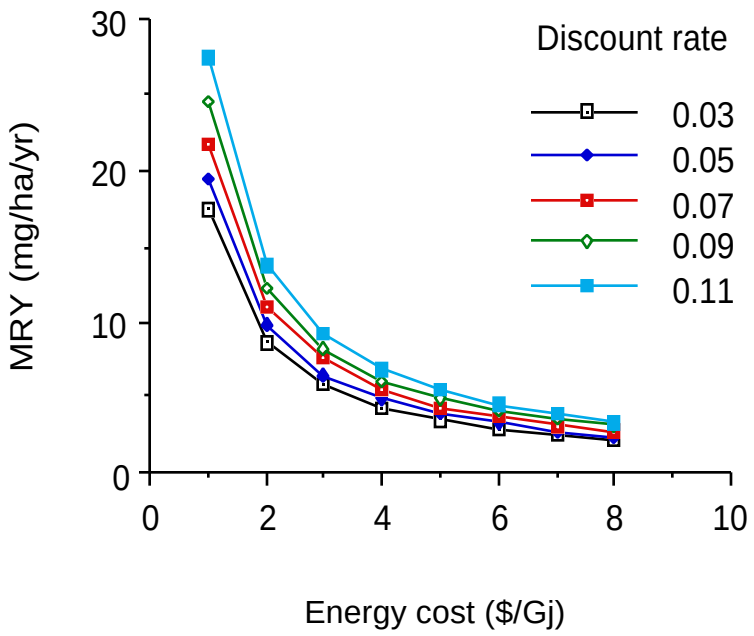

Figure 3.4. MRY_e versus energy cost at varying discount rates in scenario I.

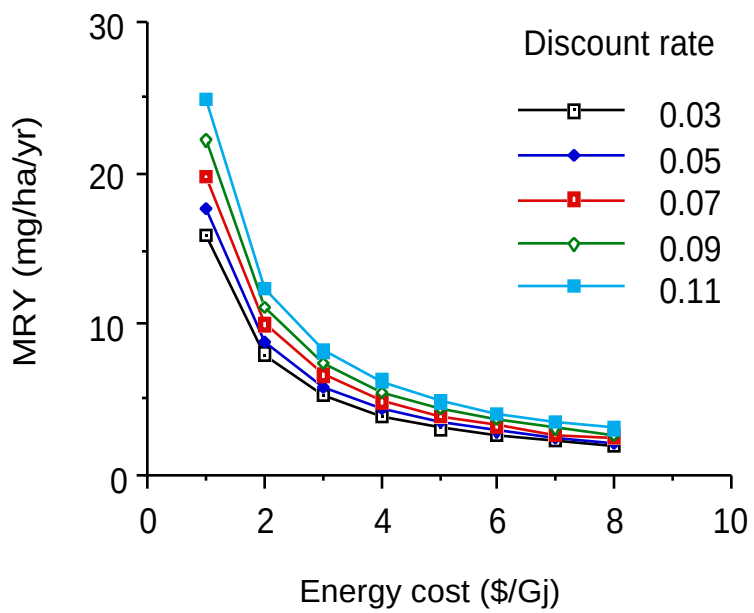

Figure 3.5. MRY_e versus energy cost at varying discount rates in scenario II.

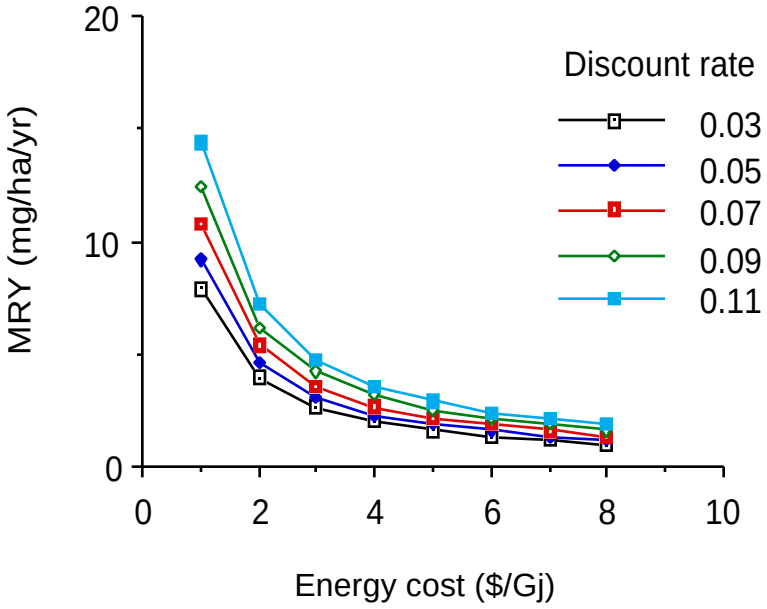

Figure 3.6. MRY_e versus energy cost at varying discount rates in scenario III.

respectively. With the energy cost of $2/Gj and a real discount rate of 5%, the MRY_e is 9.73 Mg/ha/yr, 8.87 Mg/ha/yr, and 4.57 Mg/ha/yr under scenarios I, II, III, respectively.

The NPVs were calculated for two cases: fiber production and energy production. In determining the NPV, the different combinations of fiber or energy prices, biomass yields, and discount rates were considered for the three scenarios. The fiber price varied from $15/Mg to $85/Mg by $10/Mg increments. The energy price ranged from $1.00/Gj to $8/Gj with intervals of $1.00/Gj. The biomass yield varied from 5 Mg/ha/yr to 20 Mg/ha/yr by increments of 2.5 Mg/ha/yr.

The NPVs are linearly related to the fiber price or the energy price and the biomass yield for a given discount rate. Figures 3.7 to 3.12 show the relationships between NPV and fiber or energy price with an assumed silver maple biomass yield of 10 Mg/ha/yr. The discount rate has a significant effect on the net present values, especially when the fiber and energy prices are high. As the discount rate decreases, the net present value becomes more sensitive to the change in the fiber price and the energy price.

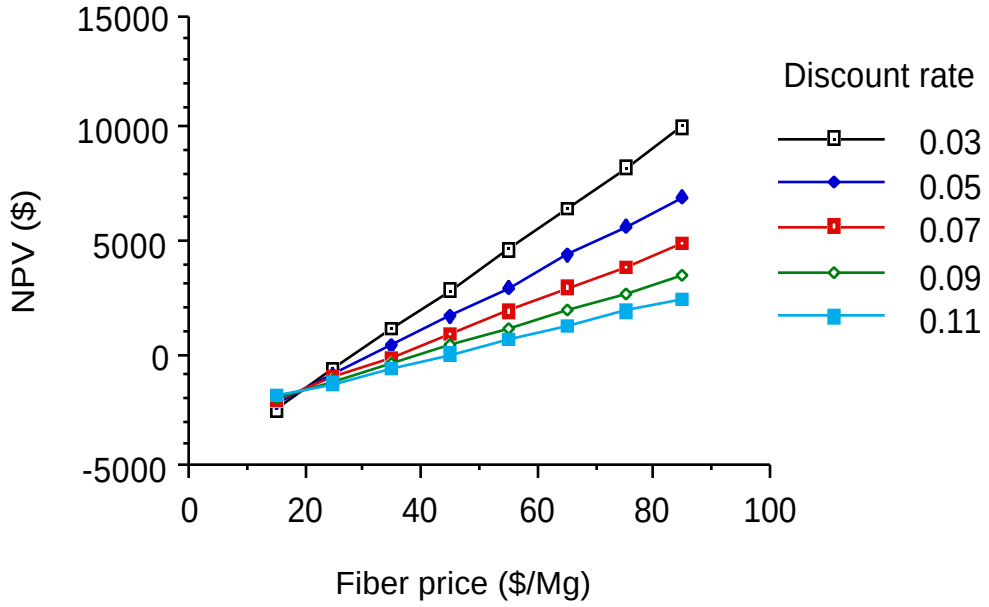

Figure 3.7. Per ha NPV versus fiber price at varying discount rates at a yield of 10 Mg/ha/yr in scenario I.

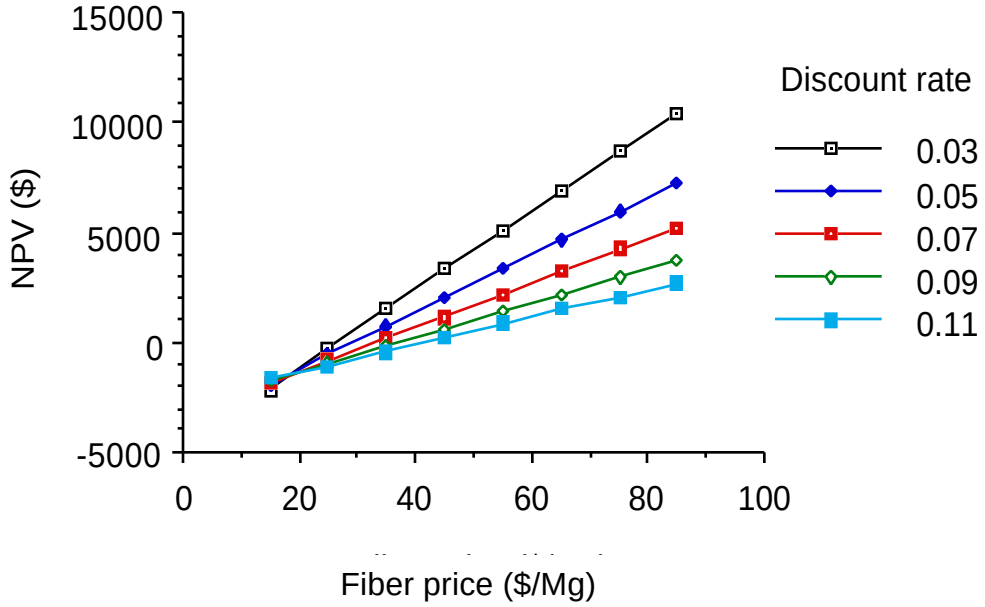

Figure 3.8. Per ha NPV versus fiber price at varying discount rates at a yield of 10 Mg/ha/yr in scenario II.

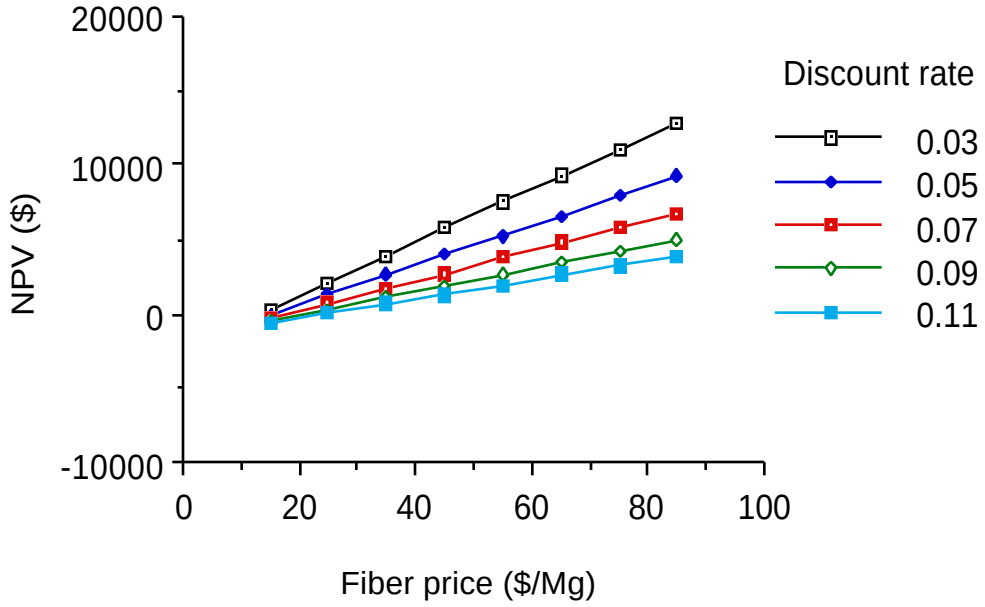

Figure 3.9. Per ha NPV versus fiber price at varying discount rates at a yield of 10 Mg/ha/yr in scenario III.

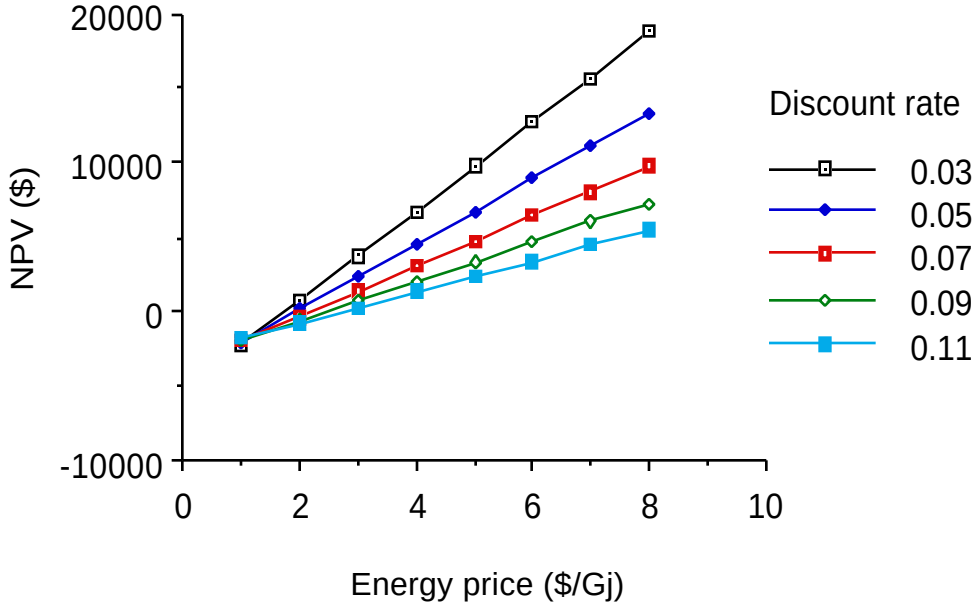

Figure 3.10. Per ha NPV versus energy price at varying discount rates at a yield of 10 mg/ha/yr in scenario I.

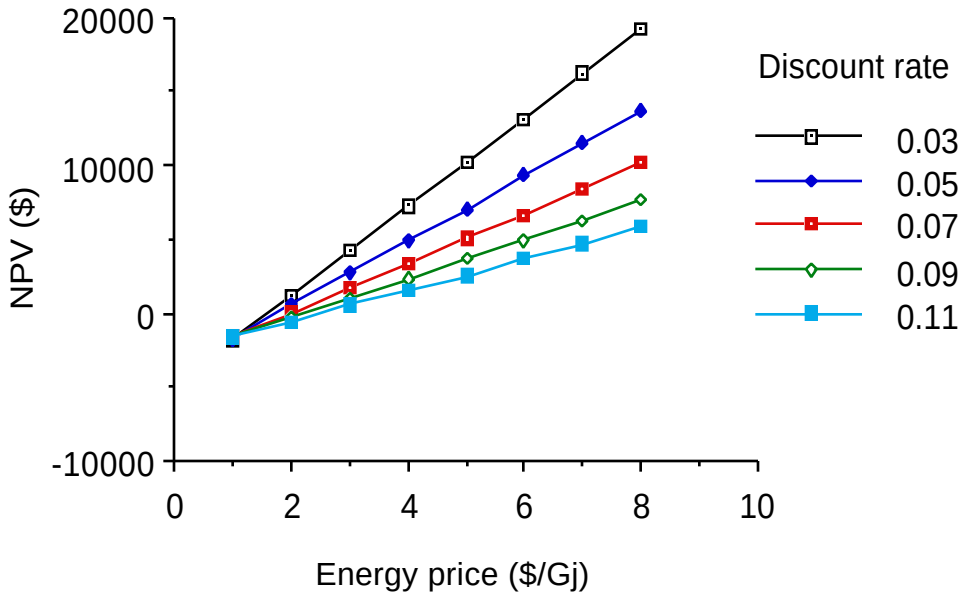

Figure 3.11. Per ha NPV versus energy price at varying discount rates at a yield of 10 Mg/ha/yr in scenario II.

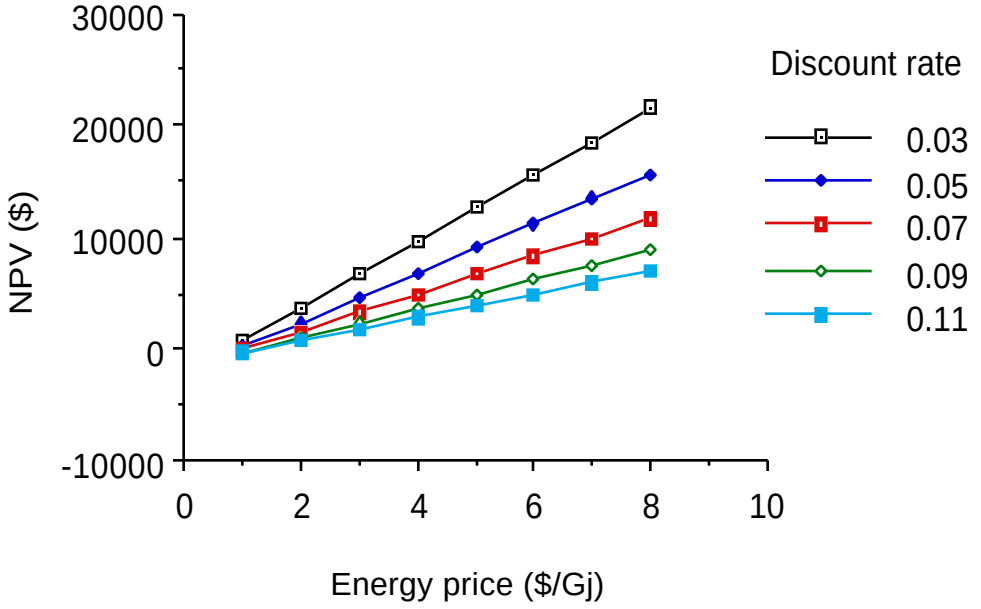

Figure 3.12. Per ha NPV versus energy price at varying discount rates at a yield of 10 Mg/ha/yr in scenario III.

From the fiber production stand point and for the case of the yield of 10 Mg/ha/yr and fiber price of $25/Mg (with a real discount rate of 5%), the NPVs per ha are -$993, -$612, and $1290, respectively for scenarios I, II, and III. With the values of the other parameters unchanged, if only the fiber price is increased to $35/Mg, the NPV per ha increases to $332, $712, and $2615 for scenarios I, II, and III, respectively. If only the yield is increased to 15 Mg/ha/yr (~6.7 t/ac/yr) with all other costs unchanged, the investment produces a positive profit, and the NPVs per ha are $319, $792, and $2708 for scenarios I, II, and III, respectively.

For energy production, in the case of the yield of 10 Mg/ha/yr and energy price of $1/Gj with the real discount rate of 5%, the NPVs per ha are -$2092 for scenario I, -$1712 for scenario II, and $191 for scenario III. In this case, if the energy price increases to $2/Gj, the NPVs per ha become $120, $500, and $2403, respectively, for scenarios I, II, and III, indicating that a positive profit is produced for the investment. If the biomass yield is increased to 15 Mg/ha/yr with other parameters unchanged, the NPVs per ha improve to -$1330, -$858, and $1058, respectively, for scenarios I, II, and III. If only the discount rate is reduced to 3% for the case of biomass yield of 10 Mg/ha/yr and an energy price of $1/Gj, the net present values per ha are improved (reduced further) to -$2216, $-1767, and $649 for scenarios I, II, and III, respectively.

The IRR was also determined for both fiber and energy production. The same ranges of the biomass yield, fiber price, and energy price used in calculating the NPV were used to estimate IRR. The relationships between IRR and the fiber and energy prices are shown in Figures 3.13 and 3.14, respectively. The IRR is positively related to both fiber price and energy price. But the marginal effect of the fiber price or the energy price on the IRR diminishes as the fiber price or energy price increases.

For fiber production, in scenario I, when fiber price is $25/Mg and the biomass yield is 10 Mg/ha/yr or higher, the IRR remains positive. For instance, if the yield is 12.5 Mg/ha/yr, the IRR is 3.5%. If the yield increases to 15 Mg/ha/yr, the IRR goes up to 6.2%. When fiber price is $35/Mg, a yield of 7.5 Mg/ha/yr or more produces a positive IRR. In this case, a yield of 7.5 Mg/ha/yr produces an IRR of 2.0%. If the yield goes up to 10 Mg/ha/yr, the IRR reaches 6.3 %, producing an attractive economic return. If fiber price increases to $45 Mg, even a yield of 5 Mg/ha/yr results in a positive IRR. The IRRs under scenario II are a little higher than those under scenario I for given combinations of

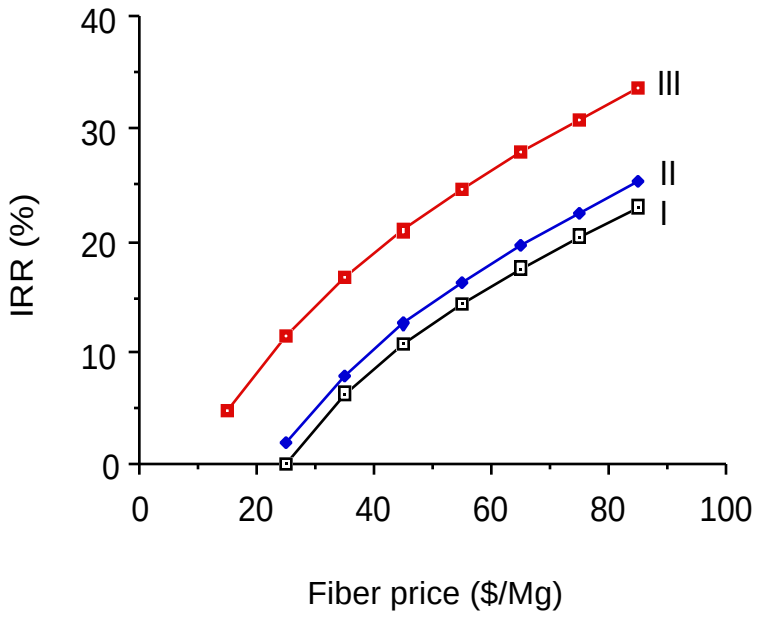

Figure 3.13. IRR versus fiber price at a yield of 10 Mg/ha/yr.

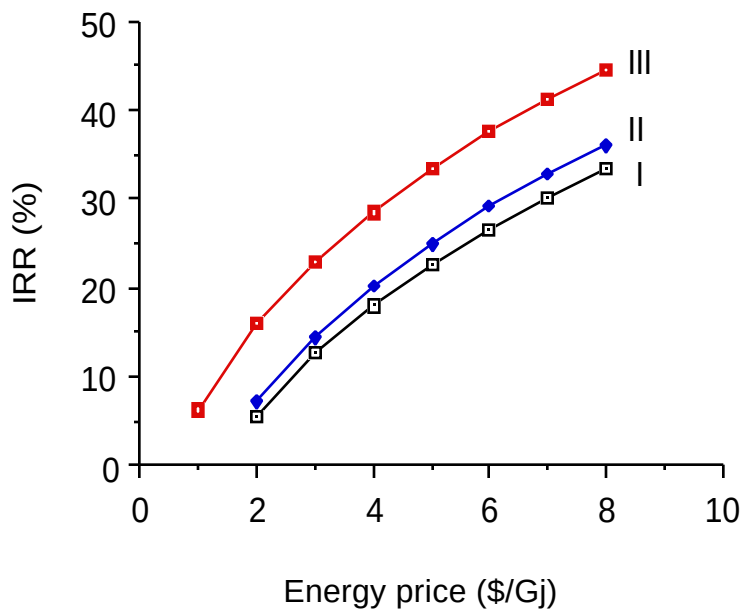

Figure 3.14. IRR versus energy price at a yield of 10 Mg/ha/yr.

biomass yield and fiber or energy price. However, the IRRs under scenario III are significantly higher than those under scenario I. For the case of a yield of 10 Mg/ha/yr and fiber price of $25/Mg, the IRRs are 0.1% in scenario I, 1.9% in scenario II, and 11.6% in scenario III.

For energy production, in scenario I, when energy price is $1/Gj, the biomass yield should be 17.5 Mg/ha/yr or higher to secure a positive IRR. If energy price is $2/Gj, a yield of 7.5 Mg/ha/yr or higher produces a positive IRR. In this case, the IRR is 1.2% with a yield of 7.5 Mg/ha/yr and 5.5% with a yield of 10 Mg/ha/yr. If energy price goes up to $3/Gj, even a yield of 5 Mg/ha/yr still produces a positive IRR. With an energy price of $3/Gj, the IRRs are 2.1% for the yield of 5 Mg/ha/yr, 8.1% for the yield of 7.5 Mg/ha/yr, and 12.6% for the yield of 10 Mg/ha/yr. As with fiber production, the IRR increases by a small amount from scenario I to scenario II but the IRR increases significantly from scenario I to scenario III.

CONCLUSIONS OF SILVER MAPLE ANALYSIS

The results of this assessment indicate that this silver maple SRWC plantation is economically feasible under certain biomass yield and cost conditions. When the biomass is used as a fiber source for paper and paperboard production or for wood composite products such as oriented strand board, chipboard, or fiberboard where established markets in the upper Midwest exist with relatively higher market price per dry ton (Mg) of biomass, the breakeven yields are much lower compared with those when the biomass is valued as an energy resource.

The MRYs for fiber production, in the case of $25/Mg of fiber cost and a 5% real interest rate, are 13 Mg/ha/yr, 11.85 Mg/ha/yr, and 6.10 Mg/ha/yr under scenarios I, II, and III, respectively. The MRYs for energy production, in the case of $2/Gj of energy cost and a 5% real interest rate, are 9.73 Mg/ha/yr, 8.87 Mg/ha/yr, and 4.57 Mg/ha/yr under scenarios I, II, and III, respectively. The MRYs even under the current technology level and without government cost sharing (scenario I) are roughly twice the currently achieved silver maple yields recorded by ISU foresters at the Hickory Grove SRWC energy plantation. Note that no fertilizer has been applied to any SRWC plots at the Hickory Grove site since that start of the project in 1986 and that the soils are fertile loam/clay loam soils classified as LCC IIw and IIe.

The analyses using NPVs and the IRR show similar results. Given a yield of 10 Mg/ha/yr, a fiber price of $25/Mg, and a 5% real interest rate, the per ha NPV is -$993,

-$612, and $1290, respectively, under scenarios I, II, and III. In the case of the yield of 10 Mg/ha/yr, energy price of $2/Gj, and a 5% real interest rate, the NPVs are $120, $500, and $2403 under scenarios I, II, and III, respectively. In the case of the yield of 10 Mg/ha/yr and fiber price of $25 Mg, the IRRs are 1.0%, 1.9%, and 4.8% under scenarios I, II, and III, respectively. And in the case of a yield of 10 Mg/ha/yr and a energy price of $2/Gj, the IRRs are 5.5%, 7.1%, and 16.0% under scenarios I, II, and III, respectively.

Overall, under current costs and SRWC technology applied to this Iowa site, assuming harvesting cost of $ 26/Mg and energy priced at $4/Mg, the biomass yield required to break even equals the observed silver maple yields of 6.5 Mg/ha/yr at the Hickory Grove SRWC research site. With modest cost reductions, such as lower cost planting stock and a multiple row planter as assumed in scenario II, and with an energy price of $3/Mg, the observed biomass yield from silver maple at the Hickory Grove SRWC project site equals the minimum required yield.

Advances in technology associated with planting and harvesting, genetic improvement in planting stock, increases in fiber and energy prices, and government subsidies such as the CRP cost-share for establishment and rent payments are all important elements that will determine the cost-effectiveness and profitability of this silver maple SRWC system.

If extra-market benefits associated with the SRWC system such as carbon sequestering, soil and water conservation, and wildlife habitat improvement are considered, this system and other SRWC systems in general would approach viability without significant reductions in costs, improvements in yields, or governmental subsidies.

METHODOLOGY FOR BASIC SRWC ANALYSIS

On the basis of field experiences at Hickory Grove with several different SRWC systems and species (the DOE/Amana silver maple viability trial, the Ames Agroforestry Project, and the Riparian Bufferstrip project on Bear Creek), the following system is defined as a "basic SRWC economic model" for Iowa. It is assumed that the activities and costs in the basic model reflect hybrid poplar and willow tree species and to a lesser extent silver maple and green ash tree species. The basic model assumes a rotation length of 10 years and a total production cycle of 20 years. There are two harvests, one at 10 years and the other at 20 years. A spacing of 1.8 m x 2.4 m is used with about 2200 stems/ha

planted. Machine and chemical site preparation is assumed as is single-row machine planting of rooted plant material or improved seedlings.

The basic model assumes coppice regrowth of the winter-cut tree stems that is greater than the initial rotation's growth. Biomass yield is assumed to be 11 Mg/ha/yr for the initial rotation and 13.75 Mg/ha/yr for the subsequent coppice harvest at year 20.

Note that this assumption of relying on coppice regeneration is being challenged in view of the forest industries' successes in the Pacific Northwest with short-rotation fiber plantations where superior clonal material is planted at the end of each 6–10 year rotation. A determining factor in the adoption of this replanting strategy will be the rate of genetic improvement relating to biomass yield and pest resistance of SRWC species grown on Iowa sites.

The basic model assumes that a dedicated energy system is the primary purpose. It also assumes that concern for soil erosion and water quality will affect management. In the model considerable attention will be paid to weed control, but there is no fertilization because it is assumed that the system will be sited on LCC IIIe or IV lands.

Data from Iowa SRWC field research sites, custom farming rates for Iowa, and SRWC literature are used to estimate activity costs. All costs are stated in 1993 dollars and exclude inflation. Thus, the entire model will be evaluated in real dollars using a real alternative rate of return of 5%. No cost-share or other subsidy from governmental or nongovernmental organizations is included in the basic SRWC economic model.
Table 3.45 presents the activities, years of occurrence, and the costs associated with the basic model, which is outlined below:

I. Land Rent:

A land rent cost of $150/ha (~ $61/ac) is assumed. On average statewide, low quality farmland rents for $26 - $82 per acre in 1994.

II. Site Preparation:

a. Mechanical site preparation: Site preparation could entail use of a disk (offset or tandem) to prepare a good planting bed.

Total cost for all elements of site prep = ~$ 35/ ha

Labor input: 1.24 hr / ha (0.5 - 1.0 hr / ac)

an operator with tractor & disk

Cost of labor: $ ~9/ ha ($7/ hr)

Table 3.45. The activities, year of occurrence, and values (costs and return) of the basic SRWC model for Iowa.

Activities	Year	Values ($ per unit)	Comments
Land rent	1-20	- $150/ha	marginal cropland
Site preparation	0	- $124/ha	chemical and mechanical
Machine planting	0	- $235/ha	$0.105 per plantlet—planting 2242 trees/ha
Plants	0	- $448/ha	$0.20 per plantlet, source
Herbicide	0	- $121/ha	post-plant, pre-emergent application of two herbicides late season, prior to year 1
Herbicide	2	- $121/ha	post-plant, pre-emergent application of two herbicides
Herbicide	10	- $121/ha	post-plant, pre-emergent application of two herbicides
Annual management	1 - 20	- $40/ha	supervision, property taxes, and insurance
Harvest cost	10	- $25/Mg	includes transportation cost, ~40 km one-way. Expected yield = 11 Mg/ha/yr
Harvest cost	20	- $25/Mg	includes transportation cost, ~40 km one-way. Expected yield = 13.75 Mg/ha/ yr
Biomass harvest (initial cut)	10	$40/Mg	Expected biomass yield = 11 Mg/ha/yr
Biomass harvest (coppice cut)	20	$40/Mg	Expected biomass yield = 13.75 Mg/ha/yr

Machine: ~$ 26 / ha ($10.30/ ac) Iowa custom rates

b. Chemical site preparation: Site preparation could entail a single banded application of a broad-spectrum herbicide such as glyphosate (e.g., Roundup) to prepare a good planting site. This method would be used on sites with existing vegetation cover, on sloped ground >5%, and near sensitive areas such as streamsides.

Total cost for all elements of site prep = ~$ 32/ ha

Labor input: 1.24 hr / ha (0.5 hr / ac)

One operator with tractor and spray unit. Assume operator has proper

and current certification as a Iowa Pesticide Applicator.

Cost of labor: $ ~9 / ha ($7/ hr)

Machine: $ ~11 / ha ($4.50/ ac)

Chemical: $ ~13/ ha (~$5/ac) (2.3 l/ ha - 1 qt/ac, assume price @ $50/gal for glyphosate) Herbicide site preparation involves a chemical spray with a herbicide either in fall or early spring prior to planting with a 1.0 m (~3 ft) wide "kill" strip for each tree row.

III. Planting:

Assume contract planting with a single-row tree planter and small to medium hp farm tractor. Assume a two person planting team. The 1993 Iowa tree planting contract cost per seedling = $0.105 per seedling (labor plus machine). Assume an average planting rate of 1 acre per hour. Assume planting ~1,200 trees per hour. Rugged terrain and wet conditions can greatly reduce trees planted per hour.

Labor input: Two people per planter rig

(1 person planter pulled by tractor with one operator)

~5 person hrs / ha (~2 person hr / ac)

Cost of labor: $0.06 / seedling

Machine: $0.045 / seedling

IV. Planting Stock:

Assume that hybrid poplar will be 1-year-old rooted cuttings. The assumed price per plantlet is $0.12. Tree willow could be planted as unrooted cuttings. Silver maple and green ash would be planted as seedlings.

V. Weed Control:

Assume one herbicide application each year for the first three years. The herbicide would have both pre- and post-emergent control of grass and broadleaf weeds.

Chemical: One herbicide—small tractor with a herbicide sprayer or commercial custom spray rig used to apply tank mixed pre-emergent herbicides. Immediately after planting, over-spray with pre-emergent herbicide in ~1 m wide bands along tree rows.

Total cost labor, machine, and chemical = $ 54/ha (~$22/ ac)

Labor input: 1.24 - 2.471 hr / ha (0.5 - 1.0 hr / ac) @$7/ hr with benefits

One operator plus machine.

Cost of labor: ~$ 9/ ha ($3.50/ ac)

Machine: ~$ 9 / ha ($4.50/ ac)

Chemical: $ ~37/ ha ($7.5 - 20/ ac; avg. ~ $14/ac) (Apply herbicide in 3-ft wide strips. Thus for one acre of trees planted at 4 x 8 ft spacing, only 36% of the acre has herbicide applied to it. The recommended herbicide : Oust (Sulfometuron-Methyl)

VI. Field Cultivation:

Field cultivation for the first and second years is recommended. Note that if needed one of the field cultivation costs could be shifted to a low-rate (~70 kg/ha) nitrogen fertilization with a slightly higher cost estimated at $55/ha.

Total cost labor and machine = $35/ ha ($14/ ac)

Labor input: 1.24 - hr / ha (0.5 - 1.0 hr / ac)

an operator with tractor & disk

Cost of labor: $ ~9/ ha ($7/ hr)

Machine: ~$26 / ha ($10.30/ ac) Iowa custom rates

VII. Annual Management/ Miscellaneous Maintenance:

Annual management includes overhead, miscellaneous labor, insurance, and property taxes.

Total costs = $40/ ha (~$16/ ac)

VIII. Harvesting and Transportation:

The total harvesting and transportation cost is directly dependent on biomass yield. It is estimated to be $25/Mg (dry metric ton) in this model. An assumed 10% loss of biomass is included in the harvesting and in-field processing phase cost estimates. It is assumed that a 40 km one-way haul is made from the production site to the end-use facility. The transportation cost component is estimated to be about $3/Mg .

Harvesting of SRWC systems could involve as few as one person to as many as three persons. A mechanized system with in-field chipping or chunking for stems could involve three people, an operator for the feller/skidder machine, an operator for the chipper/chunker machine, and a field supervisor.

Whole-tree harvesting and hauling to a conversion site could involve only one person, the feller/skidder machine operator. Labor input would be required, however, at the conversion site if the biomass must be processed into chips or chunks for conversion purposes. Safety concerns suggest that two person crews should be used for harvesting.

Labor input varies with the type of truck/trailer or truck/chip van unit used to carry the woody biomass to the conversion facility. Generally there is one operator per truck/trailer unit.

RESULTS OF BASIC SRWC ANALYSIS

The basic model was evaluated using two financial decision criteria, NPV and annual equivalent worth (AEW). A before-tax discounted cash flow analysis was done using QUICKSILVER, a forestry investment computer program. All costs and returns are in 1993 dollars. An inflation-free (real) discount rate of 5% was used as the alternative rate of return.

The analysis considered four scenarios: two production cost levels (basic model and subsidy model) and two biomass price levels, $40/Mg and $50/Mg (see Table 3.46 for parameters). The subsidy scenarios II and IV assume that a governmental program similar to the CRP will exist. This biomass program will pay 100% of the land rent for a 20 year period and 75% of the cost of establishment of the SRWC plantation. The two biomass price levels were selected to reflect an estimate of the current market price per Mg (Price = $40/Mg) of biomass in various regions of the United States and an optimistic, future market price for woody biomass.

For all four scenarios, the initial rotation is expected to yield 11 Mg/ha/yr and the coppice rotation is expected to yield 13.75 Mg/ha/yr, a 25% increase assumed from the established root system.

The results in Table 3.47 show that the basic model (scenario I) is not economically viable. The AEW of - $110.16/ha represents a net annual loss from producing woody biomass under this set of cost, yield, and price assumptions. Consider scenario II. If government subsidies are applied with the price at $40/Mg, then the system is expected to have an annual net return of $72.11/ha.

Table 3.46. Parameters of the four SRWC scenarios.

Scenario	Cost Parameters	Yield Parameters
I. Basic model	no subsidies see Table 3.45 Price = $40/Mg	11 Mg/ha/yr, initial rotation 13.75 Mg/ha/yr coppice yield
II. Subsidy model	100% land rent 75% estab. costs Price = $40/Mg	11 Mg/ha/yr, initial rotation 13.75 Mg/ha/yr coppice yield
III. Basic—high price model	no subsidies see Table 7.4. Price = $50/Mg	11 Mg/ha/yr, initial rotation 13.75 Mg/ha/yr coppice yield
IV. Subsidy—high price model	100% land rent 75% estab.costs Price = $50/Mg	11 Mg/ha/yr, initial rotation 13.75 Mg/ha/yr coppice yield

Table 3.47. NPV and AEW per ha for the SRWC scenarios evaluated at a real discount rate of 5%.

Scenario	NPV @ 5% ($/ha)	AEW @ 5% ($/ha)
I. Basic model	- $ 1372.85	- $ 110.16
II. Subsidy model	$ 898.62	$ 72.11
III. Basic–high price model	- $179.32	- $14.39
IV. Subsidy–high price model	$ 2092.15	$ 167.88

Scenario III depicts the effect of increasing the market price for biomass by 25% while all other costs and yields remain the same. This scenario is close to the break-even point given the NPV of - $179.32/ha and the AEW of -$14.39/ha.

The basic model does break even with a biomass price of $51/dry Mg (~$46 dry ton). Assuming a higher heat value of dry SRWC biomass of 19.77 Mj/kg (approximately

8,500 Btu/lb), this means that the biomass costs about $2.89/Gj (about $2.72 per million Btu).

Scenario IV indicates that with subsidies, a high market price for biomass, and the expected yields of 11 Mg/ha/yr and 13.75 Mg/ha/yr, the economic viability of SRWCs increases dramatically. The AEW indicates the potential of the system having a net annual return of $167.88/ha (~$68/ac).

RESULTS OF COMPARISON BETWEEN SRWC AND HEC SYSTEMS

The HEC production cost data from Anderson, Buxton, and Hallam [33] were adapted to the 20-year analysis period used in the evaluation of the four SRWC scenarios. The same four scenarios (assuming price and subsidies) were applied to the data for switchgrass using the Chariton costs. NPVs and AEWs were computed using a 5% real discount rate. The QUICKSILVER computer program was used to do all calculations for the before-tax discounted cash flow analysis of the switchgrass (HEC) scenarios. Table 3.48 presents the comparison between the SRWC and the HEC scenarios.

Table 3.48. NPV and AEW per ha for the SRWC (hybrid poplar) and HEC (switchgrass) scenarios evaluated at a real discount rate of 5%.

Scenario	SRWC		HEC	
	NPV @ 5% ($/ha)	AEW @ 5% ($/ha)	NPV @ 5% ($/ha)	AEW @ 5% ($/ha)
I. Basic model	- $ 1372.85	- $ 110.16	- $264.36	- $ 21.21
II. Subsidy model	$ 898.62	$ 72.11	$ 1892.96	$ 151.90
III. Basic–high price model	- $179.32	- $14.39	$ 997.49	$ 80.04
IV. Subsidy–high price model	$ 2092.15	$ 167.88	$ 3154.82	$253.15

For all four scenarios, switchgrass production is more economically viable, The break-even price for the switchgrass basic model (scenario) is roughly $41/Mg. Note that if the Ames production data for switchgrass are used, the biomass production costs per Mg would increase by about $10 to about $50/Mg, making it roughly equal in biomass cost

with the SRWC scenario I. The estimated AEW for switchgrass with the Ames costs applied under scenario I assumptions would be about - $93.75/ha.

Because the higher heat (energy) value reported for hybrid poplar (17 MM Btu/dry ton) is greater than that reported for switchgrass (15.5 MM Btu/dry ton), it is useful to compute the cost per million Btu given various assumed production costs per dry (short) ton. Table 3.49 provides a comparison of the cost per million Btus for hybrid poplar and switchgrass. If the production (including growing, harvesting, and transporting) costs per dry ton are the same for hybrid poplar and switchgrass, the dollar cost per million Btus for poplar is $0.20 - $0.30 lower than that for switchgrass.

Table 3.49. Comparison of cost per million Btus for hybrid poplar and switchgrass given various production costs.

Production Cost ($/dry ton)	Hybrid Poplar[a] ($/MM Btus)	Switchgrass[b] ($/MM Btus)
$35	$2.06	$2.26
$40	$2.35	$2.58
$45	$2.65	$2.90
$50	$2.94	$3.23
$55	$3.24	$3.55

[a]Assumes 17 million Btus per dry ton. Source: Arola, R. A. and E.S. Miyata. 1981. *Harvesting Wood for Energy*. USDA Forest Service. North Central Forest Experiment Station Research Paper NC-200.

[b]Assumes 15.5 million Btus per dry ton. Source: Buxton and Brown, ISU, 1994 personal communication. Also, Helsel, Z.R. and W.F. Wedin. 1983. Direct combustion energy from crops and crop residues produced in Iowa. In *Energy in Agriculture*. Elsevier Science Publishers B.V., Amsterdam.

CONCLUSIONS

Currently, ISU research indicates that woody biomass costs about $3/Gj (~$3.00/MM Btus) to produce, with Iowa yields ranging between 7.8 and 15.7 Mg/ha/yr (5–7 dry ton/ac/yr). From limited field research in Iowa, it is estimated that woody biomass can be produced, harvested, and transported for about $45-$55/Mg ($40–$50/dry ton).

It is estimated that existing SRWC systems on LCC IIw and IIe lands in Iowa are slowly approaching the break-even point without any subsidies assumed and with an assumed delivered energy price of $40/Mg ($36/dry ton).

The energy value per dry pound of woody (SRWC) seems to provide an "energy advantage" relative to switchgrass and other HECs. Also, the density of the woody biomass makes it more attractive and cost-effective for hauling longer distances relative to HEC biomass.

There is a "carbon" advantage of SRWC biomass over HEC in that more carbon is sequestered in the biomass from trees than the perennial grasses. Any future carbon tax on fossil fuels of $0.50 to $1.00 MM Btu will make SRWC "renewable" biomass very attractive to coal consuming utilities, particularly for co-fueling (co-firing wood and coal).

There are few SRWC systems planted in Iowa. It is clear from the SRWC and HEC research that the costs and yields are site-specific. More large-scale research and demonstrations of SRWC systems on various Iowa landforms and soils are needed to more accurately assess the biomass yield, cost of production, and economic viability.

If Iowa is serious about rural development, the establishment of SRWC and HEC systems on appropriate lands across Iowa will provide employment opportunities in the production and harvesting of the biomass and transporting it to end-use facilities. Moreover, capital will have to be infused into the rural economies to support the dedicated energy crops from woody and herbaceous species.

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Chapter 4

Conversion Technology

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CHAPTER 4. CONVERSION TECHNOLOGY

INTRODUCTION

The three major categories of biomass energy utilization are generation of process heat, generation of electric power, and production of liquid fuels. This chapter investigates the various technologies that can convert biomass into these more useful energy forms. Biomass encompasses a wide variety of biological materials with distinctive physical and chemical characteristics. As a result, a wide variety of conversion schemes have been developed to best take advantage of the properties of the biomass to be processed.

The conversion processes covered in this section are organized into six main topical areas: direct combustion, thermochemical conversion, biochemical conversion, indirect liquefaction, physical extraction, and electrochemical conversion. Direct combustion is simply the familiar burning of solid biomass fuels. Thermochemical conversion includes pyrolysis, gasification, and direct liquefaction. Biochemical conversion encompasses anaerobic digestion and ethanol synthesis. Indirect liquefaction is the conversion of synthesis gas from gasification into methanol. Physical extraction is the mechanical pressing of certain biomass crops to extract vegetable oils. Physical extraction is somewhat of a misnomer because further chemical and thermochemical processing of vegetable oils is usually contemplated to produce a better performing liquid fuel known as biodiesel. Electrochemical conversion encompasses fuel cells.

Much of the interest in alternative energy, including biomass, in the late 1970s and early 1980s focused on a small roof-top, backyard, or on-farm conversion systems with outputs measured in kilowatts or tens of gallons per hour. This parochial approach appeared justified by the dispersed nature of alternative energy resources, which do not lend themselves to the large, centralized conversion facilities used for fossil and nuclear fuels.

However, this approach failed to recognize the strong economies-of-scale that were lost with small conversion facilities even when using dispersed feedstocks. The resulting

energy product, whether heat, electricity, or liquid fuels, was not cost-competitive with fossil-fuel derived energy, especially as energy prices declined through the 1980s. Furthermore, this decidedly self-reliant approach to alternative energy stood little chance of impacting the larger community of energy consumers who looked to the market for their energy needs.

The resurgence of interest in biomass energy in the last few years has been accompanied by a major shift in the scale of proposed conversion facilities. The trade-off between the dispersed nature of biomass on the production side and the economies-of-scale on the conversion side have resulted in proposals for community-sized conversion facilities with outputs measured in tens of megawatts or thousands of barrels per day. These facilities would be served by large plantations of dedicated energy crops encompassing tens of thousands of acres. This focus on medium-size facilities will be evident in the analyses that follow.

METHODOLOGY

The goal of this analysis is to identify potential biomass-to-energy conversion technologies, describe their principles of operation, assess their state-of-the-art, estimate the capital and operating costs for conversion facilities based on these technologies, and identify important problems and waste streams associated with each technology. Technical information and data to perform this evaluation were collected through an extensive search of the open literature. Preference was given to publications after 1989; however, many excellent studies performed in the late 1970s and early 1980s have never been updated and represent the best source of performance and cost data for several technologies.

Capital costs and operating costs presented in this study should be considered as only approximations of actual costs. Although two independent sources were sought for cost data for each conversion technology, many of these technologies have neither been built on a commercial scale nor operated with biomass feedstock.

Also contributing to the difficulty in making economic judgments about these technologies are the different bases used in the original evaluations. Very frequently these evaluations were made for different years. To account for inflation, all cost data were converted to 1990 dollars, as described in Boehm [1]. Separate inflation index factors were used for equipment and energy. The Marshall and Swift (M&S) equipment index

was obtained from recent issues of *Chemical Engineering Magazine*. The consumer price index for energy was obtained from the *Statistical Abstracts of the United States* [2].

A second correction of bases involved the size of the conversion plant. The costs of most capital facilities are not linearly related to the size of the facility. The principle of economies of scale predicts that capital costs appreciate proportionally slower than the size of the facility; hence, the unit cost of a product decreases as the facility becomes larger. Unfortunately, conversion plants using biomass feedstock cannot capture the full benefit of economies of size because of the prohibitive expense of collecting dispersed biomass resources beyond a radius of about 50 miles [3]. This constraint sets the maximum electrical output, for example, of a biomass power plant to about 50 megawatts (MW) [3]. Accordingly, it is not appropriate to use the generation cost for a kilowatt-hour of electricity from a 200-MW coal-fired power plant, for example, to estimate the cost of electricity from biomass even if comparable technology is employed and differences in fuel costs are accounted for.

A rational basis for comparison must scale capital costs to a realistic conversion facility size. In many instances, this can be effectively estimated by the simple scaling law [4]:

$$C_s = C_b (S_s/S_b)^n$$

where C_s = predicted cost of the specified plant
C_b = known cost of the baseline plant
S_s = size of the specified plant
S_b = size of the baseline plant
n = economy of scale factor (less than unity)

The economy of scale factor depends on the kind of equipment being specified and sometimes on the size range of the equipment. This factor is reasonably well known from industrial practice for a variety of parts and equipment [4] and can be used to estimate overall costs of systems made up of such parts and equipment. This scaling law can also be applied to overall systems, but with diminishing accuracy as the system becomes more complex. For many energy and chemical process plants, a reasonable estimate for n is 0.6 [4].

In the analysis that follows, the size of biomass-fired electrical power plants is specified to be 50 MW, and the size of liquid fuel production plants using biomass feedstock is specified to be 5,000 barrels/day. Availability factors for the plants are 90%. Annual yields for biomass from plantations of dedicated energy crops are assumed to be 5 tons/acre. The fuel is assumed to have a lower heating value of 8,000 Btu/lb (dry basis) and a moisture content of 30%. The cost of biomass from these plantations is assumed to be $2.00/MM Btu unless otherwise noted.

RESULTS OF ANALYSIS

Direct Combustion

Combustion is defined as the complete oxidation of a fuel to obtain useful energy in the form of heat. Direct combustion systems are designed to produce heat that can be used directly or transferred to a working fluid such as steam. The complete combustion process involves the reaction stages of heating and drying, solid particle pyrolysis, gas phase reactions, and char oxidation reactions [5]. A flow diagram for direct combustion is illustrated in Figure 4.1.

The process of heating and drying is dominated by physical processes rather than chemical reactions. For fuels containing moisture, approximately 1,200 Btu/lb of moisture is required to dry the fuel. Obviously, field drying biomass is desired to reduce both transportation costs and heating penalties within the boiler.

The next stage of combustion is pyrolysis of the solid fuel particles. Pyrolysis is the thermal decomposition of organic material in the absence of oxygen with the release of volatile organic and inorganic compounds. These endothermic chemical reactions proceed at relatively low temperatures, which depend on the type of plant material. Hemicellulose begins to pyrolyze at 225°–325° C and lignin pyrolysis is initiated between 250°–500° C. Pyrolysis releases a variety of low molecular weight gases such as carbon monoxide (CO) and methane (CH_4), as well as a complex mixture of high molecular weight organic compounds that will condense when cooled. These condensable compounds represent much of the smoke associated with smoldering fires. The amount and kinds of volatile compounds released during pyrolysis depend on the fuel and the heating rate of the fuel. Biomass fuels generally have more volatile matter than coal. Upon completion of pyrolysis, there remains a porous carbonaceous residue known as char.

Oxidation will proceed after pyrolysis if sufficient oxygen is in contact with the pyrolysis products. Oxidation of volatile products is manifested as flaming combustion, the phenomena usually associated with burning. The products of volatile combustion are ultimately water (H_20) and carbon dioxide (CO_2) if good combustion conditions are achieved (high temperature, turbulent mixing of fuel and air, and long residence time for fuel within the boiler). In the absence of good combustion conditions, a variety of noxious organic compounds can survive the combustion process or even be created within the

Figure 4.1

boiler. Char, on the other hand, is oxidized by solid-gas reactions at the surfaces and sometimes within the pores of char particles in what may be characterized as glowing combustion. Since char is primarily carbon with a small amount of mineral matter interspersed, the products of char combustion are mostly CO_2 and a small amount of CO.

A variety of biomass materials have proven suitable for direct combustion, including whole trees, wood chips, forestry residue, agricultural residue, pulp and paper refuse, food processing wastes, municipal solid waste, and straws and grasses. Selected heating values on a moisture-free, ash-free basis are given in Table 4.1. Obviously, the moisture content of these fuels as burned can greatly alter the effective heating value in direct combustion applications.

Table 4.1 Energy content of some selected biomass feedstocks (adapted from Milne [6].

Feedstock	Heating Value (Btu/lb)[a]	Total Alkali (lb/MM Btu)
Wood		
Pine chips	8,550	0.07
White oak	8,165	0.14
Hybrid poplar	8,178	0.46
Urban wood waste	8,174	0.46
Tree trimmings	8,144	0.73
Herbaceous		
Bagasse - washed	8,229	0.25
Wheat straw - average	7,978	3.97
Switch grass	7,741	1.97
Rice straw	6,486	3.80
Waste		
Refuse derived fuel (RDF)	5,473	—
Municipal solid waste (MSW)	4,500	—

[a]Moisture-free, ash-free, higher heating value basis.

Wood and wood wastes dominate the biomass-to-power market in the U.S. [3] and much of the rest of the world. However, a variety of agricultural wastes have been utilized through direct combustion in California [7], and Denmark has a number of commercial plants that burn straw [8].

Combustors are generally categorized as either grate-fired systems, suspension burners, or fluidized bed systems [5]. Recently, a whole-tree burner has been proposed for electrical utility steam raising and is under development by the Electric Power Research Institute [9]. To date, fluidized-bed combustors (FBC) and spreader-stoker-fired boilers have proven to be the most reliable technologies for biomass combustion in stand-alone units. Suspension burners have been used in smaller units up to 10 MW, but they have more limited applications [10]. Units designed for biomass firing generally require larger furnace volumes, compared to coal-fired boilers with similar steam output, in order to handle a higher fuel throughput per unit of energy output [10]. Biomass fuels range widely in physical and chemical characteristics. Fluidized beds, in general, and circulating fluidized-beds (CFB), in particular, are more tolerant of fuel variations than other traditional combustion methods [5].

Moisture, in principle, does not have to reduce the performance of a boiler. In practice, there are two reasons that fuel moisture degrades boiler performance. First, the energy required to vaporize fuel moisture can only be recovered if exhaust gases are cooled sufficiently to condense the water vapor in this gas. Although this procedure would result in very high thermal efficiencies for a boiler burning even very high moisture fuels, it is not commonly done in practice because the condensate is often corrosive to boiler tubes. Accordingly, most direct-combustion systems are penalized by moisture in the fuel. Second, high moisture fuels simply do not burn well because the process of fuel drying suppresses fuel temperature below that required for ignition. Water contents exceeding 30% are unacceptable in most boilers for this second reason. Fluidized-bed combustors, however, because of the enormous thermal mass associated with the hot bed material, can accept biomass with moisture content as high as 50%. However, even fluidized beds are penalized in thermal efficiency by the presence of this moisture.

A disadvantage of direct-combustion systems is their relatively low thermodynamic efficiency at the sizes of relevance to biomass power systems [11,12]. The best wood-fired power plants have heat rates exceeding 12,500 Btu of fuel for every kilowatt-hour (kWh) of electricity produced. In contrast, large, coal-fired power plants have heat rates of only 10,250 Btu/kWh. Some advanced technologies, such as integrated

gasification/combined cycle plants, to be discussed subsequently, appear to be better candidates than direct-combustion systems at the scales appropriate to biomass energy systems.

High heat rates not only imply high fuel costs but excessive acreage devoted to cultivation of biomass, possibly reducing the acreage available for growing more traditional food and fiber crops. For example, a 50-MW direct-fired power plant with a nominal heat rate of 12,500 Btu/kWh will require 65,000 acres for an annual fuel supply. In contrast, one of the advanced conversion technologies based on gas-turbine technology, with a heat rate of 10,200 Btu/kWh, would require only 53,000 acres for an annual fuel supply.

One particular problem associated with biomass fuels is the tendency for certain feedstocks to cause fouling, specifically those plant materials that contain high alkali (sodium and potassium) concentrations. Table 4.1 includes an entry for the alkali content of selected biomass feedstocks. Various methods to reduce this fouling are discussed in Milne [6] and Miles et al. [13]. It is generally recommended that total fuel (single or mix) alkali content be limited to less than 0.4–0.8 lb/MM Btu, which translates to only 5%–15% cofiring of biomass with coal. Also, furnace temperatures should be kept below 1,800° F to help prevent the buildup of alkali-containing mineral combinations known as eutectics. At higher temperatures, molten eutectics bind dirt and other particulates to form slag and fouling deposits [9].

Co-firing biomass with coal is receiving consideration despite relatively low fossil fuel prices. Biomass co-combustion offers the benefits of lowering sulfur emissions, conserving landfill space, and potentially reducing fuel costs [14]. In addition, the new-source performance standards (NSPS) for industrial boilers offers the incentive of a relaxed particulate standard for co-firing with at least 10% biomass fuel: 0.10 lb/MM Btu compared to 0.05 lb/MM Btu for a coal-fired boiler of 100 MM Btu/hr capacity [15]. Most major boiler/firing system vendors offer multifuel equipment and many coal-firing boilers can be modified at relatively low cost to accommodate co-firing with biomass.

The principal disadvantages of co-firing relate to the characteristics of biomass fuels. Because of the lower energy density and higher moisture content of biomass, the steam generating capacity of co-fired boilers is often reduced [14]. Biomass can also be difficult to obtain inexpensively and on long-term contracts. A special report on co-combustion in the July 1987 edition of *Power* magazine [15] provides a comprehensive list of sites that either have experience with biomass/fossil fuel co-combustion or are planning it, including 31 U.S. electric utilities.

The high volatility content of biomass compared to most bituminous coals suggests a possible niche market for biomass in a co-firing application designed to control NO_x emissions. In a process known as reburning, a coal-fired cyclone boiler can be retrofitted to burn part of its fuel, representing 10%-25% of total heat input, in a fuel-rich zone above the main burning zone of the furnace. The resulting free-radical chemistry reduces NO_x produced in the main burning zone to molecular nitrogen [16]. A variety of fuels have been used in the reburn zone, but the best performance occurs for fuels with high volatile matter content. For this reason, natural gas, ranging between $2-$5/MM Btu in Iowa, is the fuel of choice for the reburn zone. However, recent tests at the University of Utah have shown biomass, with its high volatile content, to be a promising reburn fuel [17]. At a cost of $2.50/MM Btu, biomass may be able to compete in some instances with high-value natural gas in this potential niche market.

There are many examples of power plants that are fueled exclusively with biomass. These plants all utilize waste materials for fuel and thus represent special niche markets in biomass energy. Nevertheless, they represent important case studies for future expansion of biomass power systems. These include the 34-MW Grayling Generating Station in remote north-central Michigan firing sawmill and forestry waste; the 47-MW Mecca Biomass Power Plant in Riverside County, southern California, firing wood chips and agricultural waste, the 21-MW Camden Resource Recovery Facility in Camden County, New Jersey, firing municipal solid waste, and the 60-MW Essex County Resource Recovery Facility in Newark, New Jersey, firing municipal solid waste. Case studies for these and other biomass-fired power plants can be found in recent issues of *Power* magazine.

There are a number of manufacturers who supply combustion equipment that is suitable for direct-firing biomass fuel (wood, in particular). These are listed below.

Combustion Power Co., Inc. (National Power Co.)
Men Park, California 94025 (415) 324-4744
(fluid bed boilers/dryers, high temperature gas cleanup)

Combustion Service & Equipment Co.
Pittsburgh, Pennsylvania 15209 (412) 821-8900
(boiler systems, multifuel, biomass)

Energy Products of Idaho (JP, Inc.)
Couer D'Alene, Idaho 83814 (208) 765-1611
(energy recovery systems, wood fuels)

G & S Mill, Inc.
Northborough, Massachusetts 01532 (508) 393-9266
(wood burning boilers and furnaces)

Geneco Services, Inc.
Dallas, Pennsylvania 18612 (717) 477-2124
(steam generation by solid fuel combustion)

Industrial Boiler Co., Inc.
Thomasville, Georgia 31799 (800) 841-1313
(multifuel boiler manufacture)

Riley Consolidated, Inc.
Worcester, Massachusetts 01615 (508) 852-7100
(steam generators, CFBs, wood/waste fuel)

Tampella Power Corp.
Marietta, Georgia (404) 984-8871
(turn-key systems, biomass fuels)

Wood Products, Inc. (Midwest)
DeKalb, Illinois 60115 (815) 756-7705
(wood waste-to-energy systems, boilers)

The capital and operating costs for direct-fired biomass power plants are relatively well known because of significant operating experience with these systems. The capital cost for a new plant ranges between $1,400 and $1,800 per kilowatt capacity [3,11]. Accordingly, a 50-MW biomass power plant based on direct-combustion would cost approximately $80 million. The cost of electricity depends on capital charges and operating expenses (including fuel costs) for the plant. In many parts of the United States, biomass

can be produced for about $42.00/dry ton, or about $2.50/million Btu (MM Btu). A target price of $2.00/MM Btu is expected to be reached by 2010 [3]. On the basis of the target price for biomass, the cost of production for direct-fired biomass power is about $0.06/kWh in 1990 dollars [3,10]. In comparison, some Iowa utilities are currently paying less than $1.00/MM Btu for delivered Powder River Basin subbituminous coal. Generation costs with this coal in large, coal-fired steam power plants can be as low as $0.02/kWh [18].

The cost of collecting large quantities of biomass can be significant since it is dispersed. Wood or other biomass resources must generally be produced within no more than a 50-mile radius of the power plant to be economical, given the high transportation costs of biomass [3]. Until dedicated biomass crops become competitive with coal, biomass power systems are expected to target biomass already collected for other reasons: wood waste from forestry products, wastes from food/industrial co-products, and MSW (municipal solid waste). MSW fuel costs can be offset by the alternative cost of disposal; the tipping fee may be more than $100/ton in congested urban areas [3].

Waste streams from direct-combustion systems include solid waste in the form of bottom ash and fly ash and airborne emissions from the exhaust stack. The solid waste is currently considered nonhazardous and can be landfilled. The combustion of woody biofuels results in a relatively minor amount of ash: typically 0.5%–2% by weight. Even when accounting for dirt collected during harvesting and processing, ash contents rarely exceed 3%–5% [5]. Agricultural residues typically have higher ash content than wood fuels—as high as 15%–20% for rice hulls and cotton gin trash, but typically 5% or less for most stalks, vines, and prunings [5].

Airborne emissions from the combustion of solid fuels include particulate matter; NO_x, SO_2, CO and organic emissions; and trace metals [5] that can differ significantly from emissions from coal combustors. A study of biomass combustion under conditions typical of the suspension-burning phase in a spreader-stoker-fired boiler of a 65-kW refractory-walled reactor shows maximum NO_x emissions for various fuels as follows [3]:

Fuel	**Maximum NO_x Emissions**
Douglas fir	0.32 lb/Btu
North Carolina peat	1.70 lb/Btu
Red alder	3.02 lb/Btu

The lower operating temperatures of fluidized bed boilers can greatly reduce the emissions of NO_x but cannot totally eliminate them because of the presence of "fuel nitrogen" in some biomass feedstocks. Processes, such as staged combustion and reburning developed for coal-fired boilers, can further reduce NO_x emissions from biomass-fired or co-fired boilers.

The very low sulfur content of biomass fuels compared to many coals have led to suggestions for co-firing biomass and coal as a means of reducing SO_2 emissions from direct-combustion power plants. However, many utilities have turned instead to low sulfur, subbituminous coal from the Powder River Basin of Wyoming, a compliance coal that can meet emission standards set by the Clean Air Act without resorting to exhaust gas scrubbers or other sulfur control technology. For these reasons, western coals are potent competitors of biomass fuels in the market for sulfur emission control strategies.

Western coal resembles biomass in many other respects. Western subbituminous coal and biomass both have higher volatile content and lower sulfur content than most bituminous coals, contain up to 30% moisture content, often require boiler derating if they are to be burned, and have problems with ash fouling due to high alkali content. Two of the major differences between these two fuels are the higher density and lower cost of western coal compared to biomass.

Emissions of carbon monoxide and volatile organic compounds (VOCs) can generally be controlled by proper design of direct-combustion systems. The higher volatile content of most biomass fuels compared to coal may require a larger freeboard space to assure complete combustion of these gaseous components.

In general, the ash from biomass fuels have modest concentrations of trace metals such as arsenic, cadmium, chromium, lead, and mercury. Trace metal concentration levels for the total fuel become very low when considering the relatively low ash content of most biofuels [5].

Combustion of solid waste involves unique environmental considerations compared to other biofuels. The variety of fuels that comprise solid waste prevents simple analysis in terms of arithmetic averages or blend results. Generally, however, all solid wastes contain significant quantities of chlorine (about 0.5% for MSW) and substantial quantities of heavy metals. Chlorinated organic compounds and metal emissions must be controlled [5].

Thermochemical Conversion

The three main categories of thermochemical conversion are pyrolysis, gasification, and direct-liquefaction. There is some confusion in the literature about the definitions of these various thermal upgrading processes. The following definitions, derived from Graham et al. [19], are included to distinguish these various processes.

Defined in its broadest sense, pyrolysis is the thermal decomposition of organic matter occurring in the absence of air or oxygen. Thermal decomposition in an oxygen deficient environment (that is, one in which less oxygen is present than required stoichiometrically for complete combustion) can also be considered to be true pyrolysis as long as the primary products of the reaction are solid or liquid.

Gasification describes the process in which oxygen-deficient thermal decomposition of organic matter yields noncondensable fuel or synthesis gases as the main reaction products. Gasification generally involves pyrolysis as well as combustion to provide heat for the endothermic pyrolysis reactions. However, indirectly heated gasification is often used to describe the process in which heat is brought from outside the reaction chamber to drive pyrolysis in the absence of combustion.

Liquefaction was historically linked to hydrogenation and other high-pressure thermal decomposition processes that employed reactive hydrogen or carbon monoxide carrier gases to produce a liquid fuel from organic matter at moderate temperatures (300°–400° C). More recently, liquefaction has been used to describe any thermochemical conversion process that primarily yields a liquid tar/oil product.

Thermal upgrading of biomass generally requires a heat input of approximately 10% of the heat of combustion of the dried biomass [20]. Each of the three thermochemical conversion processes is described in detail below.

Pyrolysis can be divided into two categories. Conventional pyrolysis is characterized by a slow feedstock heating rate (less than 10° C/s), low temperatures (less than 500° C) and relatively long gas and solids residence times (greater than 5 s for the gas; solids residence times can be minutes, hours, or days in duration). Tar and char are the primary products of this slow devolatilization and secondary coking and polymerization (recombination) reactions that occur after primary pyrolysis has taken place [19]. Pyrolytic gasification, on the other hand, describes any anaerobic pyrolysis process, fast or slow, that gives noncondensable synthesis gas or medium energy fuel gas as the primary product. Tar and char are viewed as undesirable byproducts [19].

Some amount of char is always formed during the process of pyrolysis. Carbonization is the name used to describe the pyrolytic process in which the amount of char is maximized [21]. Typical pyrolytic oil from biomass has a specific gravity of 1.3 and a composition consisting of 58% carbon, 7.6% hydrogen, and 33.4 % oxygen [20].

Although a number of schemes for utilizing pyrolytic reactors to process biomass have been proposed, none have achieved commercial status. Some hybrid pyrolysis/combustion systems for coal are being tested as part of the U.S. DOE Clean Coal program that may eventually have application to biomass. Purely pyrolytic systems will not be further discussed in this analysis.

Liquefaction can be accomplished directly or indirectly. Direct liquefaction involves rapid pyrolysis to produce liquid tars and oils and/or condensable organic vapors. Indirect liquefaction involves the use of catalysts to convert noncondensable gaseous products of pyrolysis or gasification into liquid products. Methanol synthesis is an example of indirect liquefaction and is discussed in a separate section. Direct liquefaction as a thermochemical conversion process is described here.

Flash pyrolysis (as contrasted with fast pyrolysis) describes the rapid, moderate temperature pyrolysis required for producing significant quantities of liquids. Flash pyrolysis heats the biomass at rates of 100°–10,000° C/s at moderate temperatures between 400°–600° C with the result that liquid tar/oil products are maximized at the expense of char and gas. Vapor residence times are normally less than 2 seconds [19].

Fast pyrolysis is differentiated from flash pyrolysis primarily with respect to temperature. The fuel is heated at 10°–100,000° C/s at temperatures exceeding 600° C and short vapor residence times (less than 0.5 s) to maximize the production of high-quality gases at the expense of char and condensable liquids [19].

The DOE National Renewable Laboratory has invested considerable research in direct liquefaction. However, commercial applications appear to be several years away, and these systems will not be discussed further.

Gasification has more potential for near-term commercial application than other thermochemical processes and will be the subject of the remaining discussion of thermochemical processes. Gasification is the transformation of a solid fuel into a gaseous energy carrier. The process of gasification falls between pyrolysis and complete combustion. The initial chemical reactions during combustion and those of gasification are very similar [22]. Some of the benefits of gasification compared to combustion include: more flexibility in terms of energy applications, more economical and thermodynamically

efficient at a small scale, and potentially lower environmental impact when combined with gas cleaning [22].

The general gasification process, illustrated in Figure 4.2, consists of several steps [23]: heating and drying, pyrolysis, partial oxidation, and chemical transformation of

Figure 4.2

volatiles and char to produce gas. Heating, drying, and pyrolysis are similar to the processes that occur during direct combustion. Biomass begins to decompose above 100° C. Between 250° C and 600° C, the main products are charcoal and a mixture of tar and variable quantities of methanol, acetic acid, acetone, and traces of other organic molecules. Oxygen is severely limited in the reactor, with the result that only enough oxidation of char and volatiles occurs to provide the heat necessary for pyrolysis and other endothermic chemical reactions. A well-designed gasifier will decompose high-molecular-weight organic compounds released during pyrolysis into low-molecular-weight, noncondensable compounds in a process referred to as tar cracking. Furthermore, char will participate in a series of endothermic reactions at temperatures above 800° C that upgrades this solid carbon into gaseous fuel constituents [20]:

$$C + CO_2 = 2CO$$

$$C + H_2O = CO + H_2$$

$$C + 2H_2 = CH_4$$

Above 400° C, the volume percent of hydrogen (H_2) and carbon monoxide (CO) steadily increases until they become almost the sole gaseous products at temperatures near 1000° C [21]. Steam injection and addition of catalysts to the reactor are sometimes used to improve these reaction yields.

The producer gas resulting from biomass gasification consists mainly of CO, H_2, N_2, CO_2, water vapor, and hydrocarbons. Gas composition varies widely with process conditions, gasifying agent, and reactor type [23]. The most widely applied reactors for gasification of biomass are the moving bed types and the fluidized bed types [23].

Moving bed reactors can be classified into three subtypes: countercurrent, cocurrent, and crosscurrent. Countercurrent moving bed gasifiers are simple in operation and yield a high-tar content gas with an exit temperature of about 400° C [23].

Cocurrent moving bed reactors pass pyrolysis products through the oxidation zone, yielding lower tar content and lower molecular weight gases such as CO and CH_4. The product gas leaves the gasifier at a temperature of about 700° C. A disadvantage of this type of reactor is that slagging or sintering of ash may occur due to the concentrated oxidation zone. Rotating ash grates or similar mechanisms can solve this problem. Higher

gas outlet temperature and lower burn-out of ash result in a lower efficiency compared to the countercurrent reactor [23].

Crosscurrent reactors produce gas with temperature and composition in between the values of the other moving-bed type gasifiers. This type of reactor has been used mainly with charcoal feedstock [23].

Fluidized bed gasifiers have a uniform high-temperature bed that produces a low-to-medium tar content gas with an outlet temperature of about 800° C. Benefits of this type of reactor are the ability to handle a wider variety of biomass feedstock and easy scale-up from pilot size. Disadvantages include the higher gas temperature, larger quantities of ash particles, and more complex control systems to maintain process conditions [23].

Moving bed reactors are generally used for biomass with lower moisture content and feed particle diameters between 10 mm and 100 mm. Fluidized bed reactors can generally tolerate higher moisture levels and are better suited to smaller feed diameters (1–10 mm) [23].

The fuel/air ratio is the single most important parameter for determining gasifier performance. Downdraft gasifiers can have better conversion efficiency and producer gas quality than fluidized bed gasifiers because they utilize a higher fuel/air ratio [24]. Fluidized bed gasifiers, on the other hand, can generally handle a wider range of biomass feedstocks with higher moisture content [23].

The product gas from thermochemical processing contains fine droplets of pyrolytic oils and tars. This medium energy gas is suitable for on-site uses without further processing. The upgrading of the gas to high energy "syn gas," or synthetic natural gas (SNG), or to a chemical feedstock for methanol production requires cleaning of the producer gas to remove impurities [21].

Generally, a water or oil scrubbing stage is used to remove the tars and oils present in producer gas. Scrubbing is often followed by a secondary cleaning operation such as electrostatic precipitation. Upgrading to syn gas for methanol production requires even further cleaning of producer gas to remove sulfur and certain hydrocarbons [21].

Upgrading medium energy content producer gas to synthetic natural gas, in which the principal product is methane, is accomplished by the exothermic reaction [21]:

$$CO + 3H_2 \rightarrow CH_4 + H_2O$$

The hydrogen content of the gas mixture is increased to the necessary level by the shift reaction:

$$CO + H_2O \rightarrow CO_2 + H_2$$

and employing a metallic catalyst [21]. Energy content of SNG is typically three times that of the medium energy producer gas.

When air is used as the oxygen source (gasifying agent), a large percentage of the product gas will be nitrogen. This decreases the thermal value of the gas and also renders it relatively unsuitable for further upgrading to SNG or methanol. The highest quality producer gases are manufactured in oxygen-blown gasifiers or indirectly heated gasifiers.

Biomass materials deemed suitable for gasification include wood chips, forestry residue, saw dust, whole trees, bagasse (sugar cane waste), rice husks, peat, black liquor (pulping residue), and MSW. Biomass feedstocks generally suited for gasification have a moisture content of about 30% by weight with an ash content of less than 2% by weight [23]. Preparation for thermal upgrading of biomass fuels generally involves drying and comminuting to a suitable particle size [20].

A major attraction of gasification is that it can be used for a wide variety of end uses. The producer gas can be used for process heat, electric power generation, or production of liquid fuels (in the form of methanol). In principle, it can be used as fuel in internal combustion engines, gas turbine engines, or fuel cells. It lends itself well to phased introduction of biomass energy systems. For these reasons, gasification has been proposed as the basis for "energy parks" that would provide a variety of energy products [25].

The most promising application of gasification technology in the near term is integrated gasification/gas turbine cycles for electric power production. Indeed, many of the current advances in gasification technology are driven by the recent emergence of gas turbines as the preferred technology for new generating capacity among utilities and independent power producers. The current low cost of natural gas makes gas turbine power cycles attractive for new generating capacity. However, when natural gas prices rise above $4/MM Btu, gasification plants will become attractive as alternative sources of gas [25].

Because gas turbines are so closely associated with gasification technology in many efforts to commercialize biomass power, gas turbine technology is discussed as part

of this section. Separate sections have been written for methanol production and fuel cells, both of which are also dependent on gasification technology.

There are two general classes of gas turbines for power generation: heavy-duty industrial turbines (designed for power generation) and lightweight aeroderivative gas turbines. Of the two, aeroderivatives offer higher efficiency and lower unit capital costs at the modest scales required for biomass fuels [26].

Gas turbines are not directly fired with biomass because ash particles and alkali would damage the turbine blades. However, if the biomass is first gasified and cleaned before subsequently firing it in the gas turbine combustor, biomass becomes a viable fuel for these systems [26].

Gasifier/gas turbine technologies are a major focal point of the recent drive for cleaner utilization of coal. Advancements in gasification and gas-stream cleanup that are supported by the DOE Clean Coal program are also expected to benefit biomass power technology. In many respects, coal and biomass resemble one another. In terms of gasification potential, biomass has some advantages, including higher volatility and reactivity and lower sulfur content.

Coal-fired gasifier development has focused largely on oxygen-blown gasifiers. Unfortunately, the high capital costs of oxygen plants, which can be justified for large power plants envisioned for coal, become prohibitively expensive for relatively small biomass power systems. Air-blown gasifiers greatly reduce the capital costs of the power project, but the heating value of the resulting producer gas may be too low for economical firing in gas-turbine engines. Indirectly heated gasifiers, in which the endothermic heat for pyrolysis is provided by an external heat source and thereby eliminates combustion, hold the promise of producing medium Btu gas at modest capital costs.

Integrated gasifer/gas-turbine systems are attractive for several reasons including their relative commercial readiness, the ability to construct small generating capacity units without being strongly influenced by economies of scale, and the expectation that they can generate electricity at the lowest cost of all possible biomass power options. Several variations of integrated gasifier/gas-turbine power systems are discussed in the paragraphs below.

The integrated gasification/combined cycle (IGCC) is the most energy efficient power-generating cycle on the market today. The majority of current coal gasification development projects implement IGCC technology. This cycle consists of a gasifier combined with two stages of power generation. The producer gas is fired in a heavy-duty

industrial gas turbine. The resulting hot exhaust gas stream enters a boiler that raises steam for a steam-turbine bottoming cycle. However, the strong economies of scale associated with steam-turbine cycles makes combined cycles unattractive candidates for biomass-to-energy systems, which are expected to be 50 MW or smaller in size [26].

Steam-injected gas turbines (STIG) are expected to be more economical than IGCC for biomass power systems because of the absence of the steam turbine bottoming cycle. Like the IGCC, a boiler recovers heat from the hot exhaust gas. However, steam not needed for process heat (cogeneration) is injected back into the gas turbine combustor, where it is heated to the turbine inlet temperature and contributes to mass flow through the gas turbine. This increased mass flow yields more power at improved thermodynamic efficiency [26].

The intercooled steam-injected gas turbine (ISTIG) is an advanced version of the STIG. This cycle further improves thermodynamic efficiency by cooling gas flow between several stages of compression (intercooling) [26].

Several companies supply biomass gasifiers commercially. Sur-Lite Corporation of Santa Fe Springs, California, Producers Rice Mill Energy of Stuttgart, Arizona; and Morbark Industries, Inc. of Winn, Michigan, build gasifiers with less than 4 MM Btu/h output. Gasifiers with outputs exceeding 80 MM Btu/h are built by Energy Products of Idaho in Coeur d'Alene; Halycon Associates of East Andover, New Hampshire; and SEI Inc. of Quincy, Florida.

Several near-commercial, gasification-based power systems are under development. Several of these are summarized below.

The Institute of Gas Technology in Chicago, Illinois, has developed the RENUGASâ process based on pressurized fluidized-bed gasification. The 12-ton/day process design unit (PDU), designed for pressures up to 500 psig, has been tested with a variety of biomass feedstocks under varying operating conditions. Biomass conversions of over 95% have been realized with most feedstocks tested [27].

On the basis of results from the PDU, a demonstration plant that will process 70 tons/day of bagasse is being constructed in Hawaii by the Pacific International Center for High Technology Research (PICHTR). Additional research is being conducted by Westinghouse Electric on a hot gas cleanup system for operation of the RENUGASâ gasifier with a gas turbine. A team led by Northern States Power in Minnesota is currently conducting a feasibility analysis of a 70–80-MW combined-cycle power plant using an air-blown RENUGASâ gasifier.

The Battelle Laboratories in Columbus, Ohio, has developed a two-zone circulating fluidized-bed, indirectly heated biomass gasification process. There are two separate reactors: a gasification reactor that produces medium Btu gas and residual char (typically 20% of feed material), and a combustion reactor that burns the char to provide gasification heat. Circulating sand between the two reactors accomplishes heat transfer. The 10-ton/day unit can handle a wide range of feedstocks without preparation. Recent experiments with energy plantation crops (hybrid poplar and switchgrass) have demonstrated good gas production rates, product gas composition, and heating values.

Ahlstrom/Pyropower, a Finnish manufacturer of combustion and gasification equipment, offers a commercial wood gasification process that produces a clean gas for use in paper mill lime kilns. They are actively developing pressurized, circulating fluidized bed technology for coal gasification. They recently developed a joint venture with Sydkraft AB, a Swedish utility, to produce a biomass power system based on a simplified IGCC. A full-scale IGCC biomass power plant has recently been constructed in Värnamo, Sweden.

Gotaverken/Studsvik, a Swedish manufacturer of combustion and gasification equipment, has developed a commercial CFB-gasifier for lime kiln applications. They have performed tests with the CFB-gasifier pilot plant coupled to a diesel engine.

Tampella Power Corporation is using the Institute of Gas Technology's U-gas process for coal, biomass, and peat gasification. A 10-MW pilot plant has been built at Tampere, Finland.

General Electric Corporation has demonstrated the feasibility of gasifying a variety of biomass feedstocks in an air-blown, pressurized gasifier pilot plant. Biomass tested included wood chips, bagasse, and switchgrass.

Texaco Corporation has demonstrated a coal-fueled IGCC plant known as the Cool Water project in Dagget, California. The 120-MW Cool Water demonstration plant, employing an oxygen-blown coal gasifier, operated from 1984 to 1989. The pressurized, entrained flow gasifier is fed a coal slurried in water and employs cold-gas cleanup. A new application of the process technology will permit the Cool Water facility to use a sewage sludge and bituminous coal fuel mixture. Texaco has demonstrated that under high pressures and temperatures, sewage sludge mixed with coal can be gasified to produce a clean synthesis gas [28].

Bechtel Group, Inc., and Florida Power & Light are studying the coproduction of electricity and methanol using Shell Oil Company dry-feed and Dow slurry-feed gasifiers, a General Electric advanced gas turbine, and liquid-phase methanol (LPMeOH) plant.

Several coal IGCC projects under the U.S. DOE Clean Coal Technology Program [29] are relevant to biomass power via gasification. These include the Toms Creek 107-MW IGCC demonstration project, the Piñon Pine 80-MW IGCC power project, and the Wabash River 265-MW coal gasification repowering project.

The economics of gasification power systems depends on the details of the conversion process. Table 4.1 defines several 50-MW gasification power systems used in the economic analysis summarized in Table 4.2 [30]. A 50-MW gasification/gas-turbine power plant would have total capital costs of between $62 million and $98 million. Production costs would range from $0.068/kWh to $0.091/kWh if fuel is available at an optimistic $1.50/MM Btu. This analysis suggests that the most favorable economics occur for a system consisting of atmospheric gasification with cold-gas cleanup and steam-inject gas turbines. A 50-MW gasification power plant would require between 49,000 acres and 65,000 acres to support annual fuel requirements. More optimistic analyses project biomass power from advanced systems to cost as little as $0.045/kWh [31].

Gasification is not necessarily an environmentally benign technology. Indeed, many of today's Superfund Cleanup sites are the legacy of widespread coal gasification at the turn of the century to produce "town gas" for lighting and heating. Gasification produces a gas mixture consisting mainly of carbon monoxide, carbon dioxide, methane, nitrogen, hydrogen, water vapor, and small amounts of organic vapors. If the gasifier is close-coupled to a gas burner, the potentially harmful organic vapors will be consumed in the burner. However, in many applications, the hot producer gas is intentionally or inadvertently cooled enough for the organic vapors to condense to what is generically termed "tar" [32].

Although scrubbing the product gas with oil or water can remove this contaminant, the resulting liquid waste stream usually must be treated. A small effluent stream, continuously fed to the sewer, should allow the microbacteriological system to prevent water pollution by tar (containing phenol and cresol). Batch emptying of effluent vessels is not acceptable without proper treatment [23].

Combustion of the producer gas results mainly in carbon dioxide and water vapor, along with some nitrous oxides. The emission of nitrous oxides in gas combustion is less than if the biomass feedstock was combusted directly. The Bioflow gasifier in Sweden reports emissions of NO_x less than 0.12 lb/MBtu [32]. Considerably less sulfur oxides are produced than in fossil fuel combustion [33]. Typical woody biomass contains 0.05 to

Table 4.1. Definition of 50-MW gasification power systems used in economic analysis.

System	Cycle	Gasification	Cleanup
1	Simple	Pressurized	Hot gas
2	Simple	Pressurized	Cold gas
3	Combined	Atmospheric	Cold gas
4	Combined	Pressurized	Cold gas
5	STIG	Pressurized	Cold gas
6	STIG	Atmospheric	Cold gas

Table 4.2. Economic analysis of 50-MW gasification power systems (adapted from Table 5 of Reference [30]).

System	Power Out MW	Heat Rate B/kWh	Capital Cost[a] $/kW	Power Cost[b] $/kWh	ROI[c] % of Capital	Payback (years)
1	23.6	10,095	1,415	0.070	17.7	5.4
2	25.3	11,913	1,320	0.070	17.8	5.4
3	26.9	11,203	1,962	0.091	8.93	9.2
4	34.0	8,947	1,552	0.072	16.4	5.8
5	32.6	9,669	1,457	0.070	17.4	5.0
6	38.1	12,353	1,246	0.068	18.8	4.1

[a]1990 dollars.

[b]Fuel Cost = $1.50/MM Btu.

[c]Avoided power revenue = $0.060/kWh.

0.20 wt% sulfur with a HHV of about 8500 Btu/lb. This translates to about 0.12 to 0.50 lb SO_2/MBtu [34]

Biochemical Conversion

Biochemical conversion includes fermentation of biomass to produce ethanol and anaerobic digestion of biomass to produce methane. Both of these technologies are widely employed commercially, although not always with the primary purpose of energy production.

Ethanol can be produced from sugar, starch, or cellulosic feedstocks. Conventional methods of ethanol production involve the fermentation and distillation of sugars and starch. Sugars, such as those from sugar cane or sweet sorghum, can be fermented directly, while starches must first be pretreated and then hydrolyzed to produce fermentable sugars. Cellulose-to-ethanol requires sophisticated enzymatic processes that are still in the experimental stage of development.

Ethanol synthesis from starch crops, illustrated schematically in Figure 4.3, consists of the following steps [23,35]. The process begins with a *pretreatment* process in which the biomass is milled, washed, and filtered. The result is a starch paste that undergoes a *saccharization* process. The step converts the starch paste to a liquid by treating it with steam. Acid or enzymatic hydrolization breaks down the liquefied starch into fermentable sugars. *Fermentation* is accomplished by the action of yeast or other fermenting bacteria. Sugars are converted directly to ethyl alcohol by microbial action. Batch fermentation limits yields to about 10% alcohol solution, whereas continuous fermentation results in somewhat higher yields before the yeast is rendered ineffective. *Distillation* separates the alcohol and water by boiling and condensation to yield a solution that is up to 94% ethyl alcohol. Production of anhydrous ethanol (99.8% purity) from this azetropic mixture requires a final, energy-intensive step. The distillation waste stream (stillage) is treated and used for animal feed or fertilizer. Sugar crops allow the pretreatment and saccharization steps to be bypassed, as shown schematically in Figure 4.3; thus fermentation can begin immediately.

The basic biochemical conversion of cellulosic materials into ethanol consists of a pretreatment step to separate the biomass into its three main components—cellulose, hemicellulose, and lignin [36]. The cellulose and hemicellulose components are saccharified via acid or enzymatic hydrolysis. The resulting sugars can then be fermented and distilled to produce ethanol. Glucose from cellulose is easily fermented but hydrolyzation is more difficult. Hemicellulose is more easily hydrolyzed but the primary sugar, xylose, is more difficult to ferment.

One promising enzymatic hydrolysis technique is known as simultaneous saccharification-fermentation (SSF) [37]. The SSF process is currently in pilot scale development. Prior to the SSF process, cellulosic materials are treated with dilute sulfuric acid to make the hemicellulose fraction soluble, leaving solid cellulose and lignin. Next, in SSF, the cellulose fraction is exposed to cellulase enzyme along with yeast, decomposing the cellulose to glucose that is then rapidly fermented to ethanol by the yeast present.

Figure 4.3

Currently, the SSF process takes about five days to produce a 5% aqueous solution of ethanol for recovery by distillation or other techniques.

Organic wastes contain mixed pentose (xylose) and hexose (glucose) sugars that require special microbes to ferment them all. Fermentation advancement investigations include yeast found in nature that increase the rate of fermentation and genetically engineered microbes to handle a variety of feedstocks [38].

Commercial production of ethanol is dominated by large facilities to capture economies of scale. The following companies are listed in Reference [39]. Archer Daniels Midland Company in Cedar Rapids and Clinton in Iowa and Decatur and Peoria in Illinois wet mill corn to produce 300 million gallons of ethanol per year in continuous fermentation operations. Pekin Energy in Pekin, Illinois, wet mills corn to produce 60 million gallons per year of ethanol in continuous fermentation operations. South Point Ethanol in South Point, Ohio, dry mills corn to produce 60 million gallons of ethanol per year in batch fermentation operations. A. E. Staley Manufacturing of Loudon, Tennessee, wet mills corn to produce 40 million gallons of ethanol per year in batch fermentation operations. Grain Processing Corporation in Muscatine, Iowa, both wet and dry mills corn to produce 50 to 200 million gallons of ethanol per year in batch fermentation operations.

A promising alternative to fermentation of corn starch is fermentation of sweet sorghum, which can potentially yield nearly 45% more ethanol per acre than corn [37]. A sugar solution is pressed directly from sorghum plant material and thus pretreatment and saccharization steps required for corn are avoided. However, the high moisture content of sweet sorghum precludes processing at a large, centralized plant where economies of scale can be captured.

Better utilization of feedstock would result if cellulose could be fermented to alcohol, but these processes have yet to be demonstrated commercially. Compared to corn, the use of cellulosic biomass has the potential to reduce feedstock costs by 50% or more [37]. If cellulose can be fermented, the list of suitable biomass feedstocks is enormous and includes sugarcane, corn, oats and other starchy grains; sweet sorghum, grasses, wood, forestry and agricultural wastes, and MSW.

Despite ethanol production experience by several large commercial operations, capital and operation costs can vary tremendously depending upon the specific process selected, the costs of feedstock and energy, and the management of production. Industrial-scale ethanol plants resemble petrochemical plants in that they are capital intensive and benefit from economies of scale [40]. A 5,000 barrel per day plant (about 70 million

gallons per year) will have a capital cost of about $2.00/gallon of annual capacity if built from the ground up, and thus will cost about $140 million. Smaller facilities can have capital costs as high as $3.00/gallon of annual capacity, and poorly designed facilities of any size may cost $4.00/gallon of annual capacity. On the other hand, ethanol plants that are built from existing facilities, such as refineries or chemical plants, or ethanol plants integrated into a larger industrial facility can have substantially lower capital costs, often in the range of $1.00 to $1.50/gallon of annual capacity.

Operating costs, particularly the net cost of corn for feedstock and the cost of energy for distillation, contribute substantially to the production cost of the ethanol fuel. Both of these costs can fluctuate substantially from year to year. Table 4.3 illustrates low and high ranges for cost factors that contribute to the production cost of ethanol [40], reported in 1990 dollars. The net cost of corn represents the difference in purchase price of raw corn and the selling price of fermentation by-products.

Table 4.3. Ranges of production cost factors for fuel ethanol (adapted from Reference [40]).

Factor	Low ($/gallon)	High ($/gallon)
Net corn costs	0.20	0.44
Fixed costs	0.36	0.71
Energy	0.10	0.33
Enzymes, yeast, and chemicals	0.03	0.11
Maintenance	0.11	0.17
Personnel	0.07	0.19
Total	0.87	1.95

Low end production costs are about $0.87/gallon. However, the heating value of ethanol is only 70% that of gasoline. Thus this production cost is equivalent to gasoline selling for $1.24/gallon before tax, transportation, or profit. In contrast, refinery prices for gasoline in 1990 were about $0.77/gallon.

Ethanol cost about $3.60/gallon in 1980 and about $1.27/gallon in 1990 [38]. Currently, the economics of fermentation are such that the commercial viability of ethanol is entirely dependent on government incentives in the form of a tax credit, currently $0.60

for each gallon of ethanol used for fuel blending [41]. Also, a strong market for fermentation by-products is a key factor in the economic viability of ethanol-from-corn [43]. Forecasts project that improvements in technology will reduce this cost to $0.60/gallon by 2000 [38]. However, Lynd et al. reported in a 1991 *Science* article that ethanol from cellulose will have to cost as little as $0.30 to $0.40/gallon to be competitive with gasoline prices anticipated in the year 2000 [42].

The amount of carbon dioxide production accompanying fermentation is the same as that previously removed from the atmosphere by photosynthesis during feedstock production (no net CO_2). However, other energy inputs are required for the whole feedstock-to-fuel cycle, including fertilizer production, vehicle fuels, and process energy. Depending on the sources of these required energy inputs, cellulose ethanol technology has a best-case scenario of no net CO_2 accumulation and a worst case scenario of CO_2 accumulation about one-fifth that of gasoline [42].

The stillage waste byproduct has a very high biological and chemical oxygen demand and can cause serious environmental problems if dumped. Recycling of the stillage as fertilizer is possible [33]. Airborne emissions, liquid effluents, and solid wastes from ethanol production processes can be addressed by conventional waste-treatment technology [42].

The combustion of pure ethanol produces water vapor, carbon dioxide, and small amounts of aldehydes and unburned alcohol vapor. The combustion of alcohol-gasoline blends generally has emissions with no major differences than those of pure gasoline combustion, though higher aldehyde and lower carbon monoxide and hydrocarbon levels are expected [33].

Anaerobic digestion, the other major biochemical conversion process, is the decomposition of organic waste by specific bacteria in an oxygen-free environment. The process, illustrated schematically in Figure 4.4, occurs in stages, each involving specific types of bacteria, to successively break down the organic matter into more and more basic components. The desired product of the anaerobic digestion process is biogas, comprised mainly of methane (CH_4) and carbon dioxide (CO_2) along with some trace gases. Most digestion systems produce biogas that is between 55% and 75% methane by volume. Some advanced systems report over 90% methane biogas production [43].

The complete anaerobic degradation of organic matter can be described as a three-stage process consisting of hydrolysis and fermentation, transitional acetogenic dehydrogenation, and methanogenesis [36, 43–44].

Figure 4.4

The first step of hydrolysis and fermentation, involves hydrolytic and fermentive bacteria that break down proteins, carbohydrates, and fats into simpler acids, alcohols, and neutral compounds. Hydrogen and carbon dioxide are also produced. This step is followed by transitional digestion through the action of acid-forming bacteria. Products of fermentation that are too complex for methane-forming bacteria to consume are further degraded in this step to acetate, hydrogen, and carbon dioxide. Furthermore, traces of oxygen remaining in the feedstock are consumed in this step, which benefits oxygen-sensitive, methane-forming bacteria. The final step, methanogenesis, converts acetate to methane by the action of methane-forming bacteria.

The biological conversion process of anaerobic digestion is applicable to a wide range of feedstocks with medium-to-high moisture content [45]. In order to speed up the natural process of anaerobic digestion, systems are usually designed to maintain optimal conditions for digesting a specific type of waste. Waste pretreatment, heating, mixing, nutrient addition, specialized bacteria addition, and pH adjustment are examples of some of the measures that can be taken to control digester performance [43].

Examples of anaerobic reactor designs include the simple batch reactor, plug-flow reactors, continuously stirred tank reactors (CSTR), upflow reactors, and two-tank reactor systems. The batch reactor is a single vessel design in which waste is added and removed in batches and all steps of the digestion process take place in the same environment [43]. More advanced reactor designs aim to improve waste contact with active bacteria and/or to separate and control the environments for acid-forming and methane-forming bacteria [43].

Relatively new two-tank reactor technology physically separates the acid formation and methane formation phases of digestion so that each takes place under the best possible conditions. Benefits of this technology are numerous: hydrolysis and acidification occur quicker than in conventional systems; the common problems of foaming in single-tank systems are reduced by the destruction of biochemical foaming agents before they reach the methane forming reactor; and the biogas produced is typically rich in methane [43].

Typical methane yield is 8,000 cubic feet/ton of MSW. The methane from large-scale digestion of MSW and sewage sludge (SS) was found to be of the same or better quantity and quality as laboratory scale tests [45]. Sewage sludge is most commonly used as feedstock for anaerobic digestors, but other suitable feedstocks include MSW, food processing wastes, agricultural wastes, Napier grass, kelp, bagasse, and water hyacinth.

In the United States, commercial anaerobic digestion applied to municipal and food processing wastes is primarily for the benefits of waste pretreatment and volume reduction. The energy values of the resulting biogas are secondary benefits.

Biogas systems can be designed for power generation with dedicated energy crops as the feedstock. With a conservative bioconversion efficiency of 60% and a methane yield of 9,000 cubic feet/ton of volatile solids added to a digester, roughly 25% of the yearly U.S. natural gas demand could be met by using only 10% of the prime U.S. cropland (assuming an unrealistically high yield of 20 dry tons/acre/year). Bioconversion efficiencies of over 90% and methane yields of 11,000–13,000 cubic feet/ton volatile solids have been achieved in a Gas Research Institute program [46].

Refuse converted to methane (RefCoM) is an integrated waste-to-energy technology that produces gas from MSW or sewage sludge. This process results in significant waste volume reduction (better than 90%), resource recovery in the form of recycled materials (aluminum and other metals, plastics, and glass), and renewable energy production, either as biogas (55% CH_4, 45% CO_2) or through upgrading to pipeline quality methane or conversion to electricity [45].

There are several examples of relatively large biogas production facilities in the midwestern United States [43]. The Municipal Treatment Plant in Sioux Center, Iowa, uses a continuously stirred tank reactor (CSTR) anaerobic digestion system designed by DeWild, Grant & Reckert, consulting engineers, to convert 10,000 gallons/day of sludge-rich wastewater into 15,000 cubic feet of biogas per month. This biogas is burned without treatment to provide heat for the digesters and to run a Waukesha methane-powered electric generator. The electricity produced powers the air-driven aerobic RBC system.

The Municipal Wastewater Treatment Plant in Dayton, Ohio, uses eight single tank, continuously stirred reactors in its anaerobic digestion system, which was designed by Black and Veatch engineers. The system produces 18 million cubic feet of 55% methane biogas per month from 300,000 gallons/day of sludge. All biogas produced is used for on-site electric generation. A specially designed cogeneration plant, designed by Malcolm Pirnie Inc., burns the filtered biogas in three 12-cylinder engines, driving electric generators that produce the equivalent of $35,000 worth of electricity per month.

OMI Inc./Ore-Ida Foods of Plover, Wisconsin, converts 1.7 million gallons/day of wastewater from a potato processing facility into 4 million cubic feet of 70% methane biogas per month. Two anaerobic reactor tanks, designed by Biothane Corporation of Camden, New Jersey, employ a generic upflow anaerobic sludge blanket design. The

system produces untreated biogas that is used on-site for space heating and cooking, saving $8,000/month on fuel bills.

The DuPage Treatment Plant in Woodridge, Illinois, pretreats waste sludge in a tank containing acid-forming bacteria. After hydrolysis and acidification, the feed enters the second tank where biogas is created. The system produces 3.6 million cubic feet of 70% methane biogas per month. The biogas is burned on-site to run the digester operations and provide facility heating.

The H&R Corp./Miles Inc. in Elkhart, Indiana, separates two million gallons/day of wastewater into secondary and organically concentrated prime wastes. The prime waste is pretreated to ensure a good feedstock for digestion. Two 107,000 cubic-foot reactors work in series, with the second retreating effluent form the first, to produce 12 million cubic feet/month of 65% methane biogas. The biogas is compressed and dried to remove water and sulfite pollution, then burned for on-site steam generation. Savings of about 7% of the plants' energy costs are realized by using the biogas.

Four different cases were considered for the RefCoM operation with total capital costs varying from $25 million to $49 million or $63,000 to $122,000 for each ton/day capacity [45]. These costs include feed preparation, digestion, gas cleanup, and residue processing with economic assumptions listed in Table 3 of Reference [45].

Gas costs of $5.35–$6.42/MM Btu in 1990 dollars have been realized with advanced conversion systems sized to deliver 1.08 trillion Btu/year by using water hyacinth and napier grass feedstocks [46]. Cost of natural gas in Iowa during 1994 has ranged between $2–$5/MM Btu. Delivered price, of course, depends strongly on local supply. Consumers remote from natural gas pipelines, for example, would pay a premium for liquefied petroleum. In niche markets, where the feedstock is inexpensive and natural gas is not available, biogas may be a viable alternative energy resource. However, it does not appear that conversion of dedicated energy crops to biogas will be economically feasible for the foreseeable future.

The organic content of wastes is typically reduced by more than 50% (by weight) through anaerobic digestion. Many systems achieve 80%–90% organic matter reduction [43]. Effluent from digestive reactors varies depending on the types of wastes they handle. Typical effluent treatments include solids separation for use as livestock bedding, water removal with remaining mulch used as a fertilizer, or solids recycling back to the digester [44]. With the majority of organic solids removed, residual wastewater is normally suitable for traditional municipal treatment.

A thorough analysis of the environmental impact of the four RefCoM operations versus mass burn and landfilling is summarized in Table 5 of Reference [45]. On-site air emissions ranged from 8,500 to 53,300 tons/year CO_2, 20–180 tons/year NO_x, 4–21 tons/year SO_2, and 2–7 tons/year particulate. All four cases had lower emissions than mass burn [45].

Indirect Liquefaction

A flow diagram for methanol production is illustrated in Figure 4.5. Methanol (CH_3OH) is produced by the reaction of CO and H_2 by the reaction [47]:

$$CO + 2H_2 \leftrightarrow CH_3OH - \text{heat}$$

This reaction proceeds exothermically under pressures in the range of 30-300 bar. Producer gas does not necessarily achieve the necessary $CO:H_2$ ratio, in which case a shift reaction is required, employing various metallic catalysts [48].

The ratio of CO to H_2 can be adjusted by adding steam in the CO-shift reactor via the reaction [49]:

$$CO + H_2O \leftrightarrow CO + H_2 - \text{heat}$$

Prior to methanol synthesis, CO_2 and H_2S must be removed. Some remaining CO_2 can be tolerated and is actually necessary, but H_2S is a catalyst inhibitor and has to be completely removed. Since wood and other biomass feedstocks generally contain very small amounts of sulfur, CO_2 and H_2S removal can be relatively inexpensive compared to a methanol from coal process [49]. Clean synthesis gas is reacted with a catalyst at elevated temperatures and pressures with a molar ratio of carbon monoxide to hydrogen of 1:2 [50].

Considerable heat is generated by the exothermic methanol synthesis reactions that must be efficiently removed. This heat removal is required for two reasons: low temperatures favor methanol formation and rising reactor temperatures can adversely affect the catalyst's life [28].

The two reactor types most often used today for methanol synthesis are the Imperial Chemical Industries (ICI) reactor and the Lurgi reactor [28]. Both of these reactors employ gas-phase methanol synthesis technology and differ mainly in their design and heat-removal ability. The ICI process uses packed beds of catalyst with cold synthesis gas

Figure 4.5

injected between them to control reactor temperature. The Lurgi process uses a catalyst packed in the tubes of a shell and a tube heat exchanger, and heat is removed by generating steam [28].

Under the U.S. DOE Clean Coal Technology Program, a liquid phase methanol process (LPMEOH) has been developed by Air Products. This process uses small catalyst particles suspended in a hydrocarbon liquid phase, such as mineral oil [28]. The process is more tolerant of varying feed gas composition and has better temperature control than conventional gas-phase technology, resulting in a higher conversion efficiency. Developed primarily for use with IGCC power plants, the LPMEOH process can be an efficient and economical option for repowering existing pulverized-coal-fired facilities [28].

The complex reactions involved in gasification or pyrolysis of carbonaceous material produce varying mixtures of gaseous products. Reactions that produce the most desirable products for methanol synthesis can be enhanced and accelerated by introducing catalysts in the gasification process. Early research at Pacific Northwest Laboratories (PNL) demonstrated that catalytic steam gasification of wood could produce yields of methanol synthesis gas sufficient to give an overall methanol yield of approximately 160 gal/ton dry wood [51].

The Hydrocarb process is a variation of the basic biomass-to-methanol technology. This process converts biomass and natural gas feedstocks to methanol and pure carbon. The synthesis of methanol from biomass via the Hydrocarb process occurs in three basic steps: hydrogenation of biomass to methane in a hydrogasification reactor (800° C, 50 atm), thermal decomposition of methane in a pyrolysis reactor (1,100° C, 50 atm), and catalytic synthesis of methanol in a methanol converter (260° C, 50 atm) [41].

Internal combustion engines can be designed to burn neat (100%) methanol or blends of gasoline and methanol, most commonly M85, which is a blend of 85% methanol and 15% gasoline. Methanol can also serve as feedstock for production of methyl tertiary butyl ether (MTBE), an octane-enhancing gasoline additive [50].

Very little in the way of economic evaluation of methanol from biomass has appeared in the literature. The most relevant study was performed in 1985 by Wagner et al. [52] who compared capital and operating costs of methanol from natural gas with the corresponding costs of methanol from coal. This evaluation was used as the basis for an economic evaluation of the costs of a methanol-from-biomass plant with the following modifications. First, capital costs for preparing syn gas from biomass were assumed to be similar to those for coal except an acid gas removal system was assumed unnecessary for

low-sulfur biomass feedstocks. Second, biomass feedstock was assumed to cost $42/ton, which is significantly higher than that for coal. Third, Wagner's 20,000 barrel/day plant was scaled back to a 5,000 barrel/day plant using scaling methodology described in the methodology section. Finally, all costs were adjusted to 1990 dollars.

Table 4.4 gives capital costs and operating costs for methanol from natural gas whereas Table 4.5 gives the comparable production costs for methanol from biomass. These comparisons make clear the economic barriers to liquid fuels from biomass. Capital investment for a 5,000 barrel/day plant that uses biomass for feedstock would be $380 million, which is 140% higher than for a comparable plant based on natural gas feedstock. Most of this additional expense is associated with the oxygen-blown gasification plant. Capital charges for this additional plant equipment results in significantly higher operating costs for the plant using biomass feedstock compared to the plant using natural gas feedstock—$2.16/gallon versus $1.06/gallon in 1990 dollars.

Economies of scale would reduce the price of methanol from biomass to $1.43 for a 20,000 barrel/day plant. Nevertheless, since the heating value of methanol is only 57% that of gasoline, the production cost from this large plant is still equivalent to gasoline selling for $2.52/gallon. Refinery prices per gasoline in 1990 were about $0.77/gallon. These numbers suggest that methanol will not be produced from either biomass or natural gas for the foreseeable future.

Table 4.4. Capital and operating costs for a 5,000 barrel/day methanol-from-natural gas plant (1990 dollars).

	Capital Costs $ millions		Operating Costs $/gallon
Reforming	45	Nat. gas ($4/MM Btu)	0.353
Methanol synthesis	41	Utilities	0.023
Distillation	4	Catalysts	0.007
Site, other	41	Fixed costs	0.067
Working capital	24	Capital charges	0.600
Startup costs	3		
Total	158	Total	1.050

Table 4.5. Capital and operating costs for a 5,000 barrel/day methanol-from-biomass plant (1990 dollars).

	Capital Costs $ millions		Operating Costs $/gallon
Biomass handling	21	Biomass($2.50/MM Btu)	0.208
Oxygen plant	83	Utilities	0.001
Gasification	79	Catalysts	0.009
Shift reactor	6	Ash disposal	0.001
Methanol synthesis	40	Fixed costs	0.219
Site, other	102	Capital charges	1.720
Working capital	42		
Startup costs	7		
Total	380	Total	2.158

These estimates on the cost of methanol from biomass are based on conceptual processes only, with considerable variation in feedstock costs, methods of financing, process flowsheets, and plant sizes. More optimistic analyses than presented here suggest that on the basis of current laboratory technology, commercial production of methanol from biomass may be as low as $0.75/gallon. The DOE's methanol from biomass program has set a goal of $0.55/gallon ($8.30/MM Btu) based on feedstock cost of $2.00/MM Btu [46]. Yields of about 120 gallons/ton of feedstock appear necessary for commercial operation. On the basis of this yield a 5,000 barrel/day plant would require 116,000 acres for annual feedstock supply.

Biomass containing 0.18% sulfur will yield on the order of 300 ppm H_2S in the gasification process. The methanol converter of the Hydrocarb Process requires less than 5 ppm H_2S. Sulfur can be removed during biomass gasification by adding a H_2S sorbent with the feedstock [41]. Char and tar is produced in the gasification process. Scrubbing waste streams will contain tars, oils, SO_2, and other contaminants removed during gas cleanup.

Physical Extraction (Biodiesel)

In the early 1980s the U.S. Department of Agriculture conducted extensive research into the use of vegetable oils as fuel. The research showed that vegetable oils such as corn

oil, cottonseed oil, rapeseed oil, etc., could be burned in preheated engines, but their high viscosity (20 times that of diesel) would lead to coking of the injectors and rings [53].

The methyl or ethyl esters of vegetable oils make excellent diesel fuel without the viscosity problems associated with straight vegetable oil. Biodiesel is the generic name given to these vegetable oil esters [53]. A flow diagram for the production of biodiesel from oil seed is illustrated in Figure 4.6.

Biodiesel is made by a process called transesterification. Transesterification which involves reactions between methanol or ethanol with triglycerides to produce the ester fuels and glycerol. This process cleaves the oil/fat molecule into three parts and removes the glycerin. Oil cleanup is required before the reaction to remove any water (and/or food debris in waste oils) [53].

The transesterification reaction between methanol (MeOH) and a tryglyceride $Gl(FA)_3$ is represented by

$$Gl(FA)_3 + 3\ MeOH \rightarrow 3\ MeFA + Gl(OH)_3$$

where $Gl(OH)_3$ is glycerol and FA is a fatty acid [53].

Commercially this process is most often catalyzed by a base such as NaOH or KOH dissolved in a 50% excess of methanol. The reaction proceeds rapidly to completion at room temperature in about an hour. Small amounts of soap are produced by the reaction of lye with fatty acids. Upon completion, the glycerol and soap settle out and can be easily removed [53].

Waste oils or tallow (white or yellow grease) can also be converted to biodiesel using a similar process. The 10% free fatty acids (FFAs) in the waste oil will react with the catalyst and must be removed during or before the transesterification reaction [53].

The heat of combustion of biodiesel is within 95% by weight of conventional diesel. Because they burn more efficiently, they have essentially the same fuel value as diesel [53]. Suitable feedstocks include soybean, sunflower, cottonseed, corn, groundnut (peanut), safflower, rapeseed, waste cooking oils, and animal fats. Properties of some of the resulting pure ester oils are given in Table 4.6. Feedstock costs range from \$2.00–\$3.00/gallon for vegetable oils to \$0.60–\$1.00/gallon for waste fats [53].

Biodiesel can be used in unmodified diesel engines with no excess wear or operational problems. In over 100,000 km of tests using soybean oil methyl esters in light

Figure 4.6

Table 4.6. Properties of some pure ester fuels (from Table 3 of Reference [53]).

Material	Specific Gravity @ 21° C	Viscosity @ 21° C (centipose)	Higher Heating Value (MJ/kg)
No. 2 diesel fuel	0.845	3.80	45.31
Palm Oil			
methyl ester	0.882	9.13	39.58
ethyl ester	0.870	6.98	38.75
Sunflower oil			
methyl ester	0.892	7.93	39.17
ethyl ester	0.873	5.75	38.93

and heavy trucks, the Volkswagen company of Brazil found few significant problems other than more frequent oil changes (required because of ester fuel buildup in the crankcase) [53].

Another method of processing vegetable oils to a fuel better suited for use in unmodified diesel engines is hydroprocessing. The Saskatchewan Research Council (SRC) developed and patented a hydroprocess that converts a wide range of plant oils to diesel fuel additives [54]. This process includes several reactions including hydrocracking (breaking apart large molecules), hydrotreating (removal of oxygen) by using conventional hydrotreating catalysts, and hydrogenation (saturation of double bonds) [54]. Yields for this process are summarized in Table 4.7.

An economic comparison of various feedstocks has been made on the basis of a model biodiesel plant [55]. The model is a 500,000 gallon biodiesel processing facility operated as a cooperative. The facility is installed in an existing grain handling facility with plant equipment costs being the primary source of capital costs. A complete list of assumptions used in the analysis is found in Reference [55]. The results of this analysis are summarized in Table 4.8.

Soybeans seem to be the feedstock that provides the lowest biodiesel cost. However, much of the higher costs for the other feedstocks are due to underutilization of the extrusion and pressing equipment [55]. A better comparison is made according to how much of the pressing capacity is actually used. With the costs per gallon for each of the feedstocks with the appropriate amount of pressing and extrusion capital costs allocated and

Table 4.7. Yield summary of vegetable oil products of the SRC process (from Table 1 of Reference [54]).

	Soybean Oil	Sample Canola	Green Canola	No. 1 Canola	Palm Oil
Catalyst	Co-Mo	Co-Mo	Co-Mo	Ni-Mo	Co-Mo
Gas (wt% feed)	12.7	13.6	13.6	13.9	11.3
Water (wt% feed)	8.8	11.2	7.2	7.6	8.7
Naptha (wt% feed)	2.3	-----	4.9	2.6	2.0
Diesel (wt% feed)	77.4	74.5	70.1	81.1	71.1
Residue (wt% feed)	3.4	8.2	7.5	0.9	9.5

Table 4.8. Model biodiesel plant cost comparisons [from Table 1 of Reference [55]—Economic Comparisons of Multiple Feedstocks].

	Scenario I	Scenario II	Scenario III	Scenario IV
Percent soybeans	97%	0%	0%	0%
Percent tallow	0%	0%	0%	100%
Percent canola	3%	100%	0%	0%
Percent sunflower	0%	0%	100%	0%
Biodiesel cost per gallon	$1.26	$1.58	$2.48	$1.83
Capital costs as % of total cost	8%	19%	17%	35%
Percent press capacity used	100%	38%	38%	0%

given no federal support for the other feedstocks, soybeans would be the preferred feedstock for use in the community-based model biodiesel plant [55]. A primary factor in this cost analysis is the value of meal coproducts of the process. Soybeans were valued at $5.60/bu, canola @ $4.25/bu, and sunflowers @ $0.11/lb, making canola the least-cost feedstock on a per pound basis. Soybean meal (44% protein) is valued at $220/ton, canola meal (38% protein) is valued at $190/ton, and sunflower meal (28% protein) is valued at $140/ton, giving soybeans the lower cost of production per gallon of biodiesel [55]. However, at a cost of $1.26/gallon, biodiesel is not competitive with conventional diesel, which sold for $0.73/gallon in 1990.

Table 4.9 shows the cost analysis of a conceptual 7-million-gallon/year biodiesel plant using the SRC hydroprocess. Four production scenarios, along with both low and high feedstock costs, comprise the eight cases [54].

Table 4.9. Capital and operating costs (in 1990 U.S. dollars) of a 7-million gallon/year biodiesel plant based on the SRC hydroprocess (from Table 3 of Reference [54]).

Case[a]	Capital Investment ($MM)	Operating Base Cost ($MM/yr)	Feedstock Cost ($MM/yr)	Total Cost ($MM/yr)
I-A	19.9	2.8	1.77	4.59
I-B	19.9	2.8	2.22	5.04
II-A	10.0	1.3	2.22	3.53
II-B	10.0	1.3	3.33	4.64
III-A	6.3	1.0	2.22	3.25
III-B	6.3	1.0	3.33	4.36
IV-A	2.6	1.9	2.22	4.10
IV-B	2.6	1.9	3.33	5.21

[a]I = stand alone, grassroots hydrotreating facility; II = new conversion unit, existing refinery or chemical plant; III = additional hydroprocessing unit in an existing refinery; IV = biomass oil converted in an existing hydrotreating unit; A = low feedstock cost; B = high feedstock cost.

A dated but very comprehensive source on vegetable oil production is Reference [56]. This source gives a good description of the factors involved in developing and operating a vegetable oil facility with detailed economic case studies that should only need to be adjusted for inflation to bring them up-to-date.

The transesterification reaction takes place at room temperature or slightly above. No significant energy inputs other than transportation and handling requirements are needed for this conversion process. However, harvesting, transporting, and processing the feedstock to oil need to be considered in terms of energy requirements and resulting environmental impacts.

The main byproducts of the transesterification reaction are glycerol and soap. The glycerol can be sold to reduce the conversion cost. A coproduct of the oil extraction process is a valuable meal sold for livestock feed. The composition of the effluent from a

vegetable oil factory is given in Table 4.10 [57] to give some idea of the potential wastestreams that might be generated from large-scale biodiesel production.

Biodiesel has the potential to burn with fewer emissions than conventional diesel fuel. All studies to date have shown that particulate, CO, hydrocarbons, SO_2, and CO_2 emissions are reduced with biodiesel either in blends or neat [53]. A test by the Denver Regional Transportation District using biodiesel from waste vegetable oil in a diesel bus showed a dramatic reduction of visible smoke on acceleration with no significant differences in performance. The exhaust smoke opacity was tested and found to be reduced to 60% by a 30% biodiesel blend and to 26% of the conventional diesel value by 100% biodiesel [54].

Electrochemical Conversion

Fuel cells convert chemical energy of fuels directly into electricity without combustion. They are similar to batteries except that they are continuously supplied with fuel so they never become discharged. A simplified flow diagram for fuel cell operation is shown in Figure 4.7. Fuel energy is converted to electricity through flameless oxidation, which takes place at electrodes separated by an electrolyte [58]. The only by-products of this electrochemical process are water and carbon dioxide, and, because of the higher efficiency of fuel use, the amount of CO_2 produced is less per kilowatt-hour than that produced by a combustion-based system [58].

Current fuel cell designs use liquid electrolytes. The most commercially developed fuel cell uses phosphoric acid as the electrolyte and operates at about 200° C. Another liquid fuel cell features a molten carbonate electrolyte. Operating at about 650° C, molten carbonate fuel cells can achieve higher generating efficiency by internally reforming hydrocarbon fuel [58].

Fuel cells can convert up to 80% of the energy from the supply fuels into usable electric power and heat. Current phosphoric acid fuel cells (PAFC) have a 41% electrical conversion efficiency on a high-heating value basis. In the near future, 46% electrical conversion efficiencies for PAFC will be possible on the basis of currently known science and engineering. The Electric Power Research Institute has estimated that advanced molten carbonate fuel cells (MCFC) may achieve electric efficiencies greater than 60% [59]. Fuel cell efficiency is largely independent of size; high fuel-use efficiencies can be maintained even when operated at half their rated capacities [59].

Figure 4.7

Table 4.10. Undiluted vegetable oil factory effluent analysis from Table 1 of Reference [57].

	Characteristic	Value in mg/liter (except pH and where noted)
1	pH	9.5
2	Suspended solids	
	Fixed solids	280.0
	Volatile solids	110.0
3	Dissolved solids	
	Fixed solids	380.0
	Volatile solids	490.0
	Total volatile solids	**600.0**
4	Ammoniacal N	3.0
5	Albuminoid N	2.9
6	Nitrates as N	Traces
7	Dissolved oxygen (DO)	2.3
8	Biochemical O_2 demand (BOD 5 days at 20° C)	29.0
9	Chemical O_2 demand (COD)	392.0
10	Oil (in g/gallon)	10.5
11	Chloride	205.0
12	Phosphate as P	0.58
13	Phenolic compounds as phenol	29.8
14	Cyanide as Cn	None
15	Sulfide as S	None
16	Sulfate as SO_4	658.4
17	Insecticides	None
18	Total residual chlorine as Cl	None
19	Fluoride as F	0.50
20	Boron as B	None
21	Arsenic as A	None
22	Barium as Ba	None
23	Cadmium as Cd	None
24	Sodium as Na	612.5
25	Potassium as K	25.0
26	Calcium as Ca + magnesium as Mg	18.4
27	Carbonate as CO_3	None
28	Bicarbonate as HCO_3	15.9
29	Electrical conductivity (in cm/mhos)	28.0

Current technology liquid electrolyte fuel cells are relatively expensive to build and the corrosive liquids used in them reduce expected service life. A new generation solid oxide fuel cell (SOFC) developed by Westinghouse Electric Corporation is currently being tested. The solid electrolyte used in SOFCs allows for a simpler, less expensive design and longer expected life [58].

Power stations utilizing fuel cells located close to loads can reduce costly transmission lines and transmission losses and can minimize transmission line dependence in joint power supply arrangements [59]. Fuel cells are also better suited to cogeneration—its ratio of electric to thermal output is approximately 1.0 compared to a gas turbine's ratio of about 0.5 [59].

Capital costs for molten carbonate fuel cells are expected to be $1500/kW at the time of market entry but decrease to about $1000/kW for a commercially-mature unit [60]. The cost of electricity from a mature unit operating on natural gas is projected to be $0.049 to $0.085 per kWh [60]. More attractive economics result if less expensive fuel is available. The International Fuel Cells Corporation (IFC) has conducted research into the commercial development of fuel cell energy recovery from landfills [61]. The cost of electricity generated from landfill gas using mature fuel cell technology is expected to be comparable to that for an internal combustion engine/electric generator set, i.e., about $0.05/kWh. Addition of exhaust gas cleanup for the internal combustion engine system, however, is expected to add as much as $0.03/kWh, making fuel cells the preferred approach for this niche market.

Water is produced as a byproduct of the electrochemical reaction of the fuel cell. Because of this, little if any external water is required for fuel cell plant operations. The wastewater discharge from fuel cell systems is much lower and of better quality than conventional fossil-fueled plants, and problems associated with thermal discharges are nearly eliminated [59].

CONCLUSIONS

Six types of processes were evaluated for the conversion of biomass into useful energy: direct combustion, thermochemical conversion, biochemical conversion, indirect liquefaction, physical extraction, and electrochemical conversion. This analysis has focused on technologies appropriate to a size somewhere between the on-farm alternative energy technologies of the late seventies and early eighties and the large, fossil-fueled

power plants of centralized electric utilities. Constraints imposed by economies of scale and limits on transporting biomass suggest a focus on biomass power plants of about 50-MW electrical generating capacity and liquid fuel production facilities of about 5,000 barrels/day.

Of the biomass power options, direct-combustion is probably the best developed and closely resembles the steam power cycles of most coal-fired power plants. However, in the size range of 50-MW electric generating capacity appropriate to biomass applications, these plants are capital intensive and relatively inefficient (that is, they demand excessive heat inputs per kilowatt-hour of electricity generated). Co-firing biomass and coal in existing steam power plants is an attractive option for increasing biomass power generating capacity. However, the availability of inexpensive, low-sulfur western coal makes it difficult to justify co-firing with biomass as a means of sulfur emission control. Western subbituminous coals, which resemble biomass fuel in many important respects, have a delivered cost in Iowa as low as $1.00/MM Btu compared to $2.85/MM Btu or more for dedicated biomass crops. Substitution of biomass for natural gas as a reburning fuel in NO_x control technology is a niche market in direct-combustion systems worth further investigation.

Of the several options for thermochemical conversion of biomass, air-blown gasification combined with gas-turbine power generation has the best near-term prospects. Integrated gasifer/gas turbine power systems are attractive for several reasons including their relative commercial readiness, the ability to construct small generating capacity units without being adversely affected by economies of scale, and the expectation that they can generate electricity at the lowest cost of all possible biomass power options. A 50-MW plant based on one version of this technology, the steam-inject gas turbine (STIG) with atmospheric gasification and cold-gas cleanup, would cost $62 million. If biomass could be purchased at $1.50/MM Btu, the cost of electricity would be about $0.068/kWh. In comparison, many coal-fired steam plants are generating electricity in Iowa at about $0.02/kWh. Nevertheless, if a new electric capacity was to be added to Iowa, gas-turbine technology, firing either natural gas or biomass, would be among the most attractive options for utilizing these fuels.

Fermentation of starch to ethanol, like direct-combustion, is a commercially mature technology. A well-designed new plant producing 5,000 barrels/day would cost about $140 million. The production cost would be on the order of $0.87/gallon. Since the heating value of ethanol is only 70% that of gasoline, this production cost for ethanol is

equivalent to gasoline selling for $1.24 before tax, transportation, and profit. Obviously, ethanol is not currently competitive with gasoline without government subsidies.

It is expected that advanced fermentation technology will be able to convert cellulose to ethanol, which would allow less expensive feedstocks to be used in alcohol production. However, it is not clear at this time whether cheaper feedstock prices would be offset by higher capital and operating costs for this new process.

Anaerobic digestion is also a mature technology and is widely used as a waste reduction process with energy production a secondary consideration. Methane from digestion is estimated to cost $5 to $6/MM Btu compared to market prices in Iowa for natural gas ranging between $2 to $5/MM Btu. Digestion well serves a niche market but it seems uncertain that it will ever be used to process dedicated biomass crops.

The technology exists to produce methanol from biomass, although virtually no commercial experience exists for this process. On the basis of data from coal gasification and production of methanol from natural gas, the cost of methanol from biomass can be estimated. A 5,000-barrel/day plant would cost $380 million, significantly more than an ethanol plant of comparable size. With biomass feedstock costing $2.00/MM Btu, the cost of producing methanol would be $2.16/gallon. Methanol-from-biomass does not appear competitive with gasoline or ethanol for the immediate future.

The best scenario for producing biodiesel from soybeans is production costs of $1.26/gallon for a 500,000 gallon/year facility. This price is not competitive with current market prices for diesel fuel.

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Chapter 5

Existing Infrastructure in Iowa Relevant to Biomass Energy Systems

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CHAPTER 5. EXISTING INFRASTRUCTURE IN IOWA RELEVANT TO BIOMASS ENERGY SYSTEMS

INTRODUCTION

Adoption of large-scale biomass-to-energy systems will be accelerated if suitable infrastructure already exists within the state to support these systems. Infrastructure includes transportation networks to move biomass to conversion facilities or biomass-derived fuels to markets and conversion facilities that presently use of could be retrofitted to use biomass as feedstock.

Transportation infrastructure includes roads, rails, waterways, and pipeline networks. Also important to this infrastructure are commercial trucking firms and large storage facilities. Evaluation of transportation infrastructure includes calculation of the number and kinds of trucks that would be required to supply biomass-to-energy systems.

Energy conversion infrastructure in Iowa consists primarily of fossil-fueled electric power plants. Power plants are subdivided into systems based on steam turbines (mostly coal-fired), gas turbines (mostly natural gas-fired), and internal combustion engines (No. 2 fuel-oil-fired). However, there are also a few facilities that consume biomass fuels to produce gaseous or liquid fuels, process heat, or electric power.

METHODOLOGY

Several methodologies were employed to survey existing infrastructure that might support biomass energy systems. For example, a wide and thorough search and review of the existing literature on biomass production and conversion systems was done. In this process, researchers at several national and regional institutions involved in biomass research were consulted. From these sources assessments of the transportation requirements for certain biomass-to-energy systems were made. Also, using Iowa Department of Transportation data, potential storage and transportation nodes were identified. Moreover, using U.S. Department of Commerce data, the researchers conducted a thorough survey of existing commercial trucking firms in Iowa.

Calculation of transportation demands by biomass-to-energy systems required several assumptions about feedstock properties and the conversion processes. Table 5.1 lists bulk densities, moisture content, and heating value for three potential biomass

Table 5.1. Feedstock properties assumed in transportation evaluations.

Feedstock	Bulk Density (lb/ft^3)	Lower Heating Value (Btu/lb)	Moisture Content (%)
Switchgrass bales	14.5	7,741	30
Hybrid poplar logs	34.0	8,178	50
Hybrid poplar chips	20.0	8,178	30

plantation crops: switchgrass bales, hybrid poplar logs, and hybrid poplar wood chips. Four conversion plants were considered: a 50-MW steam turbine electric power plant with 28% thermal efficiency and 80% availability factor; a 50-MW gasification/gas-turbine electric power plant with 24.8% thermal efficiency and 80% availability factor; a 5,000 barrel/day biomass-to-ethanol plant, and a 5,000 barrel/day biomass-to-methanol plant.

Table 5.2 lists the dimensions for various trucks from which the hauling capacity can be computed. This information was provided by trailer suppliers or through conversations with truck and trailer suppliers. Tables 5.3–5.6 were constructed by using this hauling data plus other data from a variety of sources. For each biomass crop, researchers estimated the daily number of trips required by using both the weight limit or volume as the single trip haulage rate and the daily feedstock demand of the conversion facilities. The straight body trucks come in lengths ranging from 10 ft–24 ft. The 20 ft–24 ft length trailers generally ride on the tandem axle trucks. The 10 ft–18 ft trailers generally ride on the single axle trucks. Several different sizes have been selected to show

Table 5.2. Hauling capacity of various trucks.

Truck Type	Approximate Size
Trailer, typical hopper style	43′ × 96″ × 68″
Flat bed truck	14′ to 28′ length
Small 2 axle, double rear axle straight truck	22′ × 40″ × 92.25″
Large 2 axle, double rear axle straight truck	22′ × 52″ × 92.25″
Small 1 axle A, single rear axle straight truck	12′ × 40″ × 92.25″
Large 1 axle A, single rear axle straight truck	14′ × 40″ × 92.25″
Small 1 axle B, single rear axle straight truck	12′ × 52″ × 92.25″
Large 1 axle B, single rear axle straight truck	14′ × 52″ × 92.25″

the range of number of trips/day that might be made to haul biomass to a conversion facility. All of these sizes are common in Iowa.

RESULTS OF EVALUATION

Transportation Infrastructure

Because of the relatively small geographical area in which a biomass-to-energy system will function, road transport will likely be the principle means of transporting biomass feedstock. However, some consideration is given to rail and waterways in this report because rail and water transport are viable means of transporting biomass feedstock if the production and conversion sites are geographically situated so as to take advantage of those modes of transportation.

Iowa's transportation infrastructure serves one of the most productive agricultural states in the United States. The state has an extensive road and rail network as well as a developed waterway network on both the Mississippi and Missouri Rivers. Commercial trucking firms are ubiquitous, and much of Iowa's agricultural produce is hauled by privately owned trucks, tractors, and wagons. Among states in the United States, Iowa is tenth in total miles of highways and streets. There is little doubt that the road, rail, and waterway network in Iowa could serve a biomass production and conversion system.

Roads

The major objective of the Iowa Department of Transportation is to support the economic development of the state. Toward that end, the commercial and industrial network improvement and planning policy was adopted in 1991. This network is composed of 2,330 miles of state roads well distributed throughout the state. This network will receive a significant amount of primary construction funding resources over the next twenty years. No less than $30 million a year will be spent to improve this network. Over the next five years, the Iowa State Legislature has earmarked over $150 million per year. Improvements will focus on the development of long corridors (60 to 80 miles). The commitment of the Iowa Department of Transportation to improving the transportation infrastructure bodes well for the development of biomass-to-energy systems in Iowa among other things [1].

Iowa's roads are governed by the state, counties and municipalities. There are 10,106 miles of state highways, composing 9% of the total street and highway mileage in the state. These roads support 60.4% of the state's vehicle miles and 86.2% of heavy truck travel. (Included in these figures is Iowa's interstate highway system which has 762 miles supporting 34% of the total vehicle miles and 54.3% of total heavy truck traffic.) The state and interstate systems will provide excellent transportation support for biomass-to-energy systems if production and conversion sites can be located to take advantage of them [2].

County roads total 89,453 miles making up 79.6% of all road mileage in the state. These roads support 17.4% of the state's vehicle miles and 11.5% of the heavy truck traffic. Not all of Iowa's county roads are paved. However, heavy trucks (50,000 pound maximum payload) access rural farms and distribution points by using this network of roads [1]. However, seasonal limitations to using some roads are possible—spring, for example, is a time when ground wetness can negatively affect gravel road traffic. Also, access to many of these roads depends on the system of rural bridges in Iowa. Damaged bridges can present problems for rural commercial traffic. The Iowa Department of Motor Vehicles releases reports on embargoed roads (where traffic is prohibited) and construction projects every other week, while detour adjustment reports are released every week and bridge adjustment reports are released monthly [3].

Most likely trucks hauling biomass will depend heavily on Iowa's system of county roads. While the condition of these roads is subject to weather and traffic density, the system already supports Iowa's agricultural economy. Grain and livestock are regularly

and routinely hauled from remote farms to distribution centers [4]. Thus, the system of roads will also support the hauling of biomass feedstock from dispersed production sites to conversion facilities.

Municipal (or city) roads total 12,837 miles, 11.4% of the state's total roadways. These roads support 22.2% of the state's vehicle miles and 2.3% of its heavy truck traffic. Most municipal roads are open to commercial truck traffic [2]. While local restrictions are common, they generally do not impede the fluid movement of goods, especially bulk farm produce [3]. Trucks hauling biomass feedstock would also depend on the use of these roads. Like Iowa's county roads, municipal roads would provide sufficient infrastructure support for a biomass-to-energy system.

Figure 5.1 shows the general condition of the state's highways by region. These sufficiency ratings are based on structural adequacy, safety, and service. Ratings of less than 50 identify highways or parts of highways that need to be examined to determine if additional construction or rehabilitation is needed. Most of Iowa's highways rank above

Figure 5.1

50. The south-eastern and central districts, which likely have the most traffic, have the highest percentage of poorly rated roads. Any commercial enterprise, like a biomass conversion facility, should assess the quality of the local road network. While it is important to evaluate the ratings of these roads, a decision to locate or not to locate a biomass-to-energy system in a particular area should not be based on these sufficiency ratings. These ratings only rank state roads which account for only 9% of the total road mileage in the state [1].

Rail

All of Iowa's 4,361 miles of rail track are privately controlled by twenty-three rail companies. Six of these companies are major national carriers, which operate 70% of Iowa's rail route mileage. Four of those have significant track miles in the state—Chicago and North Western (CNW), Soo Line, Burlington Northern, and Norfolk and Western. CNW and Soo operate over
50% of the total track miles including most of Iowa's grain gathering network. Note from the Railroad Service Map (Figure 5.2) that the northern and central areas of Iowa—the prime corn-growing regions—maintain the most extensive rail network in Iowa [2].

Since 1980, the national trend has been for these Class I companies to abandon or sell off their light-density lines, which are seen as being not profitable enough. As a result, many of these lines have been picked up by new, smaller railroad companies. Since 1980, Iowa has seen the establishment of twelve of these "regional" companies. Of the sixteen smaller carriers operating in Iowa, three are regional serving Iowa and the bordering states. Thirteen carriers operate only in Iowa, providing a significant portion the state's track traffic. They handle 22.5% of all rail freight shipments that originate or terminate in Iowa and they provide 30% of Iowa's track route miles. In 1991, thirty million tons of goods were shipped by rail from points originating in Iowa, and rail companies handled twenty-five million tons arriving in Iowa from outside the state [2].

Most of the state's shipped rail goods involve bulk commodities—grain products; food products; coal, chemicals; and stone, clay, and glass products. However, a variety of other products ranging from fresh foods to farm machinery are also transported by rail [2].

Iowa's rail network might also serve a biomass-to-energy system; however, rail transport tends to be associated with trade over long distances. Some rail transport might be cost effective for transporting biomass, depending on the local network of rail lines and the principal local carrier [2].

Figure 5.2

Water

Iowa has seventy-eight river terminals; most are privately owned and most of them are on the Mississippi (see Figure 5.3). Terminal managers work closely with the Iowa Department of Transportation, the Department of Natural Resources, the U.S. Army Corps of Engineers, and the U.S. Coast Guard [2]. Water transportation is an effective means of moving bulk goods like biomass for fuel.

As Figure 5.3 shows, the Mississippi River transportation infrastructure is well-developed compared to that on the Missouri River. Total tonnage shipped has remained fairly consistent over the past several years. Terminals are ubiquitous on the Mississippi River in Iowa, especially south of Clinton, Iowa. Of major concern to Mississippi River commercial traffic is the condition of the locks and dams. Many are reaching the maximum age for which they were designed and built. The U.S. Army Corps of Engineers is in the process of doing a major study in order to assess and prioritize the costs of repairing and upgrading the system of locks and dams. State and federal agencies are committed to maintaining the viability of this waterway for future commercial exploitation [2].

The situation on the Missouri River is not as promising for commercial trade, including biomass, although certainly local movement appears promising in the areas around Sioux City, Sergeant Bluff, Little Sioux, and Council Bluffs. Missouri River handlers are not accustomed to the same volume of trade as Mississippi River handlers. The total volume shipped in 1990 (see Figure 5.3) represents a decline of about 350,000 tons since 1985, when tonnage shipped came to almost 500,000 tons [2].

Upstream demand for water is the principle concern for Missouri River commercial traffic. In order to maintain the water level in upstream reservoirs, release rates have been lowered and as a result the navigation period on the Missouri River has been shortened. This shortened commercial season has raised freight rates, which in turn has had a detrimental effect on Iowa producers and shippers. This restriction on Missouri River traffic has negatively impacted Iowa's Missouri River communities [2].

Any biomass-to-energy system located along the Mississippi or Missouri Rivers should consider river transport. The infrastructure exists in some locales to help support the transportation of feedstock. Like rail, however, the possibility of using water transport for biomass is contingent on local conditions.

Figure 5.3

Pipeline System

Iowa has an extensive underground fuel pipeline system which is owned and operated by private concerns and public utilities (see Figure 5.4a and b). The bulk of Iowa's pipeline system is designed for transporting natural gas. While the syn gas produced in the biomass gasification process cannot be burned in residential natural gas furnaces, it is possible that a system requiring a syn gas conversion site to be separately located from a power generating plant could use parts of Iowa's pipeline system [6].

Commercial Trucking Infrastructure

Iowa's commercial trucking infrastructure serves a vital agricultural and industrial economy. Trucking firms are located throughout the state (see Figure 5.5). The transportation of biomass feedstock from production to conversion sites could be easily accommodated by the system of roads and network of trucking establishments that already serve Iowa's thriving agricultural economy. Much of the transportation of Iowa's agricultural produce is moved by farmers themselves. Farmers transport produce up to ten miles from their farms with standard farm machinery. Farm wagons and trailers, which are pulled by truck or tractor, make up a large part of Iowa's transportation machinery. Wagons and trailers are manufactured to many different specifications. The largest wagons will carry a maximum payload of about 5,000 lbs. The largest trailers will carry 1,000 lbs [4]. However, the limitations in payload capacity and the high daily demand of a typical biomass conversion facility (50 MW) make it unlikely that this mode of transportation will be much used in a biomass production and conversion system.

More likely is moving biomass from production to conversion sites by commercial-sized trucks of varying sizes and types depending on the type of biomass being transported. Different feedstocks will be transported in variously sized truck trailers suitable to the physical character of the feedstock itself at the time of transporting. All of the various sizes of trucks and variety of trailers listed in Tables 5.3–5.6 are used in Iowa. Even the largest trucks (80,000 lb. gross weight limit) serve Iowa's rural economy and regularly use both gravel and paved roads. Certain areas are clearly better endowed with commercial trucking firms than others. In some cases, farmers own large trucks or trailers. A study of local transportation infrastructure will be required before a biomass production and conversions system is established.

Figure 5.4a

Figure 5.4b

Figure 5.5

Table 5.3. Illustration of the haulage capacity of different sizes of trucks that might haul poplar chips to 50-MW electric power plants based on direct combustion and gasification conversion facility (50 MW), and the number of trips per day that such facilities would require.

	Trailer	Small 2 Axle	Large 2 Axle	Small 1 Axle A	Large 1 Axle A	Small 1 Axle B	Large 1 Axle B
Truck capacity (cubic feet)	1,949	563.8	732.9	307.5	358.8	399.8	466.4
Single trip haulage (tons)	19.5	5.6	7.3	3.1	3.6	4	4.7
Number of trips/day assuming 1,025 tons fuel demand per day for direct combustion	53	183	141	331	285	257	219
Number of trips/day assuming 1,157 tons fuel demand per day for gasification	60	207	159	374	322	290	247

Table 5.4. Illustration of the haulage capacity of different sizes of trucks that might be used to haul grain to a 5,000 barrels per day plants methanol and ethanol production and the number of trips per day that such a facility would require.

	Trailer	2 Axle	1 Axle
Single trip haulage (tons)	25 limit	13.5 limit	8.5 limit
Number of trips/day assuming 2,000 tons of biomass demand for methanol	84	156	247
Number of trips/day assuming 2,625 tons of corn demand for ethanol	105	194	309
Number of trips/day assuming 11,340 tons of sweet sorghum demand for ethanol	454	840	1134

Table 5.5. Illustration of the haulage capacity of different sizes of truck rigs which might be used to haul poplar logs to a direct combustion power facility (50 MW), and the number of trips per day that such a facility would require. Trucks will haul their limit in young, green poplar logs, assuming that a cost efficient system of loading and unloading is used.

	5 Axle	4 Axle	3 Axle	2 Axle
Single trip haulage for full length poplar logs (tons)	25	21	13	6
Number of trips/day assuming 1436 tons demand for direct combustion	58	69	111	239

Table 5.6. Illustration of the haulage capacity of different sizes of flat-bed trailers* that might be used to haul switchgrass bales to a direct combustion or gasification conversion facility (50 MW), and the number of trips per day that such each facility would require.

	48′ Flat Bed	40′ Flat Bed	32′ Flat Bed	24′ Flat Bed
Single trip haulage of number of 6’ x 6’ x 4’ switchgrass bales; (bottom/top)	30 (16/14)	22 (12/10)	18 (10/8)	14 (8/6)
Single trip haulage of 1,000 lb. switchgrass bales (tons)	15	11	9	7
Number of trips/day assuming 1,083 tons demand for direct combustion	73	99	121	154
Number of trips/day assuming 1,222 tons demand for gasification	82	112	136	175

*These trailers would ordinarily be pulled by a semi-type tractor.

Storage and Transportation Nodes

As Figure 5.6 shows, Iowa is variably equipped with storage and warehousing facilities. (Note, however, that this map does not include grain processing and storage facilities, which can be seen in Figure 5.7, the map of Grain Loading and Processing Facilities [8].) Grain and loading processing facilities are located at regular intervals on well-used roads and railroads. These facilities generally do not operate at full capacity during the winter, spring, and summer months and therefore could accommodate some of

Figure 5.6

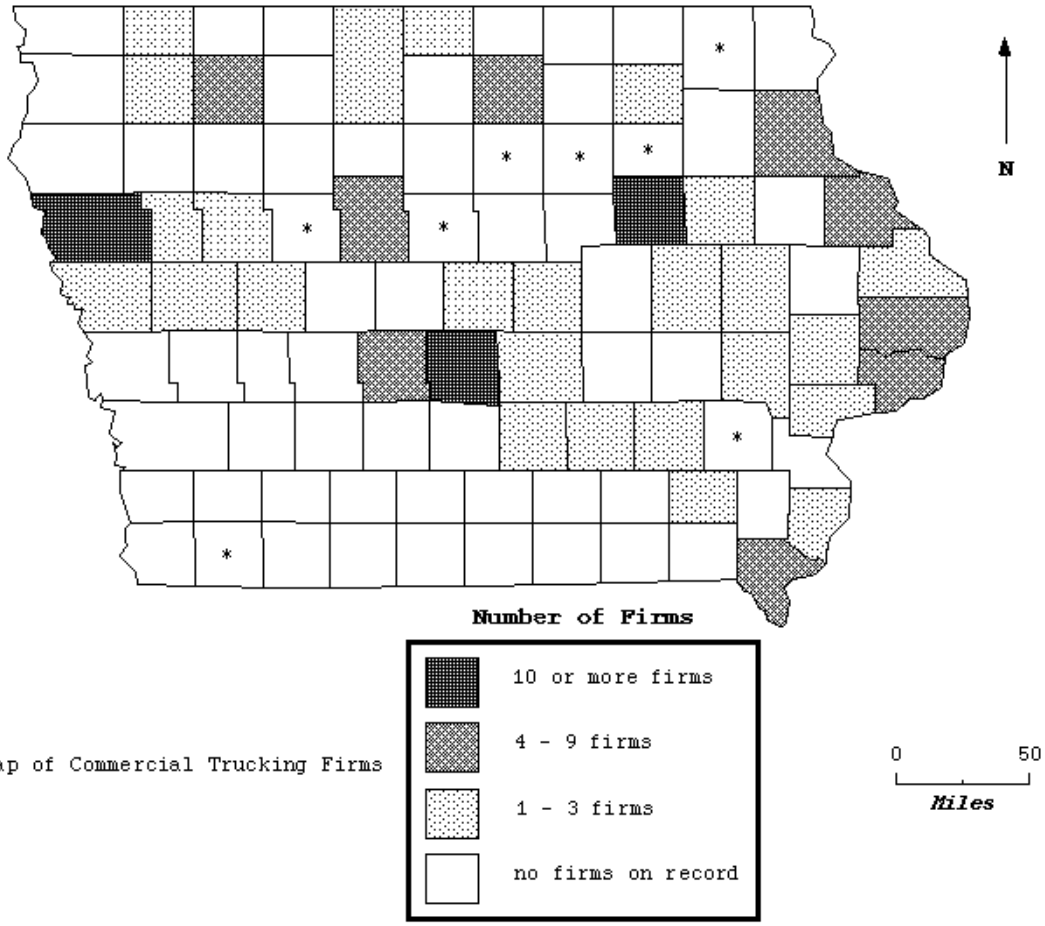
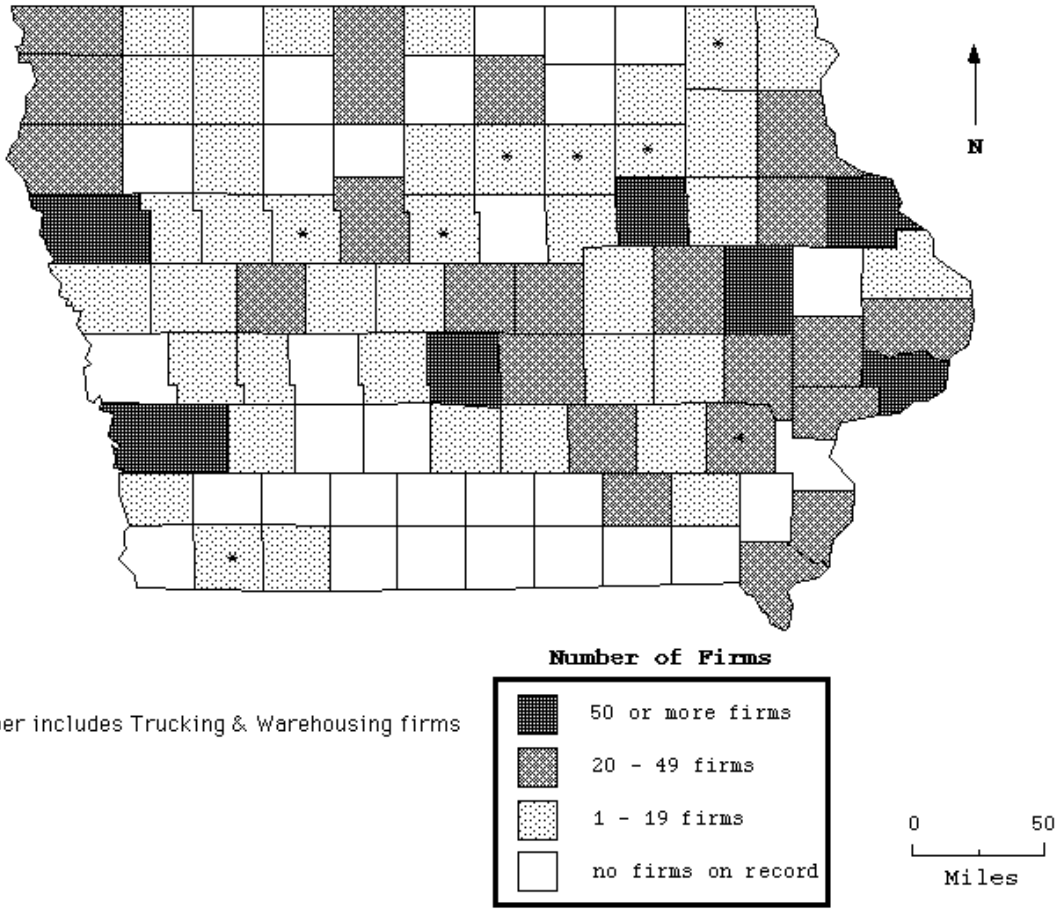

N
Number of Firms
10 or more firms
4 - 9 firms
1 - 3 firms
no firms on record
* See Map of Commercial Trucking Firms
0
50
Miles

Figure 5.7



* Number includes Trucking & Warehousing firms

the storage and transportation exchange needs of a biomass-to-energy system. (See Table 5.7, for the storage capacities of various size facilities.) These facilities are also places where biomass feedstock could be transferred from rail to road transport or vice-versa. Clearly, Iowa has a storage infrastructure that could assist in accommodating a biomass energy system. Again, however, when specific locales come under study, the specific local facilities should be carefully evaluated.

Energy Conversion Infrastructure

This infrastructure has been broadly divided into fossil-fueled, electric power plants and biomass-to-energy facilities. The electric power plants are categorized as steam, gas turbine, or internal combustion. The biomass-to-energy facilities are categorized as crop residue combustion, wood combustion, waste-to-energy, methane production (via anaerobic digestion), and alcohol production.

Power plants are further subdivided according to size: less than 20 MW_e, 20–50 MW_e, and greater than 50 MW_e. This subdivision was selected to reflect a perceived optimum size of biomass-fired power plants of 20–50 MW_e [9].

Geographic information system (GIS) maps were developed to show the county-by-county distribution of power plants in Iowa using data from Reference [10]. Figure 5.8 shows the distribution of steam power plants in Iowa according to size. Figure 5.9 shows the distribution of gas-turbine power plants in Iowa according to size. Figure 5.10 shows the distribution of internal combustion engine power plants in Iowa according to size.

Tables 5.8 and 5.9 summarize this information on power plants by size and type, respectively. A surprisingly large number of small capacity power plants exist in Iowa. Of the 329 facilities with output less than 20 MW_e, the average generation capacity is only 2.6 MW_e and the vast majority are internal combustion engines. In principle, gasifiers could be retrofitted to these small power plants to allow them to run on biomass fuels. However, these small plants account for only 11% of total electric generation capacity in Iowa.

Seventy-seven percent of the state's generating capacity resides in 27 large (>50 MW_e) power plants with average capacity of 214 MW_e. These large plants, if fired on biomass, would require only 5% of the land area within a 50 mile radius to support their average energy demand.

Table 5.7. The maximum tonnage that various sizes of storage facilities in Iowa can accommodate at any one time for switchgrass, poplar logs, and poplar chips on the basis of their densities. See Figure 5.7.

	Tons of Feedstock Stored			
Feedstock	0.5 Million bushel facility	1.25 Million bushel facility	2.50 Million bushel facility	6.0 Million bushel facility
Switchgrass bales	4.5 tons	11.3 tons	22.6 tons	54.3 tons
Poplar logs	10.6 tons	26.5 tons	53.1 tons	127.5 tons
Poplar wood chips	6.25 tons	15.6 tons	31.25	75 tons

Source: Iowa Department of Transportation. 1993. *Grain Loading and Processing Map*. Des Moines, Iowa [8].

Table 5.8. Summary of Iowa power plants by size.

	Size		
	<20 MW_e	20–50 MW_e	>50 MW_e
Number of plants	329	28	27
Total capacity (MW)	840	884	5,769
Average capacity (MW)	2.55	31.6	214

Source: Inventory of Power Plants in the United States 1990, Energy Information Administration, DOE/EIA-0095 (90) [10].

Table 5.9. Summary of Iowa power plants by type.

	Type		
	Internal Combustion	Gas Turbine	Steam Turbine
Number of facilities	292	31	61
Total capacity (MW)	370	1,132	5,991
Average capacity (MW)	1.27	36.5	98.2

Source: Inventory of Power Plants in the United States 1990, Energy Information Administration, DOE/EIA-0095 (90) [10].

Figure 5.8

Figure 5.9

Figure 5.10

The state also has 28 power plants in the target range of 20–50 MW_e, which is considered the optimal size for retrofitting to biomass fuels. However, these medium-sized plants only account for 12% of the electric generating capacity in Iowa.

A GIS map was also generated for biomass-to-energy facilities in Iowa with information from Reference [11]. This map, shown in Figure 5.11, shows the county-by-county distribution of the various kinds of biomass facilities. The largest number of facilities produce methane by anaerobic digestion, with 30 facilities spread among 27 counties. Most use sewage sludge as feedstock although there are a few instances of manure and municipal solid waste serving as feedstock. There are 12 crop residue combustion facilities in Iowa producing process heat, 9 wood combustion facilities, and 5 waste-to-energy facilities. There are only four commercial alcohol production facilities in Iowa producing ethanol from corn, not all of which is destined for fuel applications.

CONCLUSIONS

Iowa's transportation infrastructure is well-equipped to support various biomass-to-energy systems. The state's road, rail and waterway systems already support a strong and viable agricultural economy based on the movement of bulk commodities. The geographically limited area in which a biomass-to-energy system would operate makes Iowa's road system, which already accesses all of Iowa's farms, the most reliable and the cheapest of the three modes of transportation to support a biomass-to-energy system. The freight infrastructure, i.e., commercial and privately owned trucks, is also well-suited to hauling agricultural goods and therefore would effectively serve most biomass-to-energy systems.

Iowa’s existing energy conversion infrastructure could play a role in developing biomass-to-energy systems in Iowa. Many small municipalities have internal combustion engine power plants averaging a few megawatts in generating capacity that could be retrofitted with small-scale gasifiers to allow consumption of biomass fuels. Although this may have important local impact, the state-wide effect on energy consumption would be modest. Even if all 329 of these small plants were converted to biomass, it would only involve 11% of the total electric generating capacity of the state. Likewise, conversion of all midsized power plants (25–50 MW_e) to biomass fuel would only involve another 12% of the state’s generation capacity. The biggest impact would be made if cofiring of biomass

and coal were employed at the largest steam power plants, which represent 77% of the state's electrical generating capacity. Cofiring each of these plants with biomass could

Figure 5.11

Chapter 6

Iowa Human Resources to Support Biomass Energy Systems

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CHAPTER 6. IOWA HUMAN RESOURCES TO SUPPORT BIOMASS ENERGY SYSTEMS

INTRODUCTION

The principal goal of Task No. 2, "Survey of Human Resources," was to assess the labor demands of certain biomass-to-energy systems and to analyze how these systems might impact rural unemployment in Iowa. A secondary goal of this task was to assess whether Iowa has adequate human resources to support a biomass-to-energy system.

METHODOLOGY

Several methodologies were employed to assess human resource needs of biomass energy systems. A wide and thorough search and review of the existing literature on biomass production and conversion systems was performed. In this process, researchers at several national and regional institutions involved in biomass research were consulted. From these sources, assessments of labor demands of certain biomass-to-energy systems were made, and existing data on the potential impact of these systems on employment were compiled.

Only the employment effects within the production chain for Iowa are included in this assessment. Some evidence for indirect employment effects for the U.S.A. is given as well. However, employment multipliers for agriculture apply only to the entire state of Iowa, not to particular regions or counties. As such, these multipliers assume that the exchange of goods and services would take place across the entire state, which is not necessarily the case in a biomass system limited to biomass resources supplied from a 50-mile radius about the conversion facility. The indirect employment effects for a new industry in agriculture are not particularly significant, although clearly *some* indirect employment effects can be expected. For example, employment will be generated to transport biomass feedstocks from production sites to conversion facilities. However, these are considered indirect employment effects and cannot be accurately estimated. Thus,

the total impact on employment is *best* understood by assessing the effects on employment within the production chain and independent of indirect employment effects.

The methods for constructing the labor demand tables (Tables 6.2–6.4) include using data from a variety of sources. Work-year-equivalents (WYEs) for conversion were computed by using a multiplier (0.7 jobs per MW) supplied by EPRI [1] and were based on their studies of 50-MW biomass-powered electric power plants in California and Oregon.

A common assumption made in Tables 6.2–6.4 is a 50-MW electric power output with 80% availability factor. In addition, for Tables 6.2 and 6.3 both mechanical and chemical methods were used to prepare sites and control weeds.

Tables 6.5–6.8 were also constructed by using data from a variety of sources. WYEs in conversion were computed on the basis of estimates of plant labor requirements with the assistance of Shaine Tison [2] and Loren Lappes [3].

Common assumptions made in Tables 6.5–6.8 include:

- 5,000 barrels per day output with 80% availability factor
- 8 jobs in conversion process per 30,000,000 gallons per year.

An additional assumption is made for Tables 6.5–6.7: field preparation includes both mechanical and chemical preparation. Moreover, for Tables 6.5 and 6.6, a nonliquid fertilizer is applied to the fields.

RESULTS OF EVALUATION

Potential Jobs Creation in the Biomass-to-Energy Industry

A principal goal of establishing biomass-to-energy systems is to reduce the fuel dependence of the U.S.A. on foreign energy producers. A secondary and perhaps no less important goal of the development of domestic energy production systems is to generate economic activity and with it new jobs. Biomass-to-energy projects will help to create jobs within the industry itself (direct employment effects) and outside the industry—"ripple effect" jobs in support businesses and in service businesses which benefit from the income effects of new jobs (indirect employment effects) [4].

Table 6.1 estimates that the indirect jobs generated nationally by the biomass-to-energy industry to be quite significant. If Iowa is successful in further developing its

biomass-to-energy systems and in creating new biomass-to-energy systems, many of these projected jobs will be created in Iowa. While rural regions of Iowa cannot expect such significant indirect effects, certainly jobs will be created as spin offs of the new jobs within the production chain [4,5].

Likewise, Figure 6.1 estimates that the biomass-to-energy industry will create hundreds of thousands of new jobs in the United States over the next two decades. If Iowa continues to develop biomass-to-energy systems, it can expect to create many of these jobs. Many of these new jobs, however, will replace existing jobs. Some of the new jobs created in Iowa will not be new, but will supplant jobs in other places or perhaps even within Iowa [2].

Figure 6.2 illustrates the ways that jobs within a biomass-to-energy production chain might ripple through the economy. While these effects tend to be less dramatic in rural economies, regions within Iowa can expect positive ripple effects as a result of job creation with the biomass-to-energy industry. This is an indication that the development of biomass-to-energy systems should have a positive economic impact on local rural economies in Iowa [2].

Table 6.1. Projected impact of biomass electric power usage on employment in the U.S.A.

	1992	1997	2000	2010
Direct jobs generated	14,435.6	16,758.5	19,888.1	32,839.4
Indirect jobs generated	33,608.1	37,186.3	62,279.7	121,208.9
Job impacts from energy and landfill savings	36,651.5	61,531.5	86,793.5	256,584.5
Total jobs generated	84,695.2	115,476.3	168,961.3	410,632.8
Jobs displaced by biomass electric activity	18,538.3	27,703.9	40,572.6	126,795.3
Net jobs generated by biomass electric activity	66,156.9	87,7772.4	128,388.8	283,837.5

Source: Meridian Corporation and Antaries Group, Inc. 1992. Economic benefits of biomass power production in the U.S. *Biologue* 10:12–18 [5].

Labor Requirements for Biomass-Powered 50-MW Power Plants

As Tables 6.2–6.4 below illustrate, significant employment is created within the production chain of a biomass-to-energy system supplying feedstock to a 50-MW power plant. A switchgrass system clearly has less direct impact on employment than those involving SRWC (short-rotation woody crops). Figure 6.3 illustrates county-by-county unemployment trends across Iowa from 1978 to 1992. Iowa has a significant idle work force that could supply the necessary labor for such systems. Iowa is generally a net exporter of labor. New jobs would create an inducement for labor to remain in Iowa.

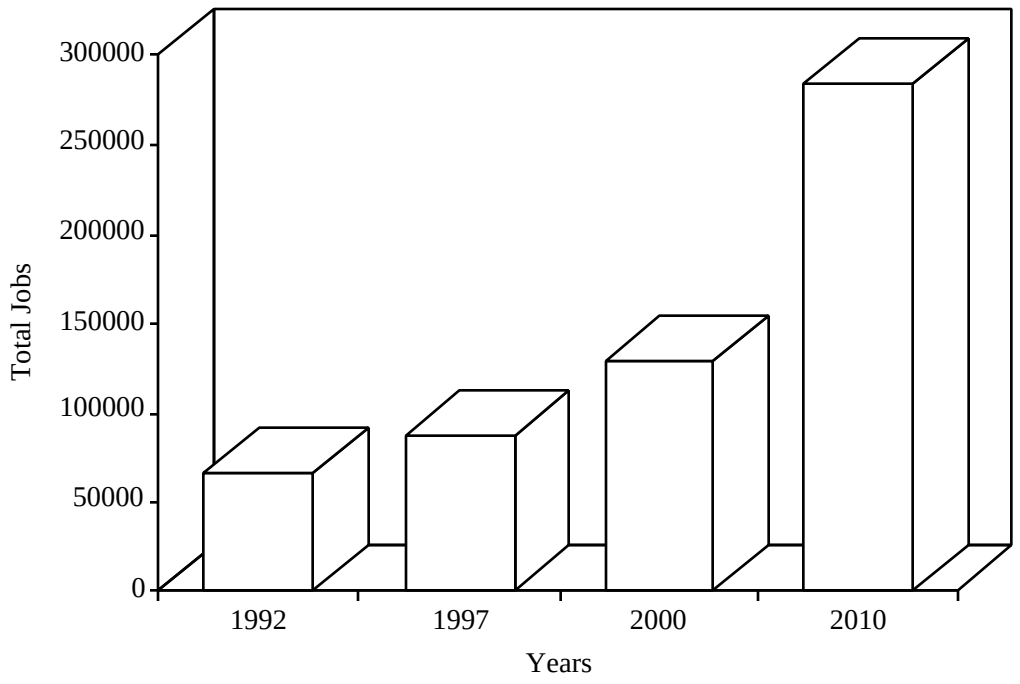

Figure 6.1. Projected impact of biomass-to-energy systems on annual U.S. employment.

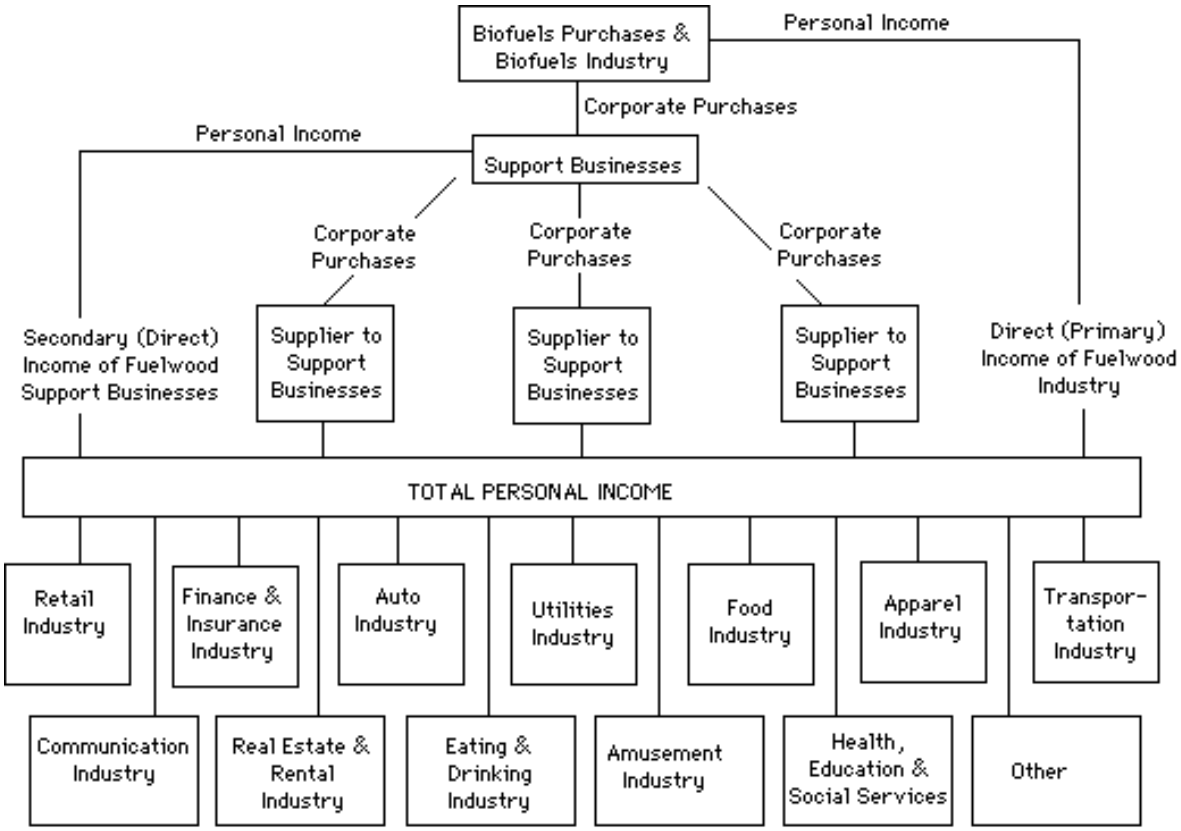

Figure 6.2. The economic ripple effect of the biofuels industry.
Source: Meridian Corporation and Antaries Group, Inc. 1992. Economic benefits of biomass power production in the U.S. *Biologue* 10:12–18 [5].

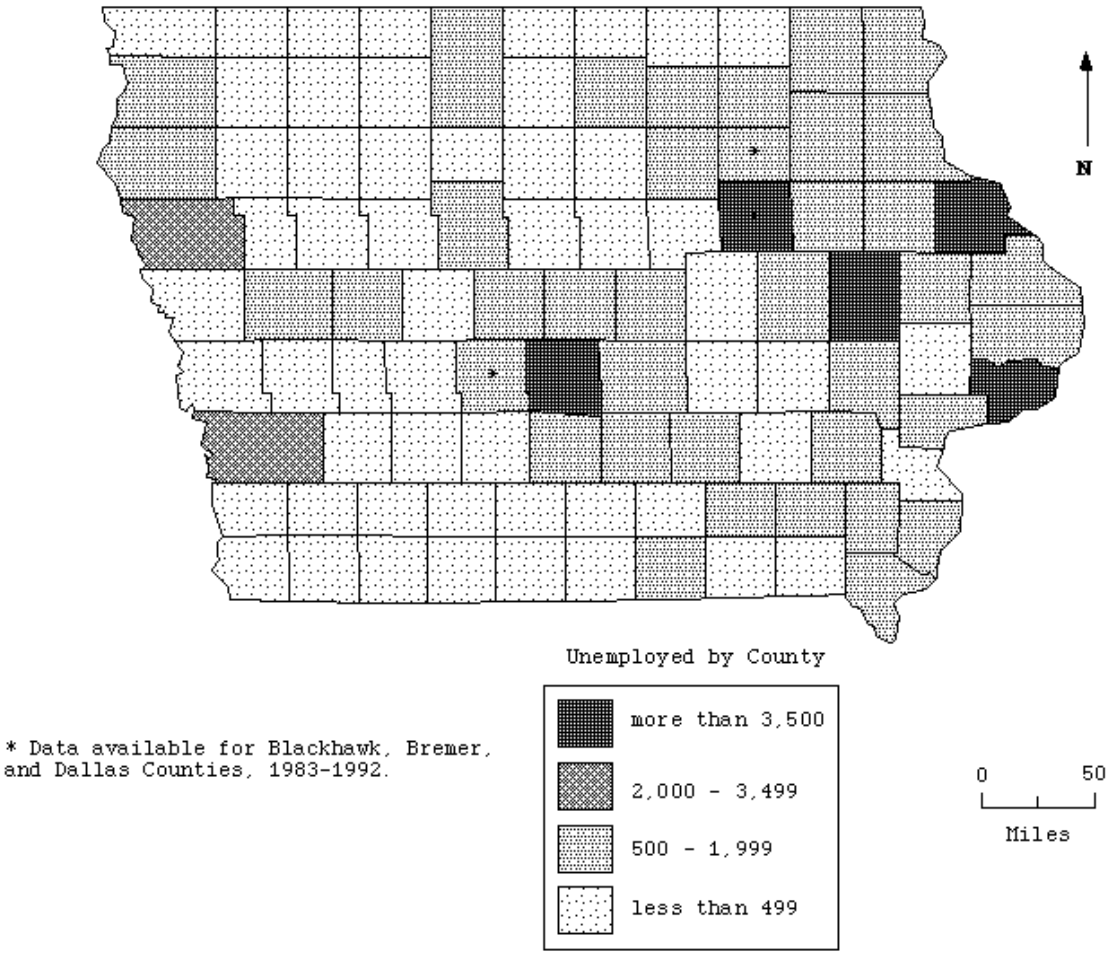

Figure 6.3. Iowa unemployment trends by county.
Source: Department of Employment Services

Labor is becoming generally more mobile so that a new industry creating new jobs in Iowa should expect to attract workers beyond the local labor market [6].

Note that jobs within the conversion process are created only if the output (in this case electricity) was previously being imported into Iowa. However, if biomass feedstock is produced on previously unproductive lands (i.e., CRP lands), then new agricultural jobs are created in Iowa.

The skills necessary to this industry are quite similar to those that other standard power plants require. The vast majority of jobs in these systems are semiskilled, which means that laborers need some specialized training before becoming optimally efficient. The demand for highly skilled workers is low. A direct combustion or gasification plant should require a single plant engineer and some supervisory skilled workers [1, 2, 7].

Table 6.2. Labor requirements for a direct combustion and gasification biomass system supplying wood chips to a 50-MW power plant.

	Direct Combustion (WYE)*	Gasification (WYE)
Site preparation (first year only)	36	42.2
Planting (first year only)	99.8	112.6
Weed control (first two years only and once every five years)	67.9	77.4
Annual maintenance	31.2	35.2
Harvesting	598.6	675.9
Conversion	35	35
Total direct employment effects**	664.8	746.1

* WYE is "work-year equivalent" for all labor demand tables (Tables 6.2–6.9). WYE is 2,000 hours of work which, if spaced evenly throughout a year, is the equivalent of working 40 hours per week for 49 weeks.

** Total direct employment effects in all labor demand tables do not include the temporary (site preparation, planting and weed control) agricultural jobs created in a biomass-to-energy system (Tables 6.2–6.4, and 6.7, 6.8).

In addition to the assumptions common to Tables 6.2–6.4 noted in the Methodology section, the following additional assumptions were made in preparing Table 6.2.

- Thirty percent moisture content for poplar chips
- Harvest of 6 tons per acre

- Requirement of 1,025 tons per day for direct combustion; 1,157 tons per day for gasification

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by Joe Colletti at Iowa State University [8].

Table 6.3. Labor requirements for direct combustion and gasification biomass systems supplying switchgrass to a 50-MW power plant.

	Direct Combustion (WYE)	Gasification (WYE)
Seeding (first year only)	42.2	47.6
Annual production	23.7	27
Conversion	35	35
Total direct employment effects	58.7	62

The following additional assumptions are made for Table 6.3.

- Thirty percent moisture content for switchgrass
- Harvest of 6 tons per acre
- Requirement of 1,083 tons per day for direct combustion; 1,222 tons per day for gasification

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by Arne Hallam at Iowa State University [9].

Table 6.4. Labor requirements for direct combustion and gasification biomass system supplying poplar logs to a 50-MW power plant.

	Direct Combustion (WYE)
Site preparation (first year only)	30
Planting (first year only)	83.9
Weed control (first two years only and once every five years)	56.9
Annual maintenance	26.2
Harvesting	503.2
Conversion	35
Total direct employment effects	564.4

The following additional assumptions are made for Table 6.4.

- Fifty percent moisture content for poplar logs
- Harvest of 10 tons per acre
- Requirement of 1,436 tons per day

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by Joe Colletti at Iowa State University [8].

Labor Requirements for Plants Converting Biomass to Liquid Fuels

As in the case of biomass-to-energy systems for electric power generation, Tables 6.5–6.8 show that ethanol and methanol production systems will create new jobs in Iowa. New agricultural jobs are created only if corn, sweet sorghum, wood chips from trees, and switchgrass are grown on previously unproductive lands. In the production of liquid fuels, new jobs are created in Iowa only when those fuels are imported into Iowa, which in this case they are. Iowa's idle work force could supply the necessary labor for these systems. Also, as stated above, labor is becoming generally more mobile so that a new industry creating new jobs should expect to attract workers beyond the local labor market.

The skills necessary to this industry are quite similar to those that fuel-refining systems require. The vast majority of jobs in these systems are semiskilled, which means that laborers would need some specialized training before becoming optimally efficient. The demand for highly skilled workers is low. An ethanol or methanol plant should require one or two plant engineers in the liquid fuels section of the plant and some supervisory skilled workers [2, 3].

Table 6.5. Labor requirements for an ethanol conversion system relying on corn and producing 5,000 barrels per day.

	Ethanol (WYE)	Methanol (WYE)
Field preparation (yearly)	22.8	25.8
Planting (yearly)	7.7	8
Harvesting	38.3	43.3
Conversion	16	16
Total direct employment effects	84.8	93.1

The following additional assumptions were made for Table 6.5.

- Harvest of 135 bushels per acre
- Requirement of 2,100 tons per day for ethanol synthesis; 2,400 tons per day for methanol synthesis

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by I.C. Anderson at Iowa State University [10].

Table 6.6. Labor requirements for ethanol conversion system relying on sweet sorghum stems and producing 5,000 barrels per day.

	Ethanol (WYE)
Field preparation (yearly)	46
Planting (yearly)	15.3
Harvesting	49.1
Conversion	16
Total direct employment effects	126.4

The following additional assumptions are made for Table 6.6.

- Approximately 50% moisture content
- Harvest of 27 tons per acre
- Requirement of 9,072 tons per day

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by I.C. Anderson at Iowa State University [10].

Table 6.7. Labor requirements for methanol conversion system relying on wood chips and producing 5,000 barrels per day.

	Methanol (WYE)
Site preparation (first year only)	87.6
Planting (first year only)	233.6
Weed control (first two years only and once every five years)	159.8
Annual maintenance	73
Harvesting	1,401.6
Conversion	16
Total direct employment effects	1,490.6

The following additional assumptions are made for Table 6.7.

- Thirty percent moisture content for poplar chips
- Harvest of 6 tons per acre
- Requirement of 1,025 tons per day for direct combustion; 1,157 tons per day for gasification.

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by Joe Colletti at Iowa State University [8].

Table 6.8. Labor requirements for methanol conversion system relying on switchgrass and producing 5,000 barrels per day.

	Methanol (WYE)
Seeding (first year only)	93.4
Annual production	52.6
Conversion	16
Total direct employment effects	68.6

The following additional assumptions are made for Table 6.8.

- Thirty percent moisture content for switchgrass
- Harvest of 6 tons per acre
- Requirement of 1,083 tons per day for direct combustion; 1,222 tons per day for gasification

The WYEs in agricultural activities were computed from the per acre hourly labor requirements supplied by Arne Hallam at Iowa State University [9].

Agricultural Employment and Expiring CRP Lands

A significant Iowa farm issue that biomass-to-energy systems can address is what to do with highly erodable lands that have been taken out of cultivation through the Federal Conservation Reserve Program (CRP). Can CRP lands be protected while still generating farm income after federal subsidies are lifted? Cultivating the land is the only way to produce farm income. However, certain perennial crops, like poplar trees and switchgrass, can generate farm income while conserving the soil.

Table 6.9 aims to illustrate the potential for farm income from expiring CRP lands by showing the direct employment effects of different biomass-to-energy systems. While corn and sweet sorghum have employment and therefore income generating potential, they

Table 6.9. Agricultural employment and expiring CRP lands. Comparing the employment potential in soil conserving and soil erosive crops.

	Agricultural WYE in Soil Conserving Crops	Agricultural WYE in Soil Erosive Crops	WYE in Conversion Processes	Total WYE
Ethanol from corn	-	68.6	16	84.6
Ethanol from sweet sorghum	-	110.4	16	126.4
Methanol from wood chips	1,474.6	-	16	1,490.6
Methanol from switchgrass	52.6	-	16	68.6
Electricity from poplar chips (direct combustion)	629.8	-	35	664.8
Electricity from poplar logs (direct combustion)	529.4	-	35	564.4
Electricity from switchgrass (direct combustion)	23.7	-	35	58.7

are soil erosive crops. Poplar feedstocks, which are soil conserving crops, have high employment and income potential. Switchgrass, which is also a soil conserving crop, has significant but lower income generating potential than corn, sweet sorghum, or poplar trees.

CONCLUSIONS

As Figure 6.3 shows, unemployment is a serious social problem in virtually every county of Iowa. Iowa has more than adequate human resources to support a biomass-to-energy system. A biomass-to-energy system would create new jobs in Iowa and generate indirect employment activity that would benefit rural regions of Iowa. Expiring CRP lands

converted to biomass feedstock production have the potential of supporting rural economic development. Such economic development also has the potential of luring labor to Iowa from other nearby states. A biomass-to-energy system producing wood chips for methanol would have the greatest employment impact on a region in Iowa, while the production of switchgrass for electric power would have the least impact on employment in Iowa.

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Chapter 7

The Potential for Financing Biomass Production in Iowa

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CHAPTER 7. THE POTENTIAL FOR FINANCING BIOMASS PRODUCTION IN IOWA

INTRODUCTION

The ultimate feasibility of large-scale biomass production in Iowa depends on its cost of production and its environmental impact in relation to other energy sources. The cost of using biomass for energy depends on its cost of production, transportation, and storage and on the cost of converting it to energy. The biomass user will compare the cost of biomass to alternative fuels, while the biomass producer will compare the returns of biomass production with the returns of other products such as crops and livestock. Biomass production and use will take place only if these costs and returns compare favorably.

The production and use of biomass for energy requires the use of land and capital equipment, both of which are durable, long-lived assets. Annual production and use may also require the use of operating capital, given the time period that elapses between the start of the production process and the realization of returns. Biomass production and use, therefore, will require financing in order to be viable. If biomass production is to become a profitable and stable agricultural enterprise, then this financing must come from the private commercial sector and not from a government subsidy. The issues related to financing biomass production and use then relate to the willingness of the private sector to finance both biomass production and use.

METHODOLOGY

The methods employed in this analysis are similar to those used in evaluating the financing of other commercial enterprises. Lenders typically take a number of factors into account in considering whether to make a given loan. Common factors are the size of the loan, the expected rate of return on the loan, the collateral available to support the loan, and the riskiness of the loan compared to other potential investment opportunities. Riskiness depends on a number of factors including risk in production of the product, market risks in

selling the product, the familiarity of the lender with the production and use practices, and the overall stability of the borrower. Each of these factors will be considered in turn as they relate to biomass production and use. Specific analytical methods and assumptions will be described as they are employed to evaluate each of these factors in the section below.

RESULTS OF ANALYSIS

Factors Affecting the Financing of Biomass Production

When contemplating the financing of biomass production, lenders will consider a number of factors. The first issue is profitability of the farmer producing biomass. The cash flow position of the borrower with respect to biomass production is a major factor. If biomass prices offered by energy consumers such as electric utilities are high enough to give the farmer a reasonable profit margin, then the lender can obtain a market rate of return on the loan and will consider making it available. If biomass prices are not high enough to give the farmer a suitable profit margin, then loans will not take place regardless of other considerations. Therefore, the main factor that encourages lenders to finance biomass production is profitability. Since production loans for annual biomass crops are similar to production loans for other annual crops such as corn and soybeans, there is no reason to expect this to affect financing. Production loans for perennial crops such as alfalfa or switchgrass will require more significant dispersals in the establishment years to cover seeding and fertilization costs. While these costs are higher than the costs for the annual crops, they are probably not large enough to form any serious barriers to financing. This will be particularly true in areas where perennials such as alfalfa or grasses are currently common. Loans for equipment used in producing these crops will be the same length as loans commonly made. As far as herbaceous crops are concerned, therefore, there seem to be few barriers to financing related to length of loan. Financing barriers are more problematic in relation to woody crops that have a longer production cycle. Such crops have establishment periods of several years before revenues become available. In such cases lenders will expect some guarantee of a market for the crop or at least other income and collateral that will support the loan during the initial stages. Given that farmers must take some time to adjust to biomass crops, potential also exists for cash flow shortfalls in the establishment years. These shortfalls relate not only to the costs of establishing the

crop but possible additional investments in machinery and equipment. Thus the lender may need to see other income sources as a protection against possible early year shortfalls. Farmers who grow biomass in addition to typical annual cash crops will create less concern in this area. For those growing biomass crops only, a more serious issue relates to loan risk. A major risk consideration is that no real track record of biomass production exists that lenders can consult for information on loan performance. While lenders will be familiar with the production of alfalfa and perennial grasses as well as forage corn, which is similar to sorghum, they will have little experience with the production of these crops for use as a fuel. This adds some uncertainty to the entire loan picture and will probably require the payment of at least a marginal risk premium by borrowers. This will be particularly true when producers of primarily row crops such as corn and soybeans consider the production of biomass crops.

Other risk considerations are also important. The price of biomass crops is very uncertain. Lenders will be more willing to make loans if the producer has a contract to deliver set quantities of biomass at fixed prices. Thus the ability of the biomass user to guarantee a price or at least a price range may be important to ensuring the financing of biomass production. Some risk is also associated with production of biomass crops. In general the crops considered for biomass production have less yield variability than commonly grown row crops such as corn and soybeans. In order to investigate the yield variability of biomass crops, annual Iowa data for the years 1965 to 1991 was regressed on a linear trend. The standard deviation of the residuals (which have a mean of zero) then gives a measure of the yield variability. As data in Table 7.1 suggest, alfalfa tends to be very stable in yields. Switchgrass and big bluestem would probably have similar stability. Sorghum harvested as a silage is also fairly stable in yield, although because of small acreages the historical data from Iowa are more variable than is typical. Its yield is similar to but lower than corn silage, which is more stable than corn for grain since the total product rather than just the seed (grain) is used. Similarly, sorghum harvested as silage has lower variability than sorghum harvested as grain. Thus the yield variability associated with biomass crops is probably not a serious impediment to competitive financing.

Table 7.1 Coefficient of variation (CV) of detrended yield/acre state level yield data for Iowa 1965- 1991.

Crop	Hay	Soybean	Sorghum Silage	Sorghum Grain	Corn Silage	Corn Grain

STD of residuals	0.1317	2.166	0.9261	5.646	1.228	10.2766

If the private sector finds that the financing of biomass production loans is too risky, one possible alternative is for the biomass user to participate in crop financing. Ample precedent for this practice exists in agriculture in both the input and processing industries. The energy company could advance the producer a certain percentage of the final market price in return for a guaranteed product at harvest time. The respective parties could negotiate acceptable terms and conditions creating one way that the biomass producer and user could share in the risks associated with production. The producer would get a guaranteed price and some financing; the user would get a stable supply of the product.

Factors Affecting the Financing of Biomass Conversion

As with biomass production, lenders will consider a number of factors when contemplating the financing of biomass conversion. The first issue is the profitability of the proposed electric plant or other energy production facility. Not only the costs and returns to biomass use will be considered. The total asset and cash flow position of the borrower is important since biomass may form only a small part of the total raw material input. If biomass users can use a feedstock with current technology, such as cofiring, the lender will have little difficulty evaluating the feasibility of converting to some biomass use and of the potential for loan payback. If the plant is considering new capacity with differences in technology, a number of risk factors enter into the decision. In evaluating profitability, the lender will consider the potential for demand expansion in the energy market. This factor may be a problem in some parts of Iowa where populations and energy demands are not rising. The lender will also need to consider the potential for changes in environmental regulations that may make different types of energy production more or less competitive. As with production, however, the major factor in the financing of biomass conversion is the expected profitability. Risks associated with energy conversion industries are those related to the price of the good produced using the biomass, such as electricity, and the price of alternative inputs such as fuels. If the price of the end product falls, the profitability of the biomass user will fall and the ability to make loan payments may drop. Similarly, if the price of other fuels falls, users who have devoted capacity to biomass use may find themselves in the high-cost production range and thus may be forced

out of the market as output prices fall. Of particular concern is the relative volatility of world energy markets. Fuels that appear competitive today may well be marginal tomorrow. Thus, an adopted technology may potentially become obsolete in terms of price competitiveness. There is considerable risk in this regard because the prices of natural gas and coal have been on a downward trend in recent years.

Any investment in new plants and equipment that use biomass is a very long-term decision that will require careful analysis by lenders. The up front costs of new plant capacity are very large and must be amortized over a long time period. Lenders will thus view the risks associated with such loans as being amplified by the time involved. As a result many lenders may be reluctant to make large loans for new plant capacity unless the potential for success seems very high. This situation is magnified by significant collateral risk since few outlets exist for obsolete power plant equipment.

CONCLUSIONS

While biomass production and use in Iowa will require financing, this should not be a serious obstacle to the production of biomass as long as the production enterprise is profitable. The reason is that the technology and practices associated with biomass production are very similar to those now in place for other crops. Thus there seems to be little reason to subsidize the financing of biomass production. The financing of expanded capacity for power plants or other users of biomass may be more problematic. Such loans are large and long term in nature, and the private sector may view them as too risky. Given the general uncertainty about energy demand and the costs of competing fuels, this venture is also a risky one for the government or any other public entity. Therefore the full potential social costs and benefits of biomass production and use should be considered before any attempt is made to subsidize the financing of expanded energy production capacity.

displace 1,442 MWe presently generated by coal. Such fuel blending could be accomplished with capital investments much less than required to retrofit small, internal combustion engine power plants for biomass.

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Chapter 8

Environmental Effects of Biomass Production and Conversion

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CHAPTER 8. ENVIRONMENTAL EFFECTS OF BIOMASS PRODUCTION AND CONVERSION

INTRODUCTION

The effects of various biomass production systems on the environment will be determined; for example, soil erosion and water quality, off-site impact of agricultural chemical use in large-scale biomass production, the impact of proposed energy conversion technologies on air and water quality, and the environmental impact of biomass production on wildlife.

METHODOLOGY

The information presented in this report was gathered through a literature review. The task was divided into three subtasks: (1) the environmental effects of increased biomass energy feedstock production, (2) the environmental effects of various biomass energy conversion technologies, and (3) the effects of increased biomass energy feedstock production on wildlife.

Since the goals of this task were quite broad, the literature review was designed to give a general overview of the types of environmental impact that could result from increased biomass production and conversion. The majority of the information presented here is either site or procedure specific because large-scale studies of the environmental effects of both biomass production and conversion are not available for the vast majority of crops and conversion technologies. As a consequence, the majority of information available is derived from either field plots or demonstration projects.

RESULTS OF ENVIRONMENTAL EVALUATION OF BIOMASS PRODUCTION

Biomass feedstock production is thought to be less environmentally detrimental than production of more traditional agricultural crops such as corn or soybeans because of

the more sustainable nature of biomass feedstocks. Such feedstocks with the most promise for Iowa are hybrid poplar and switchgrass. Corn is also an important biomass feedstock for the production of ethanol. With regard to water quality, the effects of growing corn for ethanol production are no different than other end uses for the grain. However, switchgrass and poplar affect water quality much less than corn because of the reduced necessity for inputs of fertilizers, herbicides and pesticides. In 1993, an average of 621 kg/ha of nitrogen-fertilizer was applied to corn in Iowa, down from previous years when nitrogen-fertilizer application rates were as high as 790 kg/ha. On the basis of estimates of nitrogen-fertilizer inputs for biomass energy feedstock crops (Table 8.1, Figure 8.1), a switch from corn to biomass feedstock would result in a reduction of nitrogen input of between 29% and 61% for upland sites, and 65% and 100% for wetlands.

Table 8.1. Anticipated annualized fertilization rates for energy crops on uplands and former wetland sites (kg/ha).

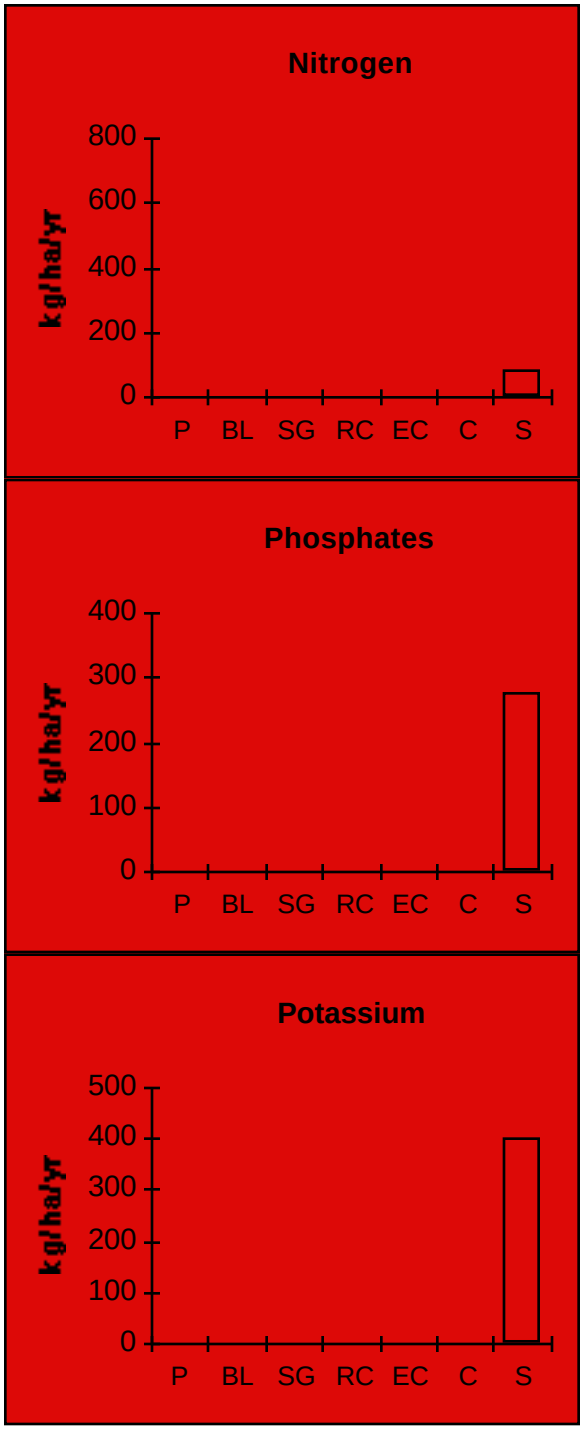
Crop Type	Uplands			Former Wetlands		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Populus Spp., sweetgum, sycamore, silver maple	245	71	71	0-136	0-27	0-27
Black locust, red alder	0	71	71	0	27	27
Switchgrass, wheatgrass	441	327	327	218	218	218
Reed canarygrass	686	327	490	545	272	436
Energy cane	762	272	436	653	272	436
Sorghum	707	381	490	545	327	436

Note: Inputs averaged over life of the crop. Fertilizer rates for former wetlands are based on very limited data. Source: Ranney, J. W., J. T. Martin, M. A. Doan, and C. A. Thomas. 1994. Energy Crops: An opportunity for restoring wetland functions. Oak Ridge National Labs [1].

Improvement of water quality in agricultural drainages due to the reduction of fertilizer, herbicide, and pesticide application is fairly intuitive. In addition to reduced amounts of detrimental inputs, biomass energy feedstocks affect water quality in a less straightforward manner. Considerable evidence exists that riparian vegetation between agricultural fields and streams acts as a filter for compounds that are detrimental to stream water quality [e.g., 2–4]. Creating vegetative filter or buffer strips in less productive

floodplain land by using biomass energy feedstock crops may therefore have both economic and environmental benefits for the farmer.

With regard to water quality, flows of sediment, phosphorous, and nitrate-nitrogen (NO_3-N) from cultivated land are of the most interest.


Nitrogen
kg/ha/yr
800
600
400
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P BL SG RC EC C S
Phosphates
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Potassium
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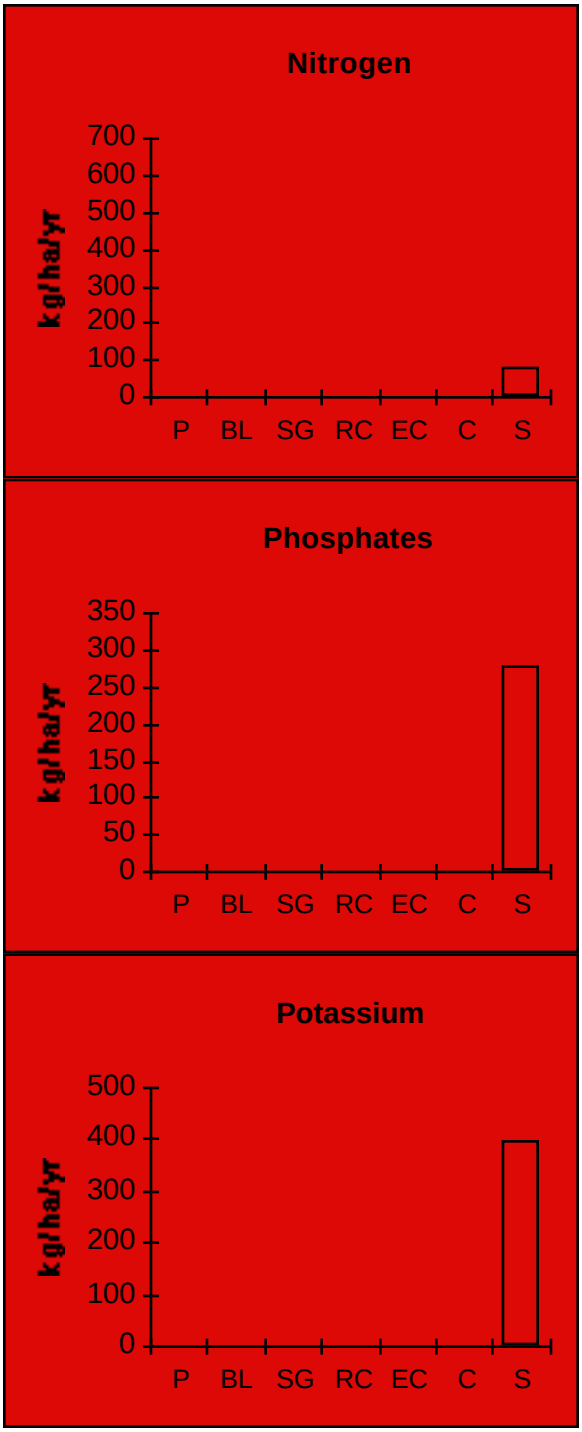
Nitrogen
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Potassium
kg/ha/yr
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P BL SG RC EC C S

Figure 1. Fertilizer application rates for Populus (P), Black Locust (BL), switchgrass (SG), Reed Canarygrass (RC), Energy cane (EC), Corn (C), and Soybeans (S). The left column charts are for upland sites; the right column charts are for former wetlands.

Sediment

Traditional row-cropping practices result in large amounts of sediment leaving cultivated land and being deposited in streams and thereby increasing sediment loads of the streams. In comparison to the traditional row-cropping schemes for corn and soybeans, crops used for biomass energy feedstocks better protect soil from erosion and reduce sediment inputs to the streams. Table 8.2 shows estimated erosion rates for biomass energy feedstocks.

Table 8.2. Anticipated annualized erosion rates for energy crop on uplands and former wetland sites (metric tons/ha).

Crop Type	Uplands			Former Wetlands		
	1st year	2nd year	Other years	1st year	2nd year	Other years
Trees	22-108	11-76	2-13	0-33	-11-33	-33-2
Perennials	33-98	2-22	2-22	0-33	-33-.2	-33-.2
Energy cane	54-65	2-22	2-22	0-33	-33-2	-33-2
Sorghum	54-98	54-98	54-98	0-33	0-33	0-33

Note: No actual measurements have been taken of erosion from energy crops. Figures were developed from various analogues with other crops across several regions. Former wetlands may be sites of sediment accumulation and thus negative erosion values.
Source: Ranney, J. W., J. T. Martin, M. A. Doan, and C. A. Thomas. 1994. Energy Crops: An opportunity for restoring wetland functions. Oak Ridge National Labs [1].

Erosion rates for corn in Iowa are approaching 27 metric tons per hectare. These rates are lower than in the past due to an increase in acreage being managed to reduce erosion. Mature biomass energy feedstock crop plantations compare well to corn with regard to annualized erosion rates (Figures 8.2a and 8.2b).

Sediment inputs to streams come from both stream banks and cultivated land. Data conflict regarding which is the more important source of sediment. In Illinois, researchers estimate that 86% of gross soil erosion comes from cultivated land, and only 4% from stream banks [5]. Similar results are presented for Indiana, where only 6% of in-stream sediment is derived from stream banks [6]. More specific studies in Illinois contradict the general findings of the Illinois Agricultural Task Force by estimating between 23% and

57% of total sediment load is derived from streambanks [7–9]. Regardless of the exact amount of sediment derived from streambanks, agricultural land is definitely an important source of sediment.

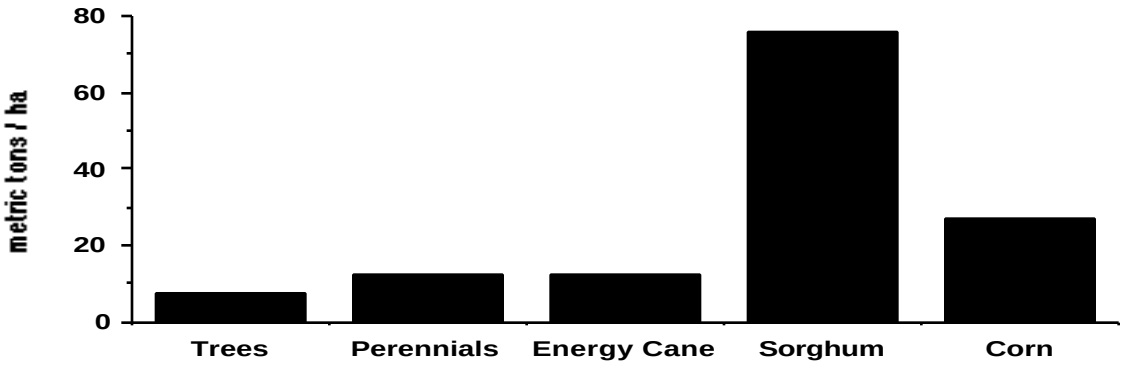

Figure 8.2a. Comparison of annualized erosion rates for corn and various biomass energy feedstock crops for upland sites. The erosion rates for biomass energy feedstock crops represent average values for mature plantations.

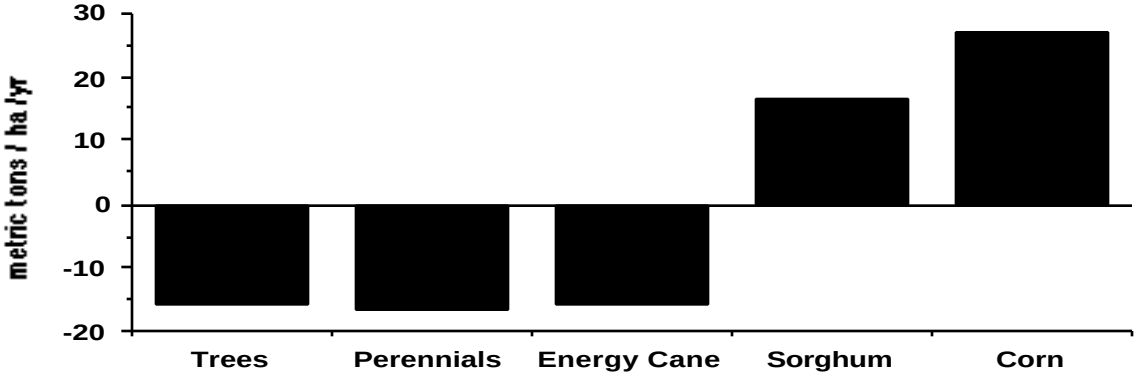

Figure 8.2b. Comparison of annualized erosion rates for corn and various biomass energy feedstock crops for former wetland sites. Negative values indicate sediment accretion. The erosion rates for biomass energy feedstock crops represent average values for mature plantations.

Biomass energy feedstock crops maintained as riparian buffer strips have an important impact on the transport of sediment to streams. Riparian zone vegetation (especially the roots of woody vegetation) stabilizes the stream channel; therefore, less sediment is input from the stream banks. In addition, vegetation increases the hydraulic resistance to flow [10]. Consequently, flow velocities through the vegetation are reduced and sedimentation occurs. Therefore, riparian vegetation downslope of cultivated fields serves as a trap for agriculturally derived sediment.

Sediment deposition within riparian areas is not spatially uniform. The majority of sediment is deposited at the edge of a forest in contact with the agricultural fields. The reduction in flow velocity due to the vegetation results in large-sized grains being deposited. In a study of riparian sedimentation in the North Carolina Coastal Plain, Cooper et al. [2] found that the thickest sediment deposits were located at the forest's edge. In addition, the type of sediment varies with location. Larger grain sizes (sand size grains and aggregates) are deposited near the forest edge [2]. In contrast, the clay-sized grains require lower velocity flows for sedimentation to occur. Clay-sized grains tend to be deposited in flatter, flood plain swamps [11].

Estimates of the amount of sediment that can be sequestered in filter strips vary. Studies have been done to quantify the deposition of sediment in riparian filter strips. Dillaha et al. [12] established 4.6 m and 9.1 m vegetated filter strips below bare soil plots and then simulated rainfall events. The 9.1 m filter strips removed 70% to 98% of the incoming sediment; while the 4.6 m filter strips removed 53% to 86% of the sediment [12]. Similarly, in filter strips consisting of fescue, Magette et al. [13] achieved a 66% reduction of incoming sediment for 4.6 m filter strips. At watershed scale in the Coastal Plain of North Carolina, 84% to 90% of the sediment removed from agricultural fields remains in the watershed; sediment retention in this case is attributed to riparian vegetation acting as filter strips [11]. Although, these data show a substantial reduction in the amount of sediment reaching streams, the performance of filter strips in limiting sediment input to streams is highly variable [13].

In order for biomass energy feedstock crops to be used effectively as filter strips, some general design criteria should be adopted. The presence of a filter strip increases the effective distance between a cultivated field and a stream bed. Cooper et al. [11] suggest that the width of the buffer strips should be proportional to the contributing area, slope, and the cultural practices in the fields above.

Vegetated filter strips are not adequate for sediment removal in all cases. Riparian areas remove more sediment when the flow through the riparian area is not concentrated. Concentrated flow tends to move more rapidly through the filter strip and thereby reduces sedimentation. Dillaha et al. [12] note that "vegetative filter strips are effective for the removal of sediment and other suspended solids from surface runoff if flow is shallow and uniform and the vegetative filter strip has not been previously inundated with sediment." One should note that riparian areas and vegetative filter strips serve only as areas of intermediate storage. Thus the sediment that is deposited within the riparian zone will eventually move from the riparian zone to the stream. The movement of the sediment depends upon the magnitude and duration of precipitation events. For example, Magette et al. [13] found that filter strips became less effective in reducing sediment load into streams as more and more runoff events occurred. Furthermore, in a study of water movement from a corn field through a riparian forest, researchers found that there was little or no accretion of sediment within the forest, but there was net erosion along the path of overland storm flow [14].

Nitrates

Permanent vegetative cover in the form of filter strips is thought to be the most effective practice available for reducing the surface-runoff losses of nutrients and the leaching of nitrates (NO_3-N) into groundwater [15]. Due to the amount of nitrogen fertilizer that is used in the production of corn in Iowa, the ability to remove nitrates both from surface water and groundwater is an important water quality consideration. In the Little River watershed in Georgia, the streamflow outputs of NO_3-N from the watershed were less than the inputs to the watershed from precipitation, despite heavy fertilizer application to row crops within the watershed [16]. The removal of NO_3-N from the water reaching the stream is attributed to the presence of riparian vegetation [17]. Crops for use as biomass energy feedstocks may be particularly effective in controlling nitrate pollution.

The reduction of nitrate inputs to water supplies by vegetation is accomplished through two primary pathways. First, nitrates may be incorporated directly into vegetative biomass such as stems, branches, and leaves. Alternatively, nitrates may be lost to the atmosphere as gaseous nitrogen via anaerobic denitrification [10].

With regard to nitrogen uptake, Lowrance et al. [17] note that riparian vegetation can serve as both a short- and long-term nutrient filter and sink if the vegetation is harvested periodically. In a study of a vegetative filter strip in Georgia, researchers found

that nitrogen in wood and leaves from a filter strip located downslope of a pigpen was higher than at any of the other sites tested [18]. In this study, the pigpen acted as a constant source of nitrogen to the filter strip. The increased levels of nitrogen in tissue ash indicate that nitrogen was being incorporated at a higher rate. Therefore, the general hypothesis that bottomland riparian forests act as nutrient filters, intercepting upland applied nutrients is supported by the study of Fail et al. [18]. Increased tissue nitrogen levels have also been reported for vegetative filter strips composed of hybrid poplar in Iowa [19, 20].

Probably the most important mechanism for reducing nitrate input into groundwater and streams is denitrification. In some cases, the uptake of nitrogen by plants is discounted as an important process and the removal of nitrates in the riparian zone is attributed entirely to denitrification (e.g., [21]). Denitrification refers to the transformation of mineralized nitrate to nitrogen gas (Eq. 1).

$$5CH_20 + 4H^+ + 4NO_3^- \rightarrow 2N_2 + 5CO_2 + 7H_2O \qquad (1)$$

Denitrification is accomplished in the presence of a facultative anaerobic bacteria usually of the genus *Phytomonas*. The anaerobic conditions that are necessary for denitrification to occur are most commonly found in flooded areas. However, significant amounts of denitrification occur in drier areas because oxygen diffusion to the center of soil aggregates is very slow and thereby allows the formation of anaerobic microzones that are both common and sufficient enough to allow for a substantial amount of denitrification to occur [22].

The amount of nitrogen that is retained by riparian vegetation is considered to be considerably higher than that retained within cultivated fields. Peterjohn and Correll [3] found that cropland retained approximately 8% of the nitrogen input, while riparian forest retained 89%. Retention in this case is measured as the difference between inputs and outputs and does not necessarily mean that the nitrogen was incorporated into plant tissue. In fact, Peterjohn and Correll [3] consider denitrification as a viable explanatory process for the high amounts of nitrogen retained by the riparian forest. Other researchers present similar findings.

Haycock and Pinay [23] compared the ability of a poplar-vegetated riparian zone and a grass-vegetated riparian zone to filter nitrogen. The poplar zone removed 99% of the input nitrate, whereas the grass zone only removed 84% of the nitrate. The greater ability

of the poplar zone to remove nitrates is attributed to the greater amount of organic material contributed to the soil. Inputs of organic carbon, in the form of leaf litter, to the soil increase the soil microbacterial biomass that is engaged in denitrification [23].

The width of the filter strip has an effect on the ability of the strip to reduce nitrogen inputs to the stream water. Vegetated filter strips 4.6 meters wide removed 54% of the incoming nitrate; filter strips 9.1 meters wide removed 73% of the incoming nitrates [12]. Therefore, it can be concluded that wider strips are more likely to produce higher-quality water. However, in cases where wide filter strips are not possible due to either physical or economic constraints, it is important to note that the majority of nitrogen retention occurs near the forest-field edge. Haycock and Pinay [23] found that the majority of the nitrate absorption occurred within the first 5 meters of the filter strip. Jordan et al. [14] report that NO_3 concentrations decreased from approximately 8 mg/L at the forest-corn field boundary to less than 0.4 mg/L halfway through the forest. Most of this reduction occurred abruptly at the edge of the floodplain forest [14]. Simmons et al. [24] found that the transition zones between cultivated fields and wetlands were also adequate at removing nitrates. During the dormant season, 36% of the groundwater NO_3 was removed within the transition zone; growing season values ranged from 50% to 78% [24].

Ground water appears to be the most important pathway for nitrate flux between cropland and the downslope riparian areas. High water tables in flood plain areas in conjunction with the large amount of organic matter contributed to the soil produces reducing conditions that are conducive to denitrification [21]. Lowrance [4] hypothesizes that the majority of nitrate removal occurs within the saturated zone of the soil. His findings indicate that although nitrate is definitely being removed from shallow ground water, it is not due to denitrification. This finding indicates that nitrate within the groundwater is more likely to be removed by vegetation uptake, and nitrate within the saturated zone of the soil is being removed due to denitrification.

Although riparian areas appear to have utility in removing nitrates from runoff and groundwater, Omernik et al. [25] hypothesize that filter strips may become saturated with respect to their ability to remove nutrients such as NO_3-N from agricultural runoff water. This concern, however, should be alleviated in a filter strip consisting of biomass energy feedstock crops, because the periodic harvesting of the vegetation associated with these crops should keep the filter strip from ever becoming saturated.

Phosphorus

Phosphorus has a high affinity for soil particles. Consequently, the movement of phosphorus through a watershed is highly correlated with the movement of sediment. Very small amounts of phosphorus added to a watershed as fertilizer pass through to the streams as soluble phosphorus [26]. Since phosphorus movement is so closely tied to sediment movement, the functioning of vegetation in filtering Phosphorus from agricultural runoff is primarily the same as for the sediment discussed above.

The dominant pathway for removal of phosphorus from cropland is the harvest [3]. In contrast to nitrates, phosphorus flux between croplands and riparian areas occurs predominantly via surface runoff [3].

Filtering phosphorus by filter strips tends to be less effective than filtering sediment. Where Dillaha et al. [12] were able to show a removal of 84% and 70% of suspended solids by filter strips 9.1 and 4.6 meters wide, respectively, the removal of phosphorus for the same strips was only 79% and 61%. In general, the amount of phosphorus removed by filter strips is considerable although some exceptionally low rates of removal have been noted [13].

Pesticides

The effects of riparian ecosystems on pesticide transport have not been studied in as much detail as have sediment and nutrients. The transport of a pesticide from a cultivated field to a stream depends a great deal on the chemical of interest. Some pesticides are strongly adsorbed to sediment particles. For pesticides of this type, riparian buffer strips function in much the same way as they do for sediment and phosphorus. “Adsorbed pesticides, such as trifluralin, are deposited with sediment and adsorbed by vegetation and organic debris in grass waterways. Persistence will determine the ultimate fate of pesticides. Chemicals that degrade quickly, such as methyl parathion or malathion, are unlikely to move from riparian zones. Persistent compounds such as trifluralin, paraquat, or chlordane are likely to disperse into the environment [10]. Some pesticides such as picloram, aldicarb, and dalapon move through the environment dissolved in either runoff or leachate [10]. Dissolved pesticides can be detained in the shallow aquifer system associated with riparian areas. However, as with the sediment adsorbed pesticides, the retention of these chemicals within the watershed will depend upon their persistence [10].

CO_2 Emissions

A common theme throughout the biomass energy literature is that there is no net emission of CO_2 to the atmosphere occurs because of the use of biomass as a feedstock for either electricity or liquid fuel production [27]. Since CO_2 is required by plants to grow, biomass merely cycles CO_2 from the atmosphere to the standing crop of biomass when it is grown renewably. The only net increase in CO_2 to the atmosphere is through the use of fossil fuels in the production process [27].

By converting from fossil fuels to biomass-derived fuels, some researchers hypothesize that the U.S. carbon emissions could be reduced by approximately 20% in the future [28]. To accomplish a 20% reduction in carbon emissions over the next 35 years, Wright and Hughes [29] estimate that the following would be necessary:

1. New feedstock plantings would have to be installed at an average rate of 1 x 106 ha/yr
2. Yields would have to increase on average 1.5%/yr for the 35-year period
3. Highly efficient conversion technologies would have to be installed at a rate of 5000 MW of new capacity/year for the next 35 years.

Carbon that is absorbed by the growing biomass and dedicated to above ground biomass can be considered to cycle every year through either decomposition or combustion [30]. Table 8.3 shows annual CO_2 flows through biomass production systems at five locations.

In addition to the CO_2 that cycles through the above ground biomass, some CO_2 is removed from the atmosphere and sequestered in the soil. The CO_2 sequestered in the soil is found as roots and soil organic matter. The replacement of corn with trees results in a net increase in soil carbon of 8 tons/acre at equilibrium [31]. In contrast, the replacement of forest with tree plantations will result in an 11 ton/acre reduction in the amount of carbon sequestered in the soil at equilibrium [31]. Perennial grasses will also aid in sequestering carbon in the soil; however, the amounts of carbon sequestered in the soil will generally be less than for trees. Perennial grasses will only result in an increase of approximately 2 tons C/acre as compared to 8 tons for trees [30].

A specific analysis has been done by Marland & Turhollow for the CO_2 emissions associated with the production of ethanol from corn [32]. They find that 26.00 $\pm$ 3.52 MJ of energy are needed to produce 1 kg of ethanol. Of this total, 8.38 MJ/kg ethanol is associated with the production of the corn. The energy required for corn production is primarily the result of fertilizers and fuel necessary for planting and harvesting the crop.

The CO_2 emissions associated with the production of ethanol are 0.550 + 0.087 kg C / kg ethanol. Of this 32.2% is attributed to corn production. Therefore, for every kg of ethanol produced, approximately 0.1771 kg C is released as CO_2. The release of CO_2 to the atmosphere currently is a net input to the atmospheric system. However, if the fuels derived from biomass feedstocks were used in the production and conversion of corn to ethanol, the release of CO_2 to the atmosphere would be a cycling of atmospheric CO_2 and result in no net increase in atmospheric CO_2.

Table 8.3. Annual CO_2 flows.

	Total Annual CO_2 Flows (tons CO_2/ year)	
Location	Standing yield	Lbs CO_2/MMBtu
	Tree crops	
Rochester	576,742	11.41
Tifton	782,763	11.18
Peoria	551,374	11.34
Lincoln	—	—
Portland	1,702,004	11.21
	Perennial grasses	
Rochester	1,086,629	11.87
Tifton	696,189	10.26
Peoria	816,100	10.26
Lincoln	1,768,125	13.22
Portland	—	—
	Energy cans and sorghum	
Tifton	145,857	10.06
Peoria	242,501	10.27

Source: Perlack, R. D., J. W. Ranney, and L. L. Wright. 1992. *Environmental Emissions and Socioeconomic Considerations in the Production, Storage, and Transportation of Biomass Energy Feedstocks*. ORNL/TM-12030. Oak Ridge National Laboratory, Oak Ridge, Tennessee [30].

Effects of Increased Biomass Feedstock Production on Wildlife

The effects of biomass energy on wildlife are primarily evident as changes in biodiversity for a given area. Increased production of biomass energy feedstock crops could potentially reduce or increase biodiversity. Few if any studies have been conducted that specifically address how biodiversity will be affected by biomass energy crop production schemes. However, the results of other studies that describe how biodiversity is affected by similar silvicultural and agricultural procedures can be used as a guide to predict how increased production of biomass energy feedstock crops would impact biodiversity. Biomass production can be envisioned as occurring on some combination of dedicated biomass energy plantations and in fringe areas of agricultural fields. Dedicated biomass plantations are defined as areas that are devoted to biomass energy feedstock production but are not necessarily associated with other more traditional agricultural pursuits. Biomass production in fringe areas of more traditional agricultural fields may be evident as buffer or filter strips between fields and riparian areas or as corridors linking larger areas of either natural forest or dedicated biomass plantations.

Habitat destruction is thought to be the most important cause of a reduction in biodiversity [33]. Specifically, the reduction of natural forest habitat due to more intensive and extensive biomass energy feedstock production is a common concern in the literature. As biomass energy becomes more economically viable, there is concern that idle land may be put into production [34]. Idle land is defined as land that is currently not used by humans, i.e., it is uncultivated and primarily used by other species. "The extent of habitat destruction from biofuels development will depend on the intensity with which natural ecosystems are harvested and the amount of 'idle' land brought into production" [34].

Intensive Land Use

Concerns about more intensive use of land for biomass feedstock production focus on the reduction in complexity of agro-ecosystems due to the production of biomass energy feedstock crops in monocultures. The desire to maximize production and minimize cost has routinely led to monoculture agro-ecosystems that virtually eliminate biological diversity [34].

Monocultures are typically planted and harvested as even-aged stands. Therefore, in addition to a reduction in plant species diversity, there is also a reduction of structural diversity. A reduction in structural diversity creates a reduction in habitat for the wildlife species that depend on diverse forest resources. Forests that become more intensively

managed for biomass feedstocks may suffer a reduction in the number of snags and result in a reduction in the number of suitable nesting sites for birds and other animals [35].

A more intensive use of crop land would entail increased use of crop residues. Crop residues are currently important sources of food and habitat for a variety of wildlife within traditional agro-ecosystems. In Nebraska, more than 400,000 sandhill cranes depend on waste corn [34]. Waste corn near the Platte River supplies the cranes with 90% of their caloric requirement for their northward migration [36]. As with crop residues, logging residues are also important for maintaining biodiversity. Intensification of the use of forest lands might lead to a more intensive use of logging residues. Removal of these residues reduces the amount of decaying material on the forest floor. These residues are important to many animal species ranging from insects to amphibians, reptiles, and small mammals [35].

Extensive Land Use

Many biomass feedstock crops are currently not economically important. In addition, some biomass feedstock crops grow well in areas that are unable to support more traditional agricultural crops such as corn and soybeans. Therefore, as biomass energy is adopted, these more marginal lands, particularly wetlands, may be brought into production. Marginal lands are not farmed for traditional agriculture because they are either too infertile or too rough [34]. However, these marginal lands also provide habitat for thousands of plant and animal species [37]. Proliferation of biomass energy feedstock crops could result in dramatic reductions in habitat as marginal lands are brought into production.

As agriculture penetrates new areas, farmers may view the wildlife populations that are encroached upon as pests. As a consequence, wildlife may be threatened by pest eradication measures such as trapping and hunting in addition to a reduction of suitable habitat.

Wetlands are some of the most diverse and densely populated wildlife habitats. In Texas and Oklahoma bird density in riparian areas is seven times greater than in other areas. Wetland habitats are important for a variety of animal species including birds, butterflies, and mammals [38]. Although wetlands offer some of the most diverse and productive wildlife habitat, they are also considered to be prime candidates for conversion to biofuels plantations [39].

A specific example is available for Iowa. Researchers have begun to evaluate the utility of silver maple as a biomass energy feedstock crop to be grown on occasionally

flooded bottomland in Iowa [39]. Outside of Iowa, cattails are being considered as biomass feedstock crops [40]. In general, the concern with more extensive land use for biomass energy feedstock production is that "biomass farming of lands that are currently not under agricultural production will permanently displace most wild users of these lands" [41]. In the event that displaced species are unable to migrate or find suitable habitat elsewhere, a reduction in biodiversity will result.

Guidelines for Biodiversity Management

Although there are potentially some dire consequences for wildlife resulting from bringing currently uncultivated land into cultivation, and a more intensive use of currently farmed land for the production of biomass energy feedstock crops, the future need not be so catastrophic. It should be possible to maintain or even increase wildlife diversity with an increase in biomass energy feedstock production. In order to avoid a drastic reduction in wildlife diversity, farmers may need to adopt some procedures that will produce suboptimal yields on the land used for biomass energy feedstock production. Below are some general guidelines for maintaining wildlife diversity.

1. Perhaps the most important guideline for maintaining wildlife diversity is to avoid monocultures. In addition to the increased chances of fungal and insect infestations in monocultures, monocultures are inherently poor habitat for wildlife. They provide habitat for only a fraction of the natural wildlife. Those species that are particularly at risk are the habitat specialists, generalists may be able to adapt more readily to monocultural conditions [41].
2. Species alien to a region should not be used as biomass energy feedstock crops [42]. Although local wildlife may be able to adapt to large tracts of indigenous species, alien species (such as Eucalyptus in the Northern Hemisphere) do not have a coexisting faunal population in place. It is less damaging to wildlife populations to use a native species.
3. Given the economic advantages of monocultures, it is unlikely that they can be avoided. However, if planned appropriately, they need not be exceedingly detrimental to wildlife population. For instance, filling gaps between forest patches with trees to be used as biomass energy feedstocks should increase the effective size of forest patches. Increased size of forest patches creates habitat more suitable to forest interior species [42]. Small areas of contrasting forest

type promote wildlife use and diversity [42]. Similar procedures can be used for herbaceous crops in between patches of prairie.

4. Along the same lines as suggestion 3, biomass energy crops can be used as corridors between similar patches of vegetation. Corridors increase the connectivity of landscapes and theoretically increase movement of species between larger habitat patches [38, 43].
5. In addition to maintaining a diversity of species within a patch of land dedicated to biomass energy feedstock production, structural diversity should also be maintained. Crops should not be harvested all at the same age in order to maintain some diversity in the age structure of the vegetation providing habitat for wildlife. For example, the inclusion of some mature trees within short-rotation woody crop plantations can increase habitat diversity and benefit wildlife [42].
6. Use riparian buffer strips. Buffer strips composed of biomass energy feedstock crops help control erosion and act as nutrient sinks. In addition, they serve as corridors and provide connectivity between larger patches of habitat [38]. Buffer strips should be constructed to be a mix of both natural vegetation and biomass energy feedstock crops. Thin buffer strips may have negative effects on bird populations. For instance, Stauffer and Best [44] predict that 20 of 32 species of Iowa songbirds would be adversely affected by leaving only a narrow buffer strip between an agricultural field and a stream. Triquet et al. [45], on the other hand showed that a 15-to-23 m wide riparian buffer strip of uncut trees surrounding a clear cut area (which could be considered analogous to an agricultural field) provided habitat for both interior and edge dwelling species of songbirds. Their results suggest that buffer strips provide habitat that encourages a high diversity of breeding birds.

Wildlife Conclusions

Since different species have different habitat needs, it is difficult to assess the impact of increased land being put to use for biomass energy feedstock production. Ranney et al. [1] indicate that it appears that short rotation woody crops are frequented by game birds, game animals, common woodland birds, and songbirds during the late phases of their rotation. Some water fowl are have also been seen to frequent plantations of short rotation woody crops [1]. Herbaceous crops are also thought to be more beneficial to

wildlife than traditional agricultural crops. This is due, in part, to the less frequent harvests associated with biomass energy feedstock crops. Less frequent harvest results in more seed supplies, and a longer duration of cover and disturbance free nesting sites [1].

These findings seem to indicate that although there is the potential for a reduction in biological diversity due to increased production of biofuel crops, it is not an inevitable consequence. If biomass energy feedstock crops are planted with some consideration to maintaining wildlife diversity, particularly at a regional scale, the impact on wildlife may be minimal.

BIOMASS CONVERSION

Direct Combustion

The environmental effects from two scales of combustion are considered here: residential wood combustion (small scale), and the generation of electricity and (large scale). Types of existing systems for use in residential wood combustion include fireplaces, non-airtight stoves (such as potbelly stove), nearly airtight stoves, and airtight stoves.

Emissions from residential wood combustion depend heavily upon the operating conditions. For instance, dried wood should be used as the feedstock. If wood is not dried prior to combustion, the moisture in the fuel will result in lower combustion temperatures; and incomplete combustion will result. The results of incomplete combustion are high emissions of particulates and carbon monoxide. Furthermore, if sufficient secondary air is not supplied above the fuel bed to completely burn the volatiles, high hydrocarbon emissions will occur.

Typical emissions for wood burning under a variety of conditions are compared in Table 8.4 to emissions from burning a variety of agricultural waste products. The important thermal decomposition products of wood are particulates, volatile hydrocarbons, and carbon monoxide.

The techniques available for evaluating the air quality impact of combustion are predominantly those for assessing the emissions associated with large, centralized emissions sources. Although the lack of techniques specifically for small-scale use hinders any attempt to predict the air quality impact of small-scale combustion, some attempts have been made to estimate it.

Tables 8.5 and 8.6 were derived by using available predictive techniques to predict ground-level concentrations of pollutants from wood combustion devices. This analysis

was performed for a single wood combustion device burning 3 kg of wood per hour with a 10 m high chimney subjected to a 2 m/s wind.

Braunstein et al. [46] has compared a community of 247 houses using wood heat to a 1,000MW coal-fired power plant. Total particulate emissions during 4 months of heating would be 18 tons. The comparable total particulate emissions from a state-of-the-art 1,000-MW coal-fired power plant serving a population of 500,000 would emit approximately 13 tons of particulate during the same time period.

Table 8.4. Air emission factors from combustion of biomass (kg/metric ton).

Source	Particulates	CO	Hydrocarbons	SO_x	NO_x
Wood/bark in boilers, 50% moisture	7.5[a]	0.5-15	0.5-1.75	0.375	2.5
Wood in residential fireplaces	5[b]	30	1.25	0	0.25
Waste open burning, agricultural and wood refuse					
Unspecified	5.25	29	5.75		
Corn	3.5	27	4		
Rice (dry)	2.25	20.75	2.5		
Rice (wet)	7.25	40.25	5.25		
Sorghum	4.5	16.75	2.25		
Sugarcane	1.75	18.25	2.5		
Oats	5.5-11	34	4.5-8.25		
Wheat	3.25-5	27-32	2.75-4.25		
Forest residues, unspecified	4.25	35	6		
Bagasse burning	5.5				
Bagasse boilers	4				

[a] Bark only, 12.5 kg/metric ton.

[b] Contains as much as 70% condensate.

Source: Braunstein, H.M., F. C. Kornegay, R. D. Roop, and F. E. Sharples. 1981. Environmental and health aspect of biomass energy systems. 463-504. Eds. Klass, D.L. and Emert, G.H. (eds). In *Fuels from Biomass and Wastes*. Ann Arbor: Ann Arbor Science Publishers Inc. [46].

We have collected information for three types of large-scale conversion of biomass to energy by combustion: hog fuel boilers, combined firing systems, and fluidized bed conversion.

Hog fuel boilers use wood refuse from sawmills to generate steam. The steam is then used in turbines. The steam capacity for most wood-fired boilers falls between 114 to 1,140 kg steam per minute. The most common firing method is the spreader stoker. Overfeed stokers are common for steam capacity less than 1,900 kg steam per minute [47].

One of the most important considerations in wood firing is the fouling potential of wood. Wood ash is high in CaO (50% to 60%), Na_2O, and K_2O (4% to 7%). Wood is expected to produce more fouling problems than residual fuel oil. Ash fouling will

Table 8.5. Maximum one-hour ground-level concentrations of emissions from one wood-burning device (µg/ m^3).

	Stove				
	Oak				
Downwind distance (m)	Particulates[a]	Hydrocarbons[b]	CO[c]	Pine particulates[d]	Fireplace particulates[e]
25	1.5	1-32	114	8.8	13.2
50	4.6	3-98	354	27.2	40.7
75	4.2	3-87	320	24.6	36.8
100	3.3	2-70	254	19.5	29.2
150	2.1	1-45	461	12.4	18.6
200	1.5	1-31	111	8.5	12.8
250	1.1	0.7-23	82	6.3	9.4
300	0.8	0.5-17	62	4.8	7.2

[a] From [48]. Emissions: 1.7 g/kg wood.

[b] From [49]. Emissions: 1-35 g/kg

[c] From [50]. Emissions: 130 g/kg wood.

[d] From [48]. Emissions: 10.0 g/kg wood.

[e] From [51]. Emissions: 15.0 g/kg wood.

Source: Braunstein, H.M., F. C. Kornegay, R. D. Roop, and F. E. Sharples. 1981. Environmental and health aspect of biomass energy systems. 463-504. Eds. Klass, D.L. and Emert, G.H. (eds). In *Fuels from Biomass and Wastes*. Ann Arbor: Ann Arbor Science Publishers Inc. [46].

Table 8.6. Peak concentrations from one wood-burning device (μg/m^3).

	Stove				
	Oak				
Time[a] (hr)	Particulates[b]	Hydrocarbons[c]	CO[d]	Pine particulates[e]	Fireplace particulates[f]
1	4.7	3-99	356	27.4	41.1
3	3.2	2-67	242	18.6	18.0
24	1.5	1-32	116	8.9	13.3

[a] Time scaling factors from [52].
[b] From [48]. Emissions: 1.7 g/kg wood.
[c] From [49]. Emissions: 1-35 g/kg
[d] From [50]. Emissions: 130 g/kg wood.
[e] From [48]. Emissions: 10.0 g/kg wood.
[f] From [51]. Emissions: 15.0 g/kg wood.

probably be more severe for wood than coal because of the presence of alkali in wood, especially young, fast-growing plant parts [47].

The primary emissions from hog fuel boilers are particulates. The other important environmental considerations are the generation of captured fly ash and bottom ash. The fly ash and bottom ash can be disposed of in landfills.

Particulate pollutant emissions and ash in the form of captured fly ash and bottom ash are expected from wood burning. However, sulfur emissions should be negligible. Nitrogen oxide emissions are expected to be lower than for coal because of the low nitrogen content of wood [47]. However, herbaceous species, particularly legumes, have greater concentrations of nitrogen than wood. Thus NO_x may be more of a problem for herbaceous materials than for woody species [27].

Particulate emissions from wood-fired boilers depend on the extent of char reinjection, boiler type, excess air used, wood waste type (e.g., logs, sawdust, chips), and wood moisture content. Hall et al. [53] reported that the single most significant factor is probably the extent of char reinjection utilized [47].

Fly ash particulates from hog fuel boilers are light in density and larger in size than fly ash from coal-fired boilers. Particulate emissions also depend on the boiler design and operating conditions and feedstock properties. Because of these variations, a specific dust

loading cannot be established. Dust loadings ranging from 1,144 to 11,441 mg/nm^3 are reported. Multicyclones or those in combination with wet scrubbers with moderate pressure drops can also be used effectively on these boilers. However, use of scrubbers may result in secondary wastewater pollution [47].

Fluidized bed conversion is more environmentally friendly than other types of boilers such as spreader-stokers or dutch ovens. The process involves the mixing of the solid fuel (biomass) with an inert heat-transfer medium (such as sand) and occasionally sorbents. The sorbents are used to capture some of the toxic compounds that could end up in the solid waste stream.

Advantages of FBC over a spreader-stoker include insignificant thermal NOx emissions. The FBC has more uniform bed temperatures, and peak temperatures are minimized resulting in little thermal NO_x being formed. The primary pollutants for FBCs are trace amounts of organics and metals derived from the feedstocks. These pollutants are present in both ash and stack discharges. The emissions of these pollutants, however, are not expected to exceed limits set by environmental regulations.

Five material or chemical agents are generated by biomass power systems that may impact the air, water, and solid waste streams: products of incomplete combustion (PICs), trace metals, particulates, acid gas precursors, and water treatment chemicals. A summary of these emissions from FBCs is given in Table 8.7.

Typical concentrations for various products of incomplete combustion in fluidized beds are listed in Table 8.8. Good fuel-air contact in fluidized beds results in reduced products of incomplete combustion compared to other biomass combustion technologies.

Trace metals are generally not volatile in FBCs due to relatively low combustion temperatures. Therefore, metals are primarily of interest in the bottom ash waste stream. Data categorizing these type of emissions are very limited.

Bottom ash waste streams for FBCs are negligible because of the relatively low density of the biomass fuel. Nearly 100% of the biomass ash is entrained in the flue gas. Two efficient particulate removal systems are available for FBCs. Electrostatic precipitators (ESPs) and fabric filter baghouses (FFBs). If one assumes a biomass fuel with an ash content of 2.2 lb/MMBtu (1.05 kg/kJ) and 7.5% fly ash removal in the heat exchangers, particulate emissions at the stack should be roughly 0.02 lb/MMBtu (0.01 kg/kJ) for an FFB and 0.20 lb/MMBtu (0.10 kg/kJ) for an ESP [54].

Thermal NOx is not a problem in FBCs because of relatively low combustion temperatures. Uncontrolled NOx emissions from biomass-fired FBCs are typically in the

range of 0.08 - 0.10 lb/MMBtu (85-110 ppmv) [55] for both treated and untreated fuels. These values are significantly lower than for other types of boilers. Some agricultural wastes and energy crops (switchgrass in particular) have nitrogen contents above the 1% level. For these resources, fuel-bound nitrogen can result in significant NO_x emissions if not controlled [54]. Sulfur dioxide emissions are relatively low from biomass fuels burned in fluidized beds as illustrated in Table 8.9. Generally, no remediation is required.

Gasification

During gasification, hydrogen chloride, hydrogen sulfide, and ammonia may be formed from chlorine, sulfur, and nitrogen contained in the biomass feedstock. Waste water is produced during gas cleaning. The presence of large quantities of complex organic materials can make the wastewater difficult to treat biologically [56], but Hos and Groeneveld [57] indicate that wastewater treatment is a manageable problem [27].

Solid wastes are obtained both from fly ash and bottom ash. The chemical composition of the ash from a gasifier resembles that from combustion, except that it has a higher char content [27].

Table 8.7. FBC stack emissions (nominal 50 MW).

Pollutant	Uncontrolled emission rate	Controlled emission rate
CO	14-250 ppmv 27-475 ton/year	(a)
HC	< 1 ppmv	(a)
NOx	0.08 -0.10 lb/MMBtu 174-225 ton/year	0.01 lb/MMBtu 17-23 ton/yr
SO_2	0.1-0.5 lb/MMBtu 215-1075 ton/year	0.01-0.05 lb/MMBtu 22-108 ton/year
Particulates	2.0 lb/MMBtu 4,300 ton/year	0.02 lb/MMBtu 43 ton/year
Metals		As: 11.4 u/dscf Cr: 19.2 u/dscf Hg: 0.3 u/dscf Pb: 98.5 u/dscf

(a) Emission control equipment not required; emissions inherently controlled with good combustion practices.

Source: Antares Group Inc. 1993. Electricity from Biomass: An Environmental Review and Strategy. NREL/TP-420-5637 [54].

Table 8.8. PICs generated by FBC.

Product	Concentration
CO	14-250 ppm
Formaldehyde	21 ppbv
Acetaldehyde	13 ppbv
Benzene	8 ppbv
Phenols	Not detected

Source: Antares Group Inc. 1993. Electricity from Biomass: An Environmental Review and Strategy. NREL/TP-420-5637 [54].

Table 8.9. SO_x emissions for FBC.

Fuel	Sulfur Content (weight %)	SO_2 Emissions (lb/MMBtu)
Hogged fuel	0.04	0.09
Pine bark	0.10	0.22
Oak bark	0.10	0.24
Rice husks	0.10	0.28
Cotton gin trash	0.40	1.07

Source: Antares Group Inc. 1993. Electricity from Biomass: An Environmental Review and Strategy. NREL/TP-420-5637 [54].

Tars are produced during the gasification process. The tars may be removed from the product gas by scrubbing with either oil or water. The resulting liquid waste stream must also be treated.

Dust, SO_2, and NO_x are the primary airborne emissions. Less than 0.005 grains/scf are produced. With regard to NO_x, emissions are < 0.12 lb/MBTU [58]. SO_x emissions range between 0.12 and 0.50 lb SO_2/MBTU [59].

Sellden et al. [56] present worst case data for waste streams associated with gasification. There are four steps where major negative environmental impacts could be obtained:

a. microorganisms, spores, wood dust, and light hydrocarbons obtained during the storage and treatment of biomass prior to use (see Ref. [60]).
b. solid wastes containing carbon and heavy metals
c. wastewater with a high content of organic compounds
d. gaseous components obtained upon combustion of methanol or mixtures of methanol.

Solid wastes are obtained as solid ash from the gasifier and as fly ash in the dust removal step. Generally there should be no negative effects of the deposition of the solid wastes obtained from biomass conversion. Below are some representative data for solid wastes from methanol production. The figures are based on a production of 5,000,0000

tons methanol/year from 1.1 million tons of wood or dry peat with an ash content of 0.5% and 5% and a char content of 1% [56].

	Wood	Peat
Solid Waste (char & ash) metric tons/year	72,750	291,007

There are two major wastewater streams. One results from the condensation of raw gas, the other from the wet gas clean up step. Table 8.10 shows the typical chemical make up of tar water from two gasification processes.

When methanol is burned in a power or heat production plant, the same results are obtained as those for auto motors. However, the amount of complex organic compounds are reduced in the power or heat production plant. Table 8.11 shows emissions from methanol use.

Pilot plants for producing methanol from biomass have been constructed, and the majority of the environmental data is based upon these pilot studies.

Ethanol Synthesis

Ethanol synthesis from cellulosic feedstocks is expected to produce wastewater streams with a fairly high organic content. Furthermore, some stack emissions will result; however, no toxic compounds are expected to be produced. Available technologies should make it possible to meet environmental regulations at an ethanol production facility [27].

If cellulose is to be used in ethanol synthesis, the lignin and hemicellulose must be separated from the cellulose. The critical steps in this process are (1) the separation of cellulose from lignin and hemicellulose and (2) the concurrent hydrolysis of cellulose before fermentation [61].

The waste streams associated with the production and use of ethanol as a fuel include residue from prehydrolysis, main hydrolysis, and stillage during synthesis and gaseous emissions during combustion of ethanol fuels in internal combustion engines. Table 8.12 lists waste products from the hydrolysis processes. Table 8.13 lists waste products from tillage. Table 8.14 lists gaseous pollutants from ethanol combustion.

Digestion

During anaerobic digestion, complex feedstocks such as municipal waste, sewage sludge, and agricultural wastes can be converted to methane. Potential pollutants associated with this procedure are CO_2, NO_x, and SO_2. Emission values are available for one RefCoM. Using an integrated waste to energy technology, RefCoM produces methane

Table 8.10. Chemical composition of tar water from two gasification processes. All data in mg/l except pH.

Component	Purox	RIT				
		Raw gas		Thermal reforming		Catalytic reforming
		I	II	1000° C	1100° C	800° C
Methanol	24,400	95	489	-	-	10
Acetic acid	19,800	1,013	129	24	55	158
Ethanol	9,500	-	-	-	-	-
Acetone	9,500	-	-	-	-	-
Methylethyl-ketone	1,900	-	-	-	-	-
Propionic acid	7,600	-	-	-	-	-
Butyric acid	1,900	-	-	-	-	-
Furfural	9,500	-	-	-	-	-
Phenol	1,900	7,116	7,300	118	116	-
Benzene	1,100	18	253	24	2	-
Toluene	-	208	n.d	25	2	n.d
Xylene	-	2	18	n.d	n.d	n.d
Pyridine	-	336	589	108	28	n.d
Napthalene	-	124	29	6	2	63
Quinoline	-	6	12	22	19	n.d
Not identified	7,200	1,451	6,881	364	179	35
NH_3	124	-	-	-	-	-
H_2	1	-	-	-	-	-
$HCO_3(-)$	7,500	-	-	-	-	-
$CO_3(2-)$	57	-	-	-	-	-
$NH_2COO(-)$	102	-	-	-	-	-
NH_4	2,300	-	-	-	-	-
HS(-)	10	-	-	-	-	-
COD		13680	18,570	692	403	308
pH		9.33	9.3	9.07	8.83	8.7

Source: Sellden, G., G. Wallin, S. A. Wangberg, and H. Egneus. 1985. The environmental effects of producing methanol from biomass via gasification. In Bioenergy 84 - Bioenergy Utilization, Vol. IV. Eds. H. Egneus and A. Ellegard. 463–469. London, U.K.: Elsevier Applied Science Publishers [56].

Table 8.11. Chemical characterization of exhaust emission from vehicles fueled with gasoline or mixtures of methanol.

Emission	Gasoline	Methanol (15%)	Methanol (95%)
Carbon monoxide g/km	9.75	19.35	13.34
Nitrogen oxides	2.51	1.83	0.78
Hydrocarbons	1.45	1.64	1.69
Methanol mg/km	4.2	115	3.38
Ethanol	-	4.8	-
Ethylene	91.6	85.3	13.5
Propylene	36.3	28.0	5.6
Benzene, toluene	252.7	344	-
Formaldehyde	26.3	29.5	110.8
Acetaldehyde	<4.4	<4.4	<23.0
Acrolein	<0.4	<0.4	<0.4
Methylnitrite ug/km	94	75	5.7
Polyaromatic hydro-carbons ug/km	170	170	6.2
Benzon(a)pyrene	5.4	5.4	<0.1

Source: Sellden, G., G. Wallin, S. A. Wangberg, and H. Egneus. 1985. The environmental effects of producing methanol from biomass via gasification. In Bioenergy 84 - Bioenergy Utilization, Vol. IV. Eds. H. Egneus and A. Ellegard. 463–469. London, U.K.: Elsevier Applied Science Publishers [56].

gas from MSW and sewage sludge. CO_2 emissions range from 8,500 to 53,300 tons per year. NOx emissions range from 4 to 21 tons per year, and SO_2 emissions range from 2 to 7 tons per year particulate [62].

Pyrolysis

Fast pyrolysis produces biocrude oil that can be used without upgrading as a No. 6 fuel oil replacement or as a feedstock for producing chemicals and polymers. A second product is charcoal.

According to Johnson et al. [63], some of the advantages of biocrude oil are that it has about four times the volumetric energy density relative to the starting biomass feedstock

Table 8.12. Waste streams after production of ethanol by acid hydrolysis. The figures are based on a production of 330,750 metric tons of ethanol in the GIT- Process.

Waste Stream	Wet Weight (metric ton)	Dry Weight (ton)	Comment
Bark	432,180	216,090	Bark and lignin are used as fuels. Ash residue 26,460 met ton, which must be deposited.
Lignin	1,411,200	418,950	
Centrifuge sludge	361,620 (a)	194,040 (a)	Residue from main hydrolysis 46% water, 16% $CaSO_4$ (gypsum) 13% lignin, 3% other organic compounds, e.g. furfural and hydroxymethyl-furfural
Fermentation and stillage waste	749,700	388,080	For use as fodder
Waste water sludge	176,400 (a)	35,280 (a)	Waste water obtained from the process steps
Total for deposition	564,480	255,780	

(a) For deposition

Source: Wangberg, S. A., G. Wallin, and H. Egneus. 1985. The environmental effects of producing ethanol from ligno-cellulosic plant material. In Bioenergy 84 - Bioenergy Utilization, Vol. IV. Eds. H. Egneus and A. Ellegard, 470-475. London, U.K.: Elsevier Applied Science Publishers [64].

and is a storable liquid that can be transportable by dedicated pipeline or tanker to end users [63]. In addition, biocrude is an oxygenated fuel that has a gross energy content of about 25 MJ/l (90,000 -95,000 Btu/gal). An advantage of biocrude oil over No. 6 fuel oil is that it contains little sulfur.

Emissions from pyrolysis systems are not well characterized. Air emissions can consist of particulates and gases in the form of HCl, H_2S, NO_x, and Hg. Estimates indicate that SO_x emissions are about 700 ul/l; NO_x, about 8 to 1000 ul/l; HCl, 100 ul/l; and particulates 114 mg/nm^3 [47]. Solid waste streams may contain undesirable leachates.

Table 8.13. Chemical composition of stillage from some processes producing ethanol from sugar and starch. All figures in mg/l.

Parameter	Ethanol Production Facility				
	ECI	CII	ISU	KOC	RCC
BOD	28,400	20,800	38,600	54,400	43,100
COD	36,800	23,100	60,500	98,700	54,400
Solids, tot	12,200	35,000	52,000	40,400	39,400
$NO_2 + NO_3$	0.45	2.6	0.25	0.08	<0.5
NH_4	4.5	10	31.5	0.37	0.05
SO_4	300	-	466	388	299
PO_4	400	-	477	544	700
Ag	<0.002	-	0.02	0.01	0.004
As	<0.015	-	0.005	0	<0.005
Ba	0.09	-	0.3	-	0.39
Cd	0.01	-	0.006	0.006	0.2
Cr	0.02	-	0.006	0.02	0.058
Hg	<0.002	-	-	0.0015	0.004
Pb	0.05	-	0.03	0.04	0.1
Zn	4.41	-	5.2	13.8	5.05

Source: Wangberg, S. A., G. Wallin, and H. Egneus. 1985. The environmental effects of producing ethanol from ligno-cellulosic plant material. In Bioenergy 84 - Bioenergy Utilization, Vol. IV. Eds. H. Egneus and A. Ellegard, 470-475. London, U.K.: Elsevier Applied Science Publishers [61].

Moreover, wastewater from pyrolysis systems can be high in BOD, COD, alcohols, phenols, and other organic compounds [47].

The wastewater streams contain large amounts of phenolic and high molecular weight hydrocarbon compounds. Depending upon the process used, the wastewater stream also contains alcohols or carboxylic acid such as acetic and formic acid [27].

Vegetable Oil

Vegetable oil can be converted into diesel fuels. Research projects evaluating the effectiveness of rapeseed and safflower oils as diesel fuels have been in place since the late 1970s and early 1980s in Idaho and Montana [65, 66]. The vegetable oils usually need to

Table 8.14. Chemical characterization of exhaust emissions from vehicles fueled with gasoline and ethanol.

Emission	Gasoline	Ethanol (23%)
Carbon monoxide g/km	9.75	13.34
Nitrogen oxides	2.51	1.83
Hydrocarbons	1.45	1.22
Methanol mg/km	4.2	5.8
Ethanol	-	128
Ethylene	91.6	78.3
Propylene	36.3	22.5
Benzene, toluene	252.7	230.3
Formaldehyde	26.3	24.1
Acetaldehyde	<4.4	16
Acrolein	<4.4	<1.0
Methylnitrite ug/km	94	334
Ethylnitrite	-	447
Polyaromatic hydrocarbons ug/km	170	63
Benzon(a)pyrene	5.4	1.6

Source: Wangberg, S. A., G. Wallin, and H. Egneus. 1985. The environmental effects of producing ethanol from ligno-cellulosic plant material. In Bioenergy 84 - Bioenergy Utilization, Vol. IV. Eds. H. Egneus and A. Ellegard, 470-475. London, U.K.: Elsevier Applied Science Publishers [61].

be treated to form a biodiesel fuel. In the case of rapeseed oil, a transesterfication reaction with either methyl or ethyl alcohol is required to reduce the viscosity [65].

Biodiesel is less environmentally damaging than other diesel fuels because particulate emissions are reduced by up to 65%. In addition, the vegetable oils contain very little sulfur, and thus SOx emissions are nearly eliminated. The biodegradable nature of vegetable oils and biodiesel reduces the environmental damage resulting from spills.

Fuel Cells

Fuel cells directly convert the chemical energy of fuels to electric power. One technology for generating electricity from fuel cells is the IMHEX approach. Natural gas

or ethanol is preprocessed to form hydrogen or carbon monoxide. Hydrogen reacts with a carbonate ion forming water and carbon dioxide. The CO_2 is returned to a cathode [67]. The environmental impacts of fuel cell technology are minimal. Since the fuel is not combusted, emissions of NOx are very small, less than 1 ppm, compared to conventional technologies with emissions of 10–100 ppm [67]. In addition, CO_2 emissions are less than one-third of those resulting from the use of conventional coal-fired power plants. When coupled with increased biomass production, fuel cells can be considered CO_2 neutral. Emissions of SO_2 are also only a small fraction of those associated with conventional technologies [67].

CONCLUSIONS

This report represents an overview of the potential environmental effects of the production of biomass energy feedstock crops and their subsequent conversion to energy. (See Appendix B for a summary of these environmental effects.) With regard to the production aspect of biomass energy, it appears that biomass energy crops can be less environmentally detrimental than more traditional crops. Biomass energy crops typically require fewer chemical inputs in the form of fertilizers, pesticides, and herbicides than high-yielding food crops. Furthermore, management strategies coupling biomass energy crops with traditional crops, (e.g., the use of biomass energy crops as filter strips between upland agriculture and streams) have the potential to reduce the inputs of nitrates, phosphorus, and sediment to streams. Poplar in particular appears to be a good candidate for adoption as a biomass energy feedstock based on its environmental impacts.

The effect of increased production of biomass energy feedstock crops on wildlife could potentially be either positive or negative. Management will be key in determining just how wildlife is affected. If producers are willing to accept suboptimal yields (primarily by avoiding monocultures), wildlife populations may increase. However, large-scale adoption of biomass production in monoculture would result in a loss of natural wildlife habitat and likely in a loss of biodiversity.

The conversion of biomass to energy appears to be less environmentally damaging than most currently used fuels. However, the ability of biomass to be used as an energy feedstock is dependent upon economics. Ultimately the environmental effect of using biomass as an energy feedstock will probably be determined by a combination of economics and government regulations regarding power plant emissions. A great many

uncertainties associated with different conversion technologies still exist. The environmental impact of any one conversion technology is difficult to compare to others at this stage because there are too many combinations of feedstocks, conversion methods, and emission reduction methods. If economically feasible, fuel cells appear to be the least environmentally damaging of the conversion technologies described above.

More specific estimates of environmental effects of increased biomass production can be achieved through computer modeling. Models such as EPIC [68] and CREAMS may be useful tools for estimating the effects of different types of biomass energy production schemes on the quality of stream water. EPIC has been used to estimate erosion from areas planted in switchgrass in the southeastern United States [69]. CREAMS is designed to predict the delivery of runoff, pesticides, sediment, and nutrients from a drainage area within a field. It has been used to evaluate the performance of riparian filter strips in Iowa [70]. Either of these two models, or both, could be used to develop more specific estimates of the environmental effects of biomass production in Iowa.

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Chapter 9

Externalities Associated with Biomass Energy Systems

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CHAPTER 9. EXTERNALITIES ASSOCIATED WITH BIOMASS ENERGY SYSTEMS

INTRODUCTION

Interest and concern with the way human action is altering the natural environment has been increasing as we learn more about the world in which we live and the ways we are affected by changes in that environment. The growth in industrialization and the related increase in production and consumption of energy based on the use of nonrenewable fossil fuels has generated a growing concern about the effects these activities are having on the environment. Iowa is a state that has shown such concern in a number of ways. As an agricultural state, the idea of generating energy for industrial, agricultural, and residential use from renewable sources that can be grown on the land is an obvious one. This report, as part of a larger research project intended to explore the potential for producing energy from biomass crops on a commercial scale, focuses on the environmental externalities that accompany the energy fuel cycle and attempts, where possible, to estimate the economic value of the relative effects of biomass with alternative fuel systems.

Economists define externalities as costs or benefits derived from the production or consumption of a good (or service) that are not accounted for within the good's market price. Attempts to quantify environmental costs by a process called monetization have proved difficult. These efforts have usually followed one of three approaches: (1) Damage cost approach, which estimates the dollar value of the damages imposed on the parties affected by the externality. This approach is generally regarded as preferable by economists. (2) Control cost approach, which estimates the dollar cost of the equipment needed to control externalities at some chosen level. Control costs are generally easier to estimate than damage costs. (3) Mitigation cost approach, which measures the dollar cost of compensating for the damage once it has occurred, such as planting trees to absorb increases in carbon dioxide (CO_2) levels. When estimates of the dollar value of externalities are discussed in this chapter, the approach used to monetize the externality will

be described. Care should be taken when comparing the dollar values obtained from these approaches since conceptually they are measuring different attributes of the problem.

As with many production processes, the biomass fuel cycle will generate external costs. Some of these include soil erosion, pesticide run-off, and water pollution during crop production; air pollution during transportation; and further air pollution, water pollution, and their related health effects during conversion. However, the significance of biomass as related to externalities is that it has the potential to decrease the magnitude of these externalities relative to conventional crop production and energy conversion. These decreases will be discussed.

This chapter begins by comparing biomass crop production to corn production and will consider the potential to decrease external costs when biomass is grown in place of corn. This section will also investigate the impact of growing biomass crops on land that is not being used for corn production, where the result could be increased environmental damage.

A discussion of the conversion of biomass into energy follows. The consideration of externalities focuses on the comparison of pollution damages between biomass-fired plants and coal-fired plants, since 86% of Iowa's electrical production comes from coal-fired plants (11% nuclear, 2% hydro, and 1% oil and gas).

The impact of power generation from biomass or coal on human health are described. This impact can be localized or extend great distances and can be difficult to describe because people react differently to pollutants. This section also poses an ethical dilemma since it can involve valuing changes in a person's health or the loss of human life.

This discussion is followed by a consideration of the impact energy conversion has on global warming, ozone depletion, and acid rain. The primary focus will be on comparing the external costs from producing power with coal to those from producing power with biomass.

Monetizing the external costs described in this chapter poses several problems: (1) interpreting scientific information and then estimating an economic value on the basis of this information; (2) comparing methodology used by different sources, particularly when the sources estimate a dollar value for the same externality by using different methods; (3) comparing economic values estimated in different years when the methodology may not allow for inflating to present dollars; and (4) using aggregate dollar values to compare alternatives when per unit damages are needed and when they are difficult to estimate partly because of the problem stated in number (1) above. Since there

is limited information on the dollar value of the damages from most pollutants, an effort was made to describe the potential external cost that may result from each pollutant when it was not possible to estimate the damages in dollars.

METHODOLOGY

The information which is presented in this chapter was collected through a literature review. The review focused on three areas: biomass crop production as compared to corn production; health effects from the chemicals used in production and pollutants emitted during transportation and conversion of the biomass; and the impact of biomass crop production and conversion on global environmental concerns, such as the greenhouse effect, ozone depletion, and acid rain.

The search was aimed at locating studies which delineated dollar values for these environmental externalities that biomass production, transport, and conversion have the potential to decrease or increase. When dollar values were found, the methodology used to obtain these values was reviewed. If it was methodologically permissible, the dollar amounts were inflated to 1993 dollars.

While many of the externalities from the energy fuel cycle can be identified on the basis of their direct measurement or estimation, this does not signify that it is always possible to measure the effects and costs of these processes. An added complicating factor is the complex nature of the various components of the natural environment, their interactions, and the complex linkages of many human activities on the natural system. In general, any estimates of the economic and social costs of these externalities are based on extrapolations from limited data and limited knowledge. We can often be reasonably sure that there will be some costs from these side effects, but we will seldom be able to provide a reliable estimate of the actual cost. An order of magnitude is often the best that can be done, and often not even that.

What follows is based on the existing scientific consensus, where one exists, and on the best information currently available. The potential for error is substantial and the conclusions must be viewed with caution.

RESULTS OF EVALUATION

Biomass Crop Production in Relation to Environmental Externalities

This section compares externalities that result from the production of biomass crops with those that result from the production of corn. Most of the environmental impact of biomass crop production is site specific. One must consider composition of the soil, soil permeability, and organic matter content; field topography, slope, and length; climate differences, rainfall intensity, and duration; and vegetative cover and tillage practices in any attempt to estimate the dollar value of the environmental damages [1].

Soil Erosion

Most soil erosion results from raindrops that break-up soil granules. Once the ground surface is saturated, the additional rain collects soil granules as it runs along the slope of the ground, removing the topsoil [1]. Erosion can also result from strong winds blowing across unprotected soil, especially during droughts [2].

Vegetative cover can decrease erosion, depending on the canopy effect, the surface-cover effect, and the infiltration effect [1].

- Canopy effect: where vegetative cover protects the soil from the rain.
- Surface-cover effect: where ground cover slows the flow of water over the surface.
- Infiltration effect: where ground cover increases the absorptive quality of the soil.

Row crops, such as corn, have a low level of canopy and surface-cover and thus increase soil erosion over natural levels [1]. Since the first cultivation of Iowa land, its 16 in. of topsoil have been reduced to 8 in. [3]. In Iowa, a loss of 1 in. of topsoil reduces corn yields by 3–6 bushels an acre. Before the recent emphasis on conservation, the trend was a loss of one inch from Iowa's cornfields every 14 years, or 10 tons per acre annually [3,4]. Although Iowa's erosion rate for corn has been reduced, it is still 27 metric tons per hectare, even with increased erosion management by farmers.

The Soil Conservation Service and the USDA have estimated that a loss of 5 tons of topsoil per acre per year or 11 metric tons per hectare per year is the maximum sustainable erosion rate (or tolerance rate) for 70% of United States farmland [5]. This indicates that

the soil could withstand such topsoil losses in the long-run, while maintaining productivity. The Office of Technology Assessment estimated that natural soil formation is only 1 metric ton per hectare per year [6]. Under tropical and temperate agriculture conditions, from 200 to 1,000 years are needed to renew 2.5 cm or 340 metric tons of topsoil. This rate, 0.2–3.0 metric tons per hectare per year, is much lower than the United States tolerance level of 11 metric tons per hectare per year [7].

Impact of Soil Erosion on the Farm

Soil erosion leads to adverse economic impacts both on and off farms. Although on the impact of soil erosion farms does not seem to be an externality since the farmers' activities affect their own land, this impact should nevertheless be described because it affects the future productivity of the land and future generations. In the short-run, loss of productivity may lead to increased fertilizer costs. However, the long-run degradation of the soil that leaves infertile, barren land has compelled farmers to cultivate marginal land, which is less productive and more susceptible to erosion.

As fertile, nutrient-rich topsoil is eroded by water and wind, productivity is reduced. The erosion reduces root zone, decreases water-holding capacity, alters soil texture, reduces organic matter content, and accelerates further run-off [5]. This increases food production costs as the need for fertilizer is increased while productivity falls [4].

Colacicco et al. [8], relying on studies by Crosson, Benbrook and Myers, estimate that productivity losses and increased fertilizer expenses caused by erosion in the United States cost farmers $500 million to $1 billion per year. Another estimation presented by Colacicco et al. [8] set erosion costs at $1.7 to $1.8 billion, including $1.2 billion in erosion control costs; thus on-farm damages were assessed between $525 and $588 million for the year 1983. McCullough et al. estimate that farmers suffer $625 million annually in costs from reduced yields, extra fertilizer, and soil conservation measures [9]. Pimentel et al. [7] estimate that the losses are much higher. With a minimum of 10% reduced annual crop yield and fertilizer loss of $5 billion, the on-farm costs of erosion total $18 billion every year in the United States [7]. Furthermore, corn yields are predicted to decline an average of 4.6% in the United States and 4.2% in the Corn Belt over the next 100 years with erosion continuing at the 1982 erosion rate [8].

The economic value of top soil losses from erosion has been estimated to be between $5 and $40 per ton by agricultural economists and soil scientists [10]. Using the Erosion Productivity Impact Calculator (EPIC), Colacicco, Osborn, and Alt estimated the

present value of the profit loss (per ton of soil erosion) averaged over United States cropland to be $0.49 [8]. Soil erosion may cost farmers more than $1.2 billion per year [8].

Impact of Soil Erosion off of Farms

The impact of soil erosion off of farms focuses on environmental damages that are not typically accounted for in the price of agricultural products. Edwin Clark II [1,11] used the damage cost approach to estimate the off-farm externalities. The damages of soil erosion were allocated among in-stream and off-stream costs. Admitting that the estimates were imprecise, Clark delineated the damages caused by erosion and then estimated the value of those damages that could be directly attributed to cropland erosion [1].

Off-stream damages from soil erosion are experienced during floods, with an increase in the frequency and depth of flooding, an increase in the volume of the water-soil moisture in flood flows, and direct flood damage from sediment displacement. In the United States, over 3 billion tons of sediments settle in the waterways every year [12]. Before sediments reach the waterway, however, additional off-stream damages occur through the siltation of water conveyance facilities. Removing sediment-laden water from the waterway results in additional costs. In 1980, the estimated off-stream damages in the United States were between $1.1 and $3.1 billion. The damages directly attributable to cropland were estimated at $660 million [11].

In-stream damages caused by sediment altering the waterway include losses of aquatic organisms, decreased utility derived from water-based recreation, damage to water storage and treatment facilities, premature obsolescence of dams and channels, and disrupted navigation. In addition, Clark [11] attempted to estimate preservation value, the value people place on clean water even though they may never directly benefit from that water resource. In 1980, the total estimated in-stream damages were between $2.1 billion and $10 billion. The damages directly attributable to cropland were estimated at $1.5 billion [11]. Clark noted that recreational impact was the largest category of in-stream damages.

Clark estimated that the total off-farm damage due to soil erosion and sedimentation in 1980, both in- and off-stream, was from $3.2 to $13 billion, or a single point estimate of $6 billion, $2.2 billion of which was directly attributable to cropland [11]. The Conservation Foundation also attempted to estimate off-farm damages from erosion. Its

estimates were $2 to $6 billion per year in water quality, recreation, industry, and navigation losses [9].

Although studies have estimated the economic losses from cropland erosion, it is exceedingly difficult to estimate the dollar damages from a specified amount of erosion. The methodology used makes estimating the value of a decrease in erosion from biomass equally difficult. Although there have been estimates of the economic value of various outdoor recreation activities that are affected by biomass and corn production (fishing, hunting, boating, etc.), estimating the number of days lost or the changes in the quality of activities affected would be difficult even if this study focused on a specific site.

Contrasting the Soil Erosion that Results from Biomass or Corn Production

Since a choice may be made between producing present quantities of the current row crops, such as corn, or additional quantities of perennial energy crops in place of corn, it is essential to compare the impact of these respective crops on soil erosion and depletion. Comparing the external cost of producing each of these types of crops is essential to making an informed economic decision about the quantities of these crops to produce.

Biomass refers to any plant mass harvestable for conversion to fuel as well as to animal and human wastes [13]. For the purpose of this comparison, biomass will refer to perennial energy crops, such as herbaceous grasses like switchgrass or short-rotation woody crops such as poplars.

Corn depletes on-farm soil and is a major cause of off-farm water pollution through soil erosion. In 1992, corn was the crop grown on the largest area of active agricultural land, approximately 23%, covering 30.8 million hectares [6].

Erosion from dedicated energy crops, such as switchgrass and poplar, would be less than row crops grown on the same land and similar to well-managed pasture [6,14,15]. Wright and Hohenstein [16] compared the levels of erosion, measured in metric tons per hectare per year, between corn and the biomass energy crops. Corn had an erosion rate of 21.8; herbaceous energy crops, such as switchgrass, had a rate of 0.2; and short-rotation woody crops had a rate of 2.0. Annual erosion rates for the perennial energy crops may range between 0.2 to 3.0 metric tons per hectare; however, during the crop establishment phase, if conservation measures are not practiced, erosion rates may be similar to row crops at 10 to 20 metric tons per hectare [16]. Soil erosion from woody biomass, e.g., poplars, may occur during the establishment of the stand; however, once the roots and leaf cover have developed, erosion would be drastically reduced [14]. The

erosion rate declined 92% on the 14 million hectares of highly erodible land taken out of annual production under the Conservation Reserve Program (CRP) and planted with perennial grasses and trees. Notice, however, that these crops were not regularly harvested from the CRP land as a corn crop or biomass energy crop would have been [17].

As an annual crop, corn production requires soil disturbance every year; however, perennial grasses need only be reestablished approximately every 10–15 years. The woody biomass is harvested in a 3–10-year cycle and allowed to coppice, where new stems regrow from the cambium layer between the bark and the wood in the cut tree stump that is left after harvesting. This regrowth rate diminishes with the number of cuttings; thus the trees need to be replanted every 10–30 years [18].

A reduction of the soil's organic matter content from 1.8% to 3.8% can reduce corn yields by 25% [12]. Without a constant replenishment of organic matter, soil can become depleted and barren. Transformation of row-cropland to short-rotation or perennial energy crops adds 2.4 megagrams of organic matter per hectare per year over 10–20 years. This improves the structure, nutrient status, water holding capacity, and density of the soil [16]. Relative to conventional row crops, biomass crops can increase soil organic matter, which leads to gains in productivity and soil quality [6].

Lower soil temperatures maintain a higher level of soil organic matter, increasing soil quality. Perennial energy crops lower the soil temperature relative to annual row crops, except during the establishment year [6].

Corn kernels are currently harvested as a food crop or for production of ethanol. This allows corn residue to remain on the ground, which returns nearly half of corn nutrients to the soil [12]. Since the passage of the 1985 Farm Bill, which legislated conservation, many farmers have begun to practice conservation tillage, leaving residue cover on the land in order to decrease the soil erosion caused by the production of row crops. If the entire corn plant is removed for use as an energy fuel, more energy mass is harvested; but in this process valuable nutrients and ground cover are removed, exacerbating erosion and loss of soil fertility.

The external costs from soil erosion are decreased on average when biomass perennials are grown in place of row crops. The previous discussion has attempted to provide an order of magnitude for the reduction in external costs that results from biomass crop production rather than corn production. It is extremely difficult to estimate dollar values representing the decreased soil erosion damages, and no direct comparisons were located in the literature review.

Fertilizer/Pesticide Usage

The average nitrogen fertilizer application rate for corn production is 135 pounds per acre. Most perennial energy crops, such as switchgrass, require about 50 pounds of nitrogen per acre [14]. Woody tree biomass plantations may result in soil nutrient removals approximating that of a corn crop producing 150 bushels per acre. Generally, the efficiency of nitrogen fertilizer is much lower in the production of short-rotation woody crops than for traditional agricultural crops [13]. Clearly, fertilizer application will be necessary to maintain site fertility and maximize biomass growth [19].

Studies confirm that fertilizers applied to energy crops, at rates that are within soil nutrient requirements, do not leach into groundwater once the crop has been established [16]. Smil [13] studied the harvesting of total above-ground mass of 10-year-old poplars and concluded that the removal of nitrogen from the soil was 2.45 times greater than for traditional logging, exclusive stem-harvesting. In addition, phosphorous and potassium removal was 1.5 and 1.37 times greater, respectively.

The harvest of biomass energy crops and the residues from the land robs the soil of much needed nutrients. The energy needed to replace the nutrients lost when both the grain and corn plant are harvested for energy would equal 460 liters of oil per hectare at a minimum [12].

Insecticides are used on 35% to 40% of corn produced annually, but they would only be needed for energy crops when it was determined that pests pose a serious risk to the crop [14]. Herbicides, on the other hand, are used annually on 96% of corn produced; but they will be needed for perennial biomass energy crops only during the first one to two years [6,14]. In a study by Wright and Hohenstein [16], corn required 3.06 kilograms of herbicides per hectare per year, whereas the herbaceous energy crops required a low 0.25 and short-rotation woody crops required 0.39.

The use of pesticides, both insecticides and herbicides, can have adverse effects on human health. The impact can be felt physically and financially by those who are exposed to the pollutants.

Strong evidence exists linking pesticides to damage of the human immune system. Approximately ten thousand cases of cancer diagnosed in the United States every year are blamed on pesticides [20].

Herbicides and insecticides come in a variety of types that can be used in the production process, each with its unique health effects [21]. For example:

- 2,4-D causes irritation of mucous membranes and skin. Workers entering a field, one hour after it was sprayed, suffered weakness, headache dizziness, stomach pains, nausea, brief loss of consciousness, and moderate leukopenia. Also 2,4-D may cause soft tissue sarcomas [22].
- Amitrole inhibits catalase in the liver and kidneys, peroxidase, thyroid uptake of iodine, ∂-amenolevulinic acid dehydratase, and cytochrome P-450 [23].
- Diphenamed is suspected of causing ataxia, bradycardia, bradypnea, cardiomegaly, convulsions, coughing, depression, diarrhea, erythema, hemorrhage (oral, nasal, and thymus), hepatotoxicity, hyperthermia, hypoactivity, leukocytopenia, polyphagia, polyuria, salivation, tearing, thirst, and vomiting [23].
- Diuron may irritate skin, eyes, and nose [22].
- Linuron is suspected of causing bone marrow changes, carcinogenesis, exophthalmos, hemorrhagic lungs, mutagenesis, prenatal damage, ptosis, salivation, splenic changes, tearing, and weight loss [23].
- Oxyfluorfen may cause carcinogenesis, enzyme changes, hepatomegaly, mutagenesis, pigmented liver cells in bile, and renal tubular vacuolization [23].
- Paraquat exposed to workers in the form of a fine mist is blamed for nosebleeds, skin irritation, irritation and inflammation of the mouth and upper respiratory tract, cough, chest pain, asthmatic attacks, frontal headache, vomiting, and pain and swelling of the joints [22].
- Pronamide exposure can cause eye and mucous membrane irritation. Pronamide is a suspected carcinogen and it inhibits mitosis [23].
- Simazine can cause transient skin eruptions [22].
- Triflurlin exposure can cause dermal, eye, and mucous membrane irritation. The suspected effects of triflurlin are mutagenesis and prenatal damage [23].

Damages from the pesticides would be reflected in health care costs or lost income to those exposed. Pimentel et al. [20] used the damage cost approach to estimate the public health impact from pesticide usage. The cost to the United States was $787 million annually. Producing biomass in place of current row crops could decrease the amount of pesticides used and thus the damages from pesticides would also be decreased.

Water Pollution by Agricultural Chemicals

Agricultural activity has been described as the single largest source of untreated water pollution and is blamed for one-third of pollutant loadings into the nation's waters [3,24]. The USDA blames agriculture for 64% of nonpoint pollution in 165,000 miles of United States rivers and 57% of nonpoint pollution in 3.3 million hectares of lakes [2].

Compared to conventional row crops, perennial energy crops do not substantially lower the risk of agricultural chemical movement, such as leaching into groundwater, erosion into surface water, drifting in the wind to adjoining flora, or entering the food chain of animals or people, until their second or third year of growth [6].

The production of biomass can release nitrogen, phosphorous, and potassium into both surface and ground waters. Water erosion can also carry herbicides, insecticides, and soil sediment into water sources [25].

Biomass may decrease the susceptibility of the soil to erosion and thus chemical water pollution, but the environmental damage could remain substantial. The difficulty of estimating the economic value of these damages for a specific quantity or type of water pollution from chemicals is significant. We were not able to locate any estimates of these external costs.

Stream Bank Stability

Poplar trees, serving as a buffer strip in a riparian corridor bordering a stream that flows through row-cropped land, increase stream bank stability. The buffer strip reduces fertilizer nutrients infiltrating surface water, diversifies wildlife, intercepts eroded soils, and provides a wind break [26].

Poplar tree roots reduce nitrate-nitrogen in near-surface groundwater. Reduction ranges from 94.7% to 97.4% depending on the depth of the root [26]. Perennial energy crops, with their deeper root systems relative to row crops, will create the capacity for greater uptake of nitrogen and other agricultural chemicals before they reach groundwater or surface water and damage the waterway [6].

Biomass production has the potential to reduce stream bank erosion that is created by the cultivation of row crops. Again, a difficulty exists in estimating damages from stream bank erosion. We were not able to locate any estimation of the economic value of these damages.

Monoculture and Its Effects on Wildlife

Monoculture, defined as the production of the same crop on the same land through at least two crop cycles, is practiced for approximately 21% of corn planted in the Corn Belt [27]. The use of monoculture exposes a crop to high susceptibility to disease and pest infestation. Biomass is not immune to this problem either. Since cloning will likely be used in the production of the biomass fuels, particularly poplar trees, it is essential that several varieties of clones are planted in one field to create a polyculture and thus lower the risk of disease and pest infestation [18]. Monoculture energy plantations, over an expanded length of time, could result in soil erosion, crop epidemics, reduced productivity, and degradation of the quality of ground water and surface water [27]. The integration of crop rotation and/or intercropping is more suitable for maintaining soil fertility, ecological equilibrium, and self-sufficiency [28].

Production of biomass energy crops can cause a loss in or result in an increase in biodiversity; where biodiversity is defined as the variety and variability among living organisms and the ecological complexes in which they occur [6]. If current natural forest land is used in the production of a monoculture energy crop, biodiversity will be lost. If current wetlands are used in the production of the monoculture energy crop, the vanishing ecosystems could lead to a loss of critical wildlife habitat and a destruction of underground aquifer rechargers and natural enhancement of surface water quality [29]. However, if current degraded lands, such as those in set-aside or conservation programs, are revived with the production of the energy crops, biodiversity could be increased. Also, if land currently under the production of a monoculture row crop is transferred to an energy crop, biodiversity can be increased since the perennial plants and trees are more conducive to wildlife [18].

A loss of biodiversity is a significant external cost from row crop production, and it is nearly impossible to estimate the economic value of the damages resulting from agriculture's effect on decreasing biodiversity. Despite the potential biodiversity increase from producing perennial biomass crops rather than corn, however, wildlife habitat would best be preserved by allowing land to revert to natural habitat rather than using it for the production of any crop—row crop or perennial energy crop [6].

Air Pollution

Through the process of photosynthesis, green plants absorb over 230 billion tons of CO_2 annually [30]. Young trees remove CO_2 at a rate of 5 or 6 tons an acre per year, a much higher rate than older trees [31]. Traditional biomass fuels, such as crop residues and animal waste, emit CO_2 in a balanced cycle of absorption and respiration. Dedicated biomass energy crops may provide a sink for CO_2 if the biomass stock is being continually replanted [32]. Energy crops, when replacing row crops, will tend to increase the carbon content of the soil to as much as 30–40 megagrams per hectare over 20–50 years and hence will remove CO_2 from the atmosphere. This amounts to nearly twice as much carbon as row crops carry and half that found in forest land [6].

Relative to row crops, biomass could, at a minimum, reduce the need for nitrogen fertilizer, the production of which emits 2% of industrial CO_2 output [32]. However, relative to natural ecosystems, intensive cultivation of biomass trees may lead to net emissions of CO_2 from the manufacture of needed fertilizer, along with possible emissions of nitrous oxides (N_2O) from the fertilizer after its application. The soil disturbance during planting and harvesting could also increase CO_2 soil emissions relative to undisturbed soil. The energy required to plant, harvest, transport, and process the biomass could produce net CO_2 emissions as well [33].

In addition, the potential exists for the net release of CO_2 by the machines used in producing the energy crops or in manufacturing pesticides and fertilizers used on the biomass crop [34]. Farm tractors also emit hydrocarbons, nitrogen oxides, particulates, carbon monoxide (CO), and sulfur dioxide (SO_2) [25]. Typically 5% to 15% of the energy value of the biomass crop is consumed in fossil fuel use in the form of agricultural chemicals or diesel fuel [6].

Perennial energy crops will also reduce wind-blown dust and tillage dust in the air compared to annual row crops, alleviating some particulate air pollution [6].

The production of biomass can decrease the amount of CO_2 in the atmosphere, a key component in the greenhouse effect (which will be discussed extensively in a later section). Efforts have been made to estimate the economic value of the external costs that result from atmospheric CO_2 and other air pollutants. These studies will be reported later in the discussion of the impacts from energy conversion.

Transportation of Biomass

Transportation of biomass crops must be considered when evaluating the total fuel cycle to ensure that all external costs are addressed. In the state of Iowa, most biomass will be transported by trucks, with driving distances to the conversion facilities of less than fifty miles. The most significant external cost from transporting biomass will be the air pollution emitted by the trucks. Other potential external costs include increased noise and wear on roads.

For example, heavy gasoline trucks contributed 24 million metric tons of carbon to the atmosphere in 1987 [32]. Diesel engines used in truck transport of the biomass feedstock emit CO_2, CO, hydrocarbons, nitrogen oxides (NO_x), particulates, and SO_2 [25]. Large diesel trucks have the best potential for being modified to use biofuels, which may be CO_2 neutral. A switch to biofuels from diesel could cut the CO_2 emissions of the transportation industry in half [32].

In 1990, the energy cost of hauling hybrid poplars 40 kilometers to a biomass processing plant was estimated to be 2.40 gigajoules per hectare. The estimated energy cost for switchgrass was 2.79 gigajoules per hectare [17]. Since petroleum fuels used to power transport vehicles emit 170 pounds of CO_2 per million Btu [33], we expect the environmental cost of transporting biomass would be 386.8 pounds of CO_2 per hectare for poplars and 449.6 pounds of CO_2 per hectare for switchgrass.

This increase in greenhouse gases is compounded by the contribution of the air conditioners in transport vehicles leaking CFCs, a greenhouse gas and ozone depletor [32].

The air pollutants emitted during transport of the biomass feedstock contribute to the greenhouse effect, ozone depletion, and acid rain, which will all be described in a later section, as well as the following impacts on humans.

- Carbon monoxide binds to hemoglobin and interferes with the blood's ability to carry oxygen and CO_2. As a result the heart has to work harder to obtain enough oxygen for tissues. Prolonged exposure to this gas can be fatal. Those with heart disease are even more vulnerable to the poisoning effects of CO [35].
- Two types of hydrocarbons are formed: (1) aldehydes that include formaldehyde and acrolein, and (2) aromatic hydrocarbons that include benzene, toluene, and xylene. Of these hydrocarbons, benzene is one of the most toxic. It interferes with the formation of red blood cells in the bone marrow. If a person is exposed for long periods of time, they may develop leukemia and perhaps alterations in chromosomes from the lymphocytes [35]. Hydrocarbons are also a component in

photochemical smog. Effects include respiratory and eye irritation. They also cause headaches, nausea, and anorexia [35].

- Nitrogen oxides, including nitric oxide (NO) and nitrogen dioxide (NO_2), have both direct and indirect impacts. Nitric oxide directly causes methemoglobin which is an inactive form of hemoglobin [35]. Nitrogen oxides and nitrates in the air, when combined with SO_2, particulates and O_3 can cause chronic respiratory disease [36].
- Sulfur dioxide, when combined with nitrates, particulates, and O_3, can cause respiratory problems [35]. Such problems include aggravation of bronchitis, chronic nonspecific respiratory disease, bronchitis, and irreversible obstructive disease [35,36].

Estimation of the dollar value of the external costs that result from the above pollutants will be discussed during the second half of the chapter since many of these pollutants are also released during conversion of biomass or coal into energy.

Additional Impact from Biomass Production

Biomass production has the potential to reduce other environmental and social costs that would result from row crop production, such as the ability to dispose of effluent from industrial and human waste through irrigation of the fast-growing, woody trees [14,37]. High-productivity energy crops may use a substantial amount of water for their growth, which makes their production ideal in poorly drained areas or flood-prone zones [6]. However, this could adversely affect areas with strained water resources.

Along with these reductions in external costs comes the potential to increase some costs. If 11% of the nation's energy is provided by biomass, a 5% employment rise in those fields is expected [12]. Although the new jobs would benefit society, they will likely only offset those jobs lost in the energy sectors that biomass will replace. It is important to note that the forestry, logging, and agricultural industries have a higher incidence of injury than both coal mining and oil and gas extraction. According to the Bureau of Labor Statistics [38,39] for the years 1988-1991, agricultural production (excluding farms with less than 11 employees) averaged 11.7 injuries per 100 full-time workers; forestry averaged 11.2; and logging averaged 17.9; whereas coal mining averaged 10.8, and oil and gas extraction averaged 7.5. Agriculture reports 25% more injuries per man day than all other private industries [12]. One-tenth of occupational fatalities in 1992 occurred in the farming industry [40]. In Iowa, the illness and injury rates for 1980-1983 in agriculture,

forestry, and fishing averaged 9.1 per 100 full-time workers whereas mining averaged only 2.9 per 100 [41-44].

The storage and handling of the biomass crops can also pose an occupational hazard. During storage of the organic biomass crop, a breakdown of plant material occurs as microorganisms present in the biomass use the material as a resource for growth. Thus, spores and microorganisms that are formed can be a health hazard for those who must handle the stored biomass crop [25].

The production of energy from biomass requires the use of land, which may be inefficiently removed from the production of corn as a source of food. To fuel one automobile for a year by using corn-based ethanol requires 4.2 hectares of land, whereas only 0.5 hectares of land is needed to feed one person for a year [12]. Energy farming is extremely land-intensive compared to fossil-fuel recovery [13]. To produce enough biofuel to meet only current United States transportation needs, 80 million hectares, equal to about two-thirds of all harvested cropland, would be needed, even using advanced cultivation and conversion methods. Approximately 40 million hectares lie idle in any given year, much in federal programs [15]. The potential output of energy crops is limited by the available water resources, even more than the limited land resources. Plants cannot absorb CO_2 without losing water at a rate nearly 100 times greater than their absorptive rate of CO_2 [13]. Energy crops may require heavy fertilization and extensive irrigation. When a crop is heavily fertilized and irrigated from underground water sources, the energy costs of production are considerable [13].

If the state of Iowa proposes to substitute biomass energy sources for fossil fuels in aspiring to environmentalism, all aspects of environmental impact must first be considered. One benefit of biomass not previously mentioned in this chapter is its potential to be a sustainable energy source. Because biomass is renewable, society can continue to meet its energy needs without threatening the ability of future generations to meet their own needs, a requisite for "sustainability" [45]. However, if biomass is not produced in a sustainable way or if land and water resources are depleted and human health is threatened by pollutants, then biomass is not an improvement over the continued use of fossil fuels. Although not valued in dollars, these various externalities, both positive and negative in the evaluation of biomass crop production, are crucial to energy planning.

Externalities Resulting from Coal Extraction, Transportation, and Handling

The extraction of coal is not a process free of external costs. The extraction of coal from underground or surface mines can lead to soil erosion, mineral run-off including acidic water pollution, and destruction of biodiversity [46].

Coal mines are also a source of atmospheric methane emissions, a greenhouse gas [33]. Coal emits 5% to 10% of human-produced, worldwide methane, mostly from newly opened mines. In the United States, coal may add 10% to 20% of anthropogenic methane [33].

Currently, much of the coal burned in Iowa is from out-of-state. A considerable amount of this coal comes from Wyoming, which mines a low-sulfur subbituminous coal [47]. Although this fact implies that Iowa will not directly suffer the damages from those extraction externalities, the damages need to be considered as part of the costs of the coal extraction. Unfortunately, estimates of the dollar values for these damages were not located during the literature review.

Virtually all coal, with minor exceptions, is brought in by rail from outside the state. The pollution released by the trains—CO, hydrocarbons, NO_X, particulates, and SO_2—can be substantial [46]. Coal transportation results in an additional external cost. Fugitive emissions released directly from the transported coal, in the form of dust and particles, are added to the air. The subbituminous coal from Wyoming generates a great amount of dust during handling and transport. Dust lost due to winds during transport by rail can amount to 1–3 tons per car [47]. Much of this pollution will be emitted in this state; thus the residents of Iowa may suffer the health effects from the transportation emissions.

Once the coal reaches its destination, the fossil fuel is handled and much is stored before use. During the handling of the coal, high levels of dust create the risk of an explosion [47]. When dry and windy weather is experienced, open coal storage piles can further lose matter through fugitive dust, creating localized air pollution [48]. The fugitive dust can be lessened through the application of chemical additives, such as a coating, or the construction of physical wind breaks [48]. Rain and other forms of moisture can generate a highly acidic, metal-rich leachate through the oxidation of the sulfuric ores in the exposed coal piles [49]. Some of the potential leachates are iron, copper, zinc, and chromium [50]. The leaching leads to surface and ground water pollution and soil pollution.

Dollar values and the health effects for many of the emissions listed above will be reviewed in the next section.

Biomass Conversion in Relation to Environmental Externalities

When converted into energy, all energy sources interact with the environment is some way. The focus of this section will be on the external costs from combustion of biomass and coal in the conversion to energy. These external costs are incurred at various geographic scales from the local to global. They occur through the release of by-products into the environment from the combustive process, through the secondary effects of transporting the energy or fuels, and through the effects of acquiring the fuels (the latter two were described previously).

Emissions That Result from Biomass Conversion

The emissions that result from direct combustion of coal and biomass are extensive. However, the emissions from biomass combustion are generally lower than comparable coal combustion for CO_2, water, solid ash, and nitrogen oxides, and are significantly less for SO_2 and toxic metals. Emissions from chlorine compounds are generally higher, as well as particulates [51].

Bituminous coal contains three times the ash content of biomass [52]. Ash content in wood is 1% of the original wood volume, whereas bituminous coal ash content is 10%. When the greater heat content of coal is taken into account, the wood has a 1:3 advantage in ash volume. The wood ash is less toxic (fly ash from coal combustion is solid waste that must be discarded) and may be returned to the soil as a form of fertilization, containing calcium and potassium, rather than requiring disposal in landfills [51,53].

Wood combustion emits about 55 to 60 pounds of carbon per million Btu (approximately 240 pounds of CO_2); however, in the replanting and regrowth of the trees, an equitable amount of carbon can be removed from the atmosphere [33]. If the energy used to produce and process the biomass is derived from renewable sources as well, the net CO_2 emissions could be zero [15].

Coal emits about 240 pounds of CO_2 per million Btu. Among the four carbon-bearing energy sources, coal, petroleum, natural gas, and biomass, coal has the highest concentration of carbon per unit energy produced. Coal combustion emits 40% of global CO_2 emissions from energy use and 35% of United States emissions [33].

The Department of Energy estimated the potential to reduce CO_2 emissions if biomass fuel was used as a substitute for traditional fossil fuels. Assuming 1990 production levels and conversion technologies, the estimates ranged from 3% to 5% of current United States emissions [33]. (Biomass with regrowth also produces fewer metric tons of CO_2 per gigawatt-hour than nuclear power, wind power generation, and large hydroelectric plants [54].) Considering technology advances and increased land for production, biomass could cut emissions of CO_2 by 35%. Note, however, that the Office of Technology Assessment estimated that emissions would only be reduced by 1.2% at current production levels and technology [33].

Approximately 100 different chemicals are released in the combustion of wood [12]. If the wood is wet before combustion, combustion temperatures will be lower and the combustion will not be complete. This may lead to higher emissions of CO [53]. Emissions of CO for wood and bark combustion in boilers are approximately 1.0 g/kg [55].

Wood and bark combustion in boilers also emits particulates (12.5-15.0 g/kg) [55]. The emissions of particulates by biomass combustion may be higher than coal, but the estimate given suggests that particulates do not pose a major air pollution problem [55].

Coal is blamed for 50% of anthropogenic SO_2 emissions (bituminous coal contains 25 times the sulfur of biomass) and 30% of NO_x emissions [52,56]. Studies have shown that the combustion of whole trees lowers emissions of SO_2, NO_x and toxic metals relative to the combustion of coal [15,53,57].

The combustion of trees, however, may increase emissions of volatile organic compounds (VOCs) relative to coal. In electricity generation, 0.07 pounds of VOCs are released for every ton of coal burned; whereas, 1.4 pounds of VOCs are released for every ton of wood burned [57].

Methanol produced from woody biomass releases 70% less greenhouse gases than petroleum [33]. Petroleum oil emits 170 pounds of CO_2 per million Btu. Petroleum combustion produces 40% of worldwide CO_2 emissions from energy use and 45% of United States emissions. Methane is emitted during the production of oil and gas [33].

Through the process of anaerobic digestion, biomass with a moisture content of greater than 50% can be converted into methane gas to serve as a substitute for natural gas [12]. Synthetic natural gas from woody biomass produces 60% to 70% less greenhouse gases than its fossil fuel counterpart [33]. Natural gas emits the lowest amount of CO_2 of the four carbon-bearing energy sources, 120 pounds per million Btu [33]. Combustion of

natural gas contributes 15% of worldwide CO_2 emissions and 18% of United States emissions from energy use. Methane is released during the drilling, transport, and storage of natural gas [33].

Estimates of the economic value of the external costs that result from these pollutants will be discussed later in the chapter.

Impact of Energy Conversion on Human Health

The impact of biomass energy conversion or coal energy conversion on human health can be localized or extend great distances. The damages are difficult to describe and evaluate because people react differently to pollutants and the source of the pollutant is often difficult to determine. In addition, estimating the dollar value of the damages is difficult due to incomplete information and the ethical problems surrounding the estimation of the value of a change in a person's health or the loss of a human life.

Acid precipitation and dry deposition is caused by the pollution resulting from SO_2 and NO_x. Acid precipitation can lead to the leaching of toxic metals from the soil. The metals can lead to kidney damage, liver problems, and other poisonings. Intake of these metals by pregnant women can damage human fetuses [58].

Ash emitted during the combustion of coal includes toxic metals. These metals can lead to numerous health effects; three such metals are listed below.

- Cadmium adversely affects the lungs, kidneys, and bones. If cadmium is inhaled it can cause bronchitis, pneumonitis and toxemia in the liver [59].
- Lead can cause the immediate physiological effects of nausea, vomiting, abdominal pains, anorexia, constipation, insomnia, anemia, irritability, mood disturbances, and coordination loss. Immediate neurological effects of acute lead poisoning are restlessness, hyperactivity, confusion, impairment of memory, coma and death. In babies, lead causes cot deaths (sudden infant death syndrome) and stillbirths [59].
- Mercury is oxidized in the blood and brain. Once mercury is oxidized in the brain, it remains there. Those exposed to mercury vapor have symptoms such as coughing, acute bronchial inflammation, chest pains, respiratory arrest, loss of appetite, tremors, insomnia, diarrhea, vomiting, and soreness in the mouth [59].

Hydrogen sulfide lessens the sense of smell after a 2–15 minute exposure at a concentration of 100+ppm [35].

Manure in tar form is referred to as aldehyde. Aldehydes include acrolein and formaldehyde. Acrolein is the source of much of the eye irritation caused by photochemical smog. Acrolein may be a carcinogen [60]. Inhalation of formaldehyde can cause eye, nose, and throat irritation. The ingestion of formaldehyde can cause a loss of consciousness, vascular collapse, pneumonia, hemorrhagic nephritis, and abortion [61].

Tropospheric ozone, formed by a reaction of NO_X, volatile organic compounds, and heat and sunlight, produces acute effects on the respiratory tract that can lead to cough, asthma, sinusitis, and eye irritation [58]. At moderate concentrations, ozone directly attacks cells, paralyzes cilia, increases secretion of mucus, and can "shut down" portions of the lung [62]. Long-term exposure can lead to chronic lung disease, lung cancer, and increased chances for respiratory infections, such as pneumonia and bronchitis [63]. In addition, tropospheric ozone may be the largest contributor to pollution-related crop damage in the United States [2,63].

Particulates, very small solid- or liquid-suspended droplets that vary in size and impact, contribute to the generation of smog. Large particles, grit or dust, quickly settle from the air. Smaller particles remain suspended for a longer time until they form clouds and return to the earth through some form of precipitation. The particulates include elemental and organic compounds as well as toxic metals [64]. Particulates cause morbidity symptoms, such as coughing, eye irritation, sinusitis, and asthma attacks [58]. Sulfates, which account for 5% to 20% of suspended particulate matter in urban areas, can increase asthma attacks, aggravate heart and lung disease, and lower resistance to respiratory disease in children [65].

Sulfuric acid (manure) biogas in the air can cause coughing, some bronchoconstriction, and rales. At higher concentrations, throat irritation, wheezing, coughing, and expectoration are common occurrences that in some cases last for hours or months [66].

Volatile organic compounds and their health effects follow:

- Carbon tetrachloride depresses the central nervous system and causes damage to the liver and kidneys [67]. When carbon tetrachloride is inhaled, 50.0% to 78.7% is excreted through the lungs shortly after exposure. There are also health effects from acute inhalation of carbon tetrachloride. Effects include a loss of appetite, mental confusion, agitation and a feeling of suffocation [68].
- Chloroform has delayed effects (a few hours to one day) of drowsiness, restlessness, jaundice, vomiting, fever, elevated pulse rate, liver enlargement,

abdominal tenderness, delirium, and abnormal functioning of the liver and kidneys. Chloroform is also a carcinogen [69].

- Dichloroethane damages the liver and kidneys [67].
- Ethylbenzene can cause severe irritation of nose, eyes, and throat [70].
- Methylene chloride interacts with red blood cells causing forms of carboxyhemoglobin, which reduce the amount of oxygen that is carried by the blood [67]. Simultaneous exposure to CO can worsen the effects.
- Tetrachloroethylene and toluene depress the central nervous system [71,72].
- Trichloroethylene is believed to be responsible for "psycho-organic syndrome" in exposed workers. Occupational exposure to trichloroethylene may cause cancer in humans, but if the level of concentration is low, trichloroethylene is not a serious cancer hazard [73].
- Vinyl chloride damages the liver, causes bluish or pale and inflamed skin and causes the deterioration of bones in finger tips [67]. Vinyl chloride has been found to be a carcinogen [74].
- Xylene at high levels and short-term exposure leads to skin, eye, and nose irritation; difficulty in breathing; impaired function of the lungs; delayed response to a visual stimulus; impaired memory; stomach discomfort; possible changes in the liver and kidneys; and even death [75]. At both high and low levels of exposure, people suffer from headaches, lack of muscle coordination, dizziness, confusion, and a change in balance [75].

The health damages caused by the air pollutants from energy conversion are extensive. Estimating the health damages from air pollution requires information about the dose-response function for each health effect and each pollutant along with the economic value of each effect [63].

Impact of Energy Conversion on Global Warming, Ozone Depletion, and Acid Rain

Energy conversion has the potential to affect global climate in two primary ways: through its influence on the greenhouse effect and its effect on the ozone layer. In addition, combustive energy conversion is blamed for much of the increased acidity of precipitation around the world. Although the effects of acid precipitation are generally detected at the local or regional scale, the circulation of the atmosphere suggests that the impact may be far reaching. This section examines the role conversion of energy resources is thought to play on the greenhouse effect, and the ozone layer, and finally acid rain.

Greenhouse Effect

The greenhouse effect is the process whereby the atmosphere retains some of the solar radiation that strikes the earth. This effect is essential in warming the earth and allowing it to support life [30,76]. The greenhouse effect is essentially the difference between the temperature profile of the earth with the atmosphere and that which would exist without the atmosphere. Human-induced enhancements of the greenhouse effect may result in a different temperature profile of the earth than would exist in their absence. The component of the atmosphere most responsible for the natural greenhouse effect is water in all its forms [77]. Although human activities may be able to marginally alter the amount of water in the atmosphere, little evidence exists to date that suggests that human activity is having a large enough effect on this component to alter the global climate [78]. Of greater concern has been the effects of industrial production (most importantly combustive energy conversion) on the levels of the "greenhouse gases" in the atmosphere. Although the scientific community does not hold a consensus about when, they do hold a general agreement that a continuation of existing trends is very likely to increase the greenhouse effect and thus further warm the earth.

Besides water vapor, the most important greenhouse gases are CO_2, chlorofluorocarbons (CFCs), methane (CH_4), N_2O, and O_3 [30,76]. All of these, except CFCs are also by-products in the energy conversion process.

Approximately 4% to 5% of worldwide CO_2 emissions can be attributed to man-made processes [78,79]. Most atmospheric CO_2 is released through the combustion of fossil fuels, although 15% to 35% of anthropogenic CO_2 emissions result from deforestation [78]. Two percent of United States CO_2 emissions occur during the growing of agricultural food products, from the use of farm machinery, and during production of fertilizers and pesticides [33,80]. The combustion of fossil fuels releases 5.2 to 6.2 billion metric tons of CO_2 annually [33,76].

Nearly 65% of CH_4 is released during human-related activities [78,79,81]. For example, CH_4 is released by the decomposition of waste in landfills, leaks in natural gas pipes, seepage from coal mines, combustion of fossil fuels, emissions from fermenting rice paddies, burning vegetation, and from the intestinal tract of domesticated herbivores such as cattle, sheep, and goats [6,30,78,80]. Biomass burning is blamed for the release of 40 teragrams (10 x 12 g) of CH_4 per year [82]. Methane absorbs infrared radiation about 25 times more effectively than CO_2 and can be blamed for 1/8th of the heat-trapping potential of the greenhouse gases. After a decade, CH_4 oxidizes with the hydroxyl radical OH to

form carbon dioxide and water vapor, two other greenhouse gases. However, the amount of OH available in the atmosphere is decreasing as the concentration of CO increases [30,33,76,83,84].

Approximately 19% to 36% of N_2O emissions are from man-made sources [78,79,85]. This greenhouse gas is produced during the combustion of fossil fuels in car engines, coal-fired power stations, the cultivation of soils, production of some acid chemicals, and the burning of biomass [78]. Less than 7% of N_2O is released through the combustion of biomass [86]. In addition, N_2O is released by nitrogenous fertilizers and during land-clearing practices [30,32,80]. Nitrous oxide is 200 times more efficient at absorbing heat than CO_2 and is only slightly less destructive to upper-atmospheric O_3 than chlorine. Studies show that N_2O has contributed 1/10th as much as CO_2 to the greenhouse effect in recent years [30,76,84].

Located in the lower atmosphere or troposphere, O_3 is a pollutant. In the upper atmosphere or stratosphere, O_3 plays a crucial part in protecting the earth from the sun's ultraviolet rays. Not produced directly by humans, tropospheric O_3 is formed by chemical reactions between volatile organic compounds and NO_x, driven by sunlight and heat [87]. The radiative effectiveness per molecule of tropospheric O_3 is measured to be 2,000 times greater than CO_2 [58].

Typically the approach to predict the greenhouse effect of an energy conversion system is to calculate the total greenhouse warming effect for each emission, as a function of its concentration at any instant, times its absorption efficiency and then integrated over the duration of the period or lifetime of the gas for its decay phase. Then, the warming effect of the total system is calculated by summing the effects of the individual gases [88, 89]. This approach ignores the nonadditive interaction of some pollutants. The warming effect of a greenhouse gas depends on its concentration, radiative absorption, and emission characteristics, and with some gases, the radiative interferences with other gases [33]. For example, the presence of CO in the atmosphere (formed during the incomplete combustion of fossil fuels) influences the atmospheric concentrations of CH_4 and O_3 [88,90].

Energy conversion and use constitute the largest human sources of greenhouse gases, emitting 57% in 1990. Agricultural practices contribute another 14% [32]. Table 9.1 shows the percent of greenhouse gases produced by human activities and the effect of the production and conversion of biomass on emissions.

Table 9.1. Greenhouse gases—measuring enhancement by human activities [6,58,91,92].

Gas—% of Greenhouse	Power to Absorb Heat	Atmospheric Residency	Rate of Growth	Biomass's Effect on Emissions
CO_2 50	1	50-200 years	0.5%	decrease
CFCs 18	10,000	60-130 years	4%	negligible
CH_4 19	25	10-12 years	0.9%	inconclusive
N_2O 4	200	100 years	0.25%	inconclusive
O_3 8	2,000	several hours	0.5%	inconclusive
H_2O 1-2	>1	—	—	—

Substantial consequences would result if global warming were increased by human activity [93]. Major shifts in climatic patterns would affect the geographical patterns of agricultural productivity. A melting of some of the water held in glaciers on Antarctica and on northern lands could alter the levels of the world's oceans and thus greatly disturb coastal regions. Current models also suggest that global warming could increase the frequency and intensity of storms and increase the volatility of weather variations. An increase in the earth's temperature could lead to greater levels of air pollution through an alteration of the composition, concentration, and duration of chemical pollutants in the atmosphere. The temperature rise could cause an increase in urban heat stress, an extension of tropical diseases pole-ward, climate changes and altered rainfall levels, and the disruption of food supplies with the alteration of the climate. Other consequences include extinction of species through habitat alterations and losses in leisure activities associated with winter sports [84,93]. All of these changes would have further effects on the natural environment and on human behavior.

In the short-run, the more industrialized countries would experience less economic hardship than less-industrialized ones, but even they would be affected over time. The areas most affected are those that depend on unmanaged ecosystems, such as agriculture and forestry. Mid-continental regions may experience hotter and dryer climates. The climatic warming may reduce agricultural yields; however, an increase in atmospheric CO_2, which helps plants grow, may lead to subsequent increases in yields [94]. The consequences of accelerated species extinction, loss of habitat, and shifting agricultural patterns cannot be predicted at this time, but they will exist. The great complexity of the

dynamics of the global climate makes it difficult to describe the effects of any possible global warming.

Estimations of the possible economic damages that result from the human releases of greenhouse gases and the enhanced global warming are presented in the following tables. Table 9.2 and 9.3 present initial estimates of the dollar damages from CO_2. Biomass production will result in little if any net increase in CO_2 and hence not add to the atmospheric CO_2 concentration. Thus these results show potential reductions in external costs that could result from biomass energy conversion rather than energy conversion from fossil fuels such as coal. By replacing fossil fuels, biomass can help slow the predicted climate change and the damages that would result [18].

Both Nordhaus [95] and Cline [84] used a range of 1% to 2% of gross domestic product (GDP) to estimate the damages costs from benchmark warming (the doubling of CO_2-equivalent, with warming at 2.5° C).

William Nordhaus [96] presents a prescription for the world's reaction to the global warming theory. He suggests caution in approaching this problem with large-scale programs that could slow the growth of the world economy while the causes and certainty of the greenhouse effect are still unclear. Although it is not certain that global warming will occur, Nordhaus does list possible economic costs to the United States economy from warming caused by the greenhouse gases. Agriculture could be adversely affected or

Table 9.2. Present value of climate damages from CO_2 equivalent emissions (1993 dollars per ton CO_2 equivalent, carbon weight) for damages as a percentage of world output [95].

Difference between real interest rate on goods and growth rate, % per year	Present-value factor	Present value of climate damages from CO_2 equivalent emissions (1993$ per ton CO_2 equivalent) for damages as percentage of world output	
		1 ($)	2 ($)
0	200.0	38.42	76.84
1	44.4	8.54	17.07
4	7.41	1.42	2.84

Table 9.3. Estimates of annual damage from global warming to the United States economy at 1990 scale, in billions of 1990 dollars [84].

	Doubling of CO_2 (+2.5° C)	Very Long-term Warming (+10° C)
Agriculture	17.5	95.0
Forest loss	3.3	7.0
Species loss	4.0 +	16.0 +
Sea-level rise	7.0	35.0
Electricity requirements	11.2	64.1
Nonelectric heating	-1.3	-4.0
Migration	0.5	2.8
Hurricanes	0.8	6.4
Leisure activities	1.7	4.0
Water supply	7.0	56.0
Urban infrastructure	0.1	0.6
Air pollution		
Tropospheric ozone	3.5	19.8
Other	X	Y
Total	55.8 + X	302.7 + Y

positively affected by $10 billion. Mitigation costs for a sea-level rise could run as high as $100 billion. Energy costs from an increased demand for power to cool could reach $1 billion at 1981 levels of national economic output. Nordhaus also mentions numerous marketable and nonmarketable goods and services that could change in value with a change in climate. He does not present any dollar values for these private and public goods. Nordhaus concluded his economic cost estimations with the remark that the economic impact upon the United States from a climate change induced by a doubling of CO_2 concentrations would likely be small. He estimated the impact at 0.25% of national income by the middle to later part of the next century. However, he hedged this estimation with the caveat of a large margin of error.

Nordhaus attempted to estimate the costs of reducing the growth rate of the greenhouse effect through a reduction of the global anthropogenic emissions of greenhouse

gases. He noted that the cost of initial steps to reduce the greenhouse gases would be less than the benefits and might even create a more efficient world economy. Since a high percentage of the greenhouse gases are emitted through the combustion of fossil fuels, a reduction of the emissions would best be attained through a reduction of the use of those fuels. These fuels create many unwanted by-products that are not currently accounted for in their market price. Including these external costs in the market price of these fuels would reduce their use and also reduce the pollution caused by their use. This would result in an economy that operated more efficiently. However, the cost of reducing these greenhouse gases increases rapidly, and for substantial reductions may reach "economically destructive" levels. Nordhaus estimated that one-sixth of greenhouse gas emissions could be eliminated with the imposition of a carbon tax of $4 per ton of CO_2 equivalent. This leads to a burden of $6 billion per year on the global economy. However, if an attempt were made to cut greenhouse gas emissions by 50%, the tax would have to be raised to a prohibitive level, creating a burden of $200 billion on the global economy that equals 1% of total global output.

Nordhaus argued that the imposition of a moderate carbon tax would be an efficient way to achieve greenhouse gas emission reductions. Such a tax would serve as an incentive to minimize the costs of attaining a given level of greenhouse gas reduction on a global scale, where the tax would be applied in all "major" countries. He estimated that a $5 tax per ton of carbon (1 ton of CO_2 = 3.67 tons carbon) would increase the price of coal (in 1989 prices) $3.50 per metric ton or a 10% increase. Gasoline would rise 1.4 cents per gallon. This tax would decrease anthropogenic greenhouse gases 13%, generate $10 billion in tax revenues for the United States, and increase global income by $12 billion per year on a 1989 global economy scale (This scenario assumes a discount rate equal to 1% in excess of the growth of output and a doubling of CO_2 with damages equal to 1% of global output.) He discussed the ramifications of a higher carbon tax at $100 per ton of carbon. At this level, coal would be taxed $70 per metric ton, a 205% increase. Gasoline would be priced 28 cents higher per gallon. Greenhouse gases could be reduced 45%, but the global economy would shrink $96 billion.

Manne and Richards [97] carried out a regional assessment of carbon taxes as a tool for the abatement of global CO_2 emissions. Through a focus on the costs of abatement rather than its benefits, they estimated that the long-run equilibrium tax level required in all regions to raise prices sufficiently so as to make carbon-free fuels equally attractive is $250

per ton of carbon. Such a levy would increase the price of coal in the United States five-fold, and raise gasoline prices $0.75 per gallon.

Ozone Depletion

Upper-atmospheric or stratospheric ozone shields the earth from the harmful ultraviolet radiation of the sun. Although in nature, O_3 is constantly destroyed and replenished, man-made chlorofluorocarbons (CFCs) can alter the natural destruction/production cycle of O_3 by increasing the rate of destruction. The CFCs act as a catalyst in the break-down of O_3; hence one chlorine or bromine molecule from the CFCs has the potential to destroy thousands of molecules of O_3. The increased rate of destruction leads to a thinning of the stratospheric O_3 layer and decreased protection for the earth from the sun's ultraviolet rays [33]. Note that volcanic eruptions can also release O_3-depleting materials that may exacerbate the effects of man-made materials [98].

The CFCs are 100% man-made. They were developed for use in aerosol spray cans as propellant solvents, in production of Styrofoam and insulating materials, and as coolants in refrigerators and air conditioners [30]. A study by the United Nations Environmental Programme contended that the CFCs' destruction of stratospheric O_3, a greenhouse gas as well, was offsetting its addition to the greenhouse effect. Hence, a reduction in CFCs may save the O_3 layer but may not significantly decrease the greenhouse effect [84]. The CFCs trap heat ten thousand times better than CO_2 [33,82,88].

Nitrous oxide is only slightly less destructive to upper-atmospheric O_3 than chlorine [30,76]. Nitric oxide combines with O_3 and breaks it down into NO_2 and O_2 [99].

Increased penetration of ultraviolet sunlight through the atmosphere can cause sunburn, premature aging of the skin, nonmelanoma skin cancer, ocular disorders including cataracts, and suppression of immune system responses [33]. A 10% increase in ultraviolet (UV) radiation infiltrating the protective ozone layer can decrease the time of sun exposure required before the onset of erythema, or sunburn [100]. Exposure to UV can decrease the function of lymphocytes, white blood cells, suppressing the natural immune system [100].

In addition, UV radiation can damage agricultural crops and other flora by stunting growth and inhibiting photosynthesis. Moreover, UV radiation can adversely affect marine ecosystems by disrupting their reproduction and metabolic processes [100].

No estimations of dollar amounts for damages caused by O_3 depletion were located during the literature review. Nordhaus [96] asserted that the most cost effective way to

decrease the growth of greenhouse gases would be to curb CFC production, at a cost of $4 per ton of CO_2 equivalent. This implies that a phase-out of the O_3-depleting gases may be economical, particularly since two global environmental concerns can be addressed. However, a phase-out of CFCs could require a $19 to $34 billion loss of equipment that could no longer be operated [101]. This raises the issue of whether the economic damage that extra UV causes is large enough to justify the cost of dealing with the problem [97].

Acid Rain

The release of SO_2 and NO_x into the atmosphere leads to the formation of acid rain. These pollutant gases are transformed into sulfuric acid and nitric acid, mix with upper air moisture, and return to the earth as acid rain. The acidic pollutants can also reach the ground in the form of acidic snow, sleet, hail, fog, and dew; hence some refer to the phenomenon as acid precipitation. Along with the precipitation, acidic substances are deposited on the land and the biota through dry deposition of acid particles, aerosols, and gases [102]. Human-made emissions of SO_2 and NO_x have lowered the pH value of some rainfalls from the natural 5.0-6.0 to an acidic 4.5. In the most heavily polluted urban areas, precipitation has been measured as low as 1.7 [58].

Approximately 90% of NO_x are from anthropogenic sources [63,103]. The grouping of NO_x includes nitric oxide (NO) and nitrogen dioxide (NO_2) [62]. These are by-products released during the combustion of petroleum in automobile and airplane engines, during combustion of fossil fuels in power plants, during the production and application of fertilizers, and during deforestation and land use changes [6,104,105]. Nitrogen oxides react with air moisture to form acids which return to the earth in the form of acid rain [15]. Nitrogen oxides are responsible for approximately 30% of acidity in acid rain [63,106].

At least 50% of the atmospheric SO_2 comes from anthropogenic sources [76,103]. The major human sources of SO_2 are combustion of fossil fuels, particularly coal, and industrial production [107]. Sulfur dioxide combines with water vapor to form sulfuric acid and returns to earth in the form of acid rain [107]. In fact, SO_2 is responsible for approximately 70% of acidity in acid rain [63,106].

Not all impacts of SO_2 emissions adversely affect the environment. Atmospheric SO_2 forms a mist of small sulfate particles which reflects some sunlight back into space [108]. Human-produced SO_2, when oxidized in the atmosphere, produces sulfate aerosols that may act as cloud condensation nuclei and increase the ability of the clouds to reflect the

sun's rays and hence offset the effects of the greenhouse gases [109]. However, the cooling benefits from SO_2 are only experienced at a local level [83].

Acid precipitation deposits hydrogen onto the soil. The increased level of hydrogen can lead to the release of heavy-metal cations from the soil into the nearby water sources. The acidic water may corrode water pipes, leaching lead and copper. Metals such as mercury, cadmium, nickel, aluminum, lead, copper and manganese can contaminate edible aquatic wildlife and drinking water and hence enter the human system [58].

The deposition of acidic compounds through particles or precipitation impacts the environment in many ways. Increased acidity of lakes and rivers can affect the reproduction of most fish species, leading to a population of older fish with little or no replacement [58]. The increased water acidity can also destroy hundreds of other aquatic organisms, including algae, crustacea, molluscs, and insects [103]. This can greatly upset the ecosystem in a body of water, possibly leading to the death of that ecosystem.

Increased acid deposition can raise soil acidity, mobilize toxic metals, leach key soil chemicals, lower nutrient availability, and alter the species composition and decomposer micro-organisms in soils [58]. The leaching of nutrients and chemicals from the soils robs these nutrients from trees, which can lead to decreased growth or death [58]. Agricultural crops also suffer damage from the leaching of soil nutrients caused by acid rain [58].

Acid precipitation and dry deposition destroy human creations as well. The acid accelerates corrosion of metals and erosion of stone. This leads to the destruction of monuments and historical buildings [58]. It can also affect the life span of automobiles and other items subject to corrosion that are exposed to the acid precipitation.

Two studies used the damage cost approach to estimate crop losses in the United States. Adams estimated the cost to be $142 million (in 1980 dollars), while Callaway estimates were between $20.4 and $152.4 million (in 1984 dollars) [110].

Menz and Mullen used the damage cost approach to estimate (in 1982 dollars) the loss in fishing in the New York Adirondack recreational area. The estimated losses were $24.58 per angler day for a total of $1.7 million annually (with interfishery substitution) and $35.33 per angler day for a total of $1.96 million annually (without interfishery substitution) [110].

Crocker and Regens used the damage cost approach to estimate a 5% decrease in forestry yields due to acid precipitation damage. They also estimated the loss in 1978 dollars to United States commercial timber industries to be $0.75 billion, along with a $1.0 billion loss of wildlife habitat and forest recreation [110].

Acid rain damage to materials in a seventeen state region in the northeastern United States was estimated by Horst. He estimated the damage to paint at $1,179 million dollars, and residential damage at $906.8 million. Material damages attributed to local SO_2 were estimated at $473.5 million. Thus the total damage to human materials from acid precipitation was estimated at to $2,559.3 million in 1984 dollars [110].

These dollar values were obtained from several studies, estimating local and regional damages from acid precipitation. Since the estimated external costs are not presented in a per pollutant amount, the decrease in acid precipitation damage from biomass can not be easily measured. Studies which show the damages in per pollutant amounts have not been located.

Externalities from Coal Conversion

The conversion of coal into energy, predominately to produce electricity, creates many unwanted by-products. The emitted air pollutants include CO_2, NO_x, SO_2, particulates, toxic metals, and volatile organic compounds, many of which were discussed previously [111]. The coal industry has dedicated much research and development to clean coal technologies to make this abundant fossil fuel less polluting [112,113]. Many methods for removing sulfur and NO_x from the coal, before or during combustion, have been developed; however, most of these processes create either liquid or solid pollution in place of the air pollution that is abated [114]. The clean coal technologies have reduced the consequences of coal conversion as far as acid rain is concerned, with decreases in SO_2 and NO_x air pollutants. By the year 2000, the United States will cap SO_2 emissions at 8.9 million tons annually [114]. However, the coal industry has not found a cost-effective way to abate the emissions of CO_2 released during the combustion of coal. This poses a continuing problem where greenhouse gas pollution is generated during the energy conversion of coal.

Coal conversion can also create water and land pollution. The Pace University Center for Environmental Legal Studies [63] has studied such pollution problems. One electricity-generating process, which burned coal to heat water that in turn formed steam to run the turbines, produced pollutants in all phases. The combustion of the coal released the gaseous pollutants listed above along with toxic metals in the form of fly ash. This conversion process also polluted water. The heat that was converted into energy through the steam turbines had to be removed from the steam so the water could be rerouted through the combustion system. The heat was most often removed through a cooling

system that used water from a nearby water source. This led to thermal pollution of the water. The water was also screened before entering the cooling system, which removed many aquatic organisms. Other organisms that passed through the screen were killed during the cooling process. All these steps damaged the water source that was vital to the aquatic and surrounding ecosystems.

In addition, the Pace studies indicated that coal-fired electricity plants released pollutant waste streams in to water resources. These pollutants included heavy metals, sulfates, acidic cleaning solutions, coal dust, oil, fly ash, and detergents.

Solid wastes are produced from coal combustion. In 1989, the solid waste produced by the electric utility industry amounted to 80 million tons annually. These wastes included recaptured fly ash, bottom ash, boiler slag and flue gas desulfurization sludge [63,115]. The EPA ruled the solid refuse from coal combustion was a nonhazardous waste [116]. Approximately one-fifth of the solid waste is reused as cement additives, road construction material, or blasting grit; the rest is deposited in landfills [63]. This method for disposing the majority of the solid waste leaves the potential for leaching of the toxic metals, such as silicon, aluminum, and iron, into surface or underground water sources [63,117].

Dollar Damages from Pollution Released during Energy Conversion

In addition to investigating pollution problems, the Pace studies [63] attempted to estimate the external costs resulting from electricity production (all estimates in 1989 dollars). Both conventional energy conversion processes and alternative methods were examined. The Pace studies estimated the external cost from biomass conversion to be $0.00 to $0.007 per kilowatt-hour of electricity.

The Pace studies estimated the environmental costs of electricity generation from coal as $0.025 to $0.058 per kilowatt-hour. These estimations did not include air emissions of CH_4 and N_2O from coal production; air toxins released during combustion including heavy metals, emissions of volatile organic compounds, water use and pollution, land use and solid waste disposal, and environmental costs of coal extraction, processing, and transportation.

The estimates for the environmental costs of electricity production from coal were derived from an estimation of the costs of four major emissions from these plants: CO_2, SO_2, NO_x and particulates.

The Pace studies used two of the methods for valuing the environmental costs of electricity. The center considered damage costs to be the method most likely to represent the external costs to society accurately. However, the method was not always simple to apply and thus the mitigation cost approach was used as a proxy when damage costs could not be estimated.

The environmental cost from CO_2 pollution, as estimated by the Pace studies, was $0.0068 per pound of emitted pollutant. This estimate was derived by estimating the mitigation cost for CO_2 and the cost of planting enough trees to absorb an equivalent amount of CO_2, which was averaged at $50 per ton of carbon emitted.

The Pace studies estimated the external cost from SO_2 pollution as $2.03 per pound of the emission. This cost reflects the health effects from the SO_2. The studies used the valuations of $4 million per human life (mortality) and $400,000 per statistical illness or injury (morbidity) to estimate the health damage costs from the SO_2 emissions at $1.72 per pound for mortality and $0.05 per pound for morbidity. Other damage costs were taken into account to reach the total figure listed earlier. The average damage from a pound of SO_2 on materials due to corrosion from acid precipitation and dry deposition was $0.12. Crop losses were considered negligible. The visibility losses from atmospheric SO_2 were measured at $0.14 per pound of the pollutant. Damage cost estimates for ecosystems and historical monuments were not available. This adds up to Pace's total damages of $2.03 per pound of SO_2.

In addition, NO_x and O_3 were also analyzed. Since NO_x emissions are the major ones leading to the formation of tropospheric O_3, the two pollutants were examined together in the assessment of damage costs. The Pace studies concluded that health damages from NO_x and O_3 are $0.34 per pound of NO_x for mortality and $0.29 per pound of NO_x for morbidity. Damage to materials was estimated at $0.01, as was damage to crops. Visibility damages, which focus on the lost recreational benefits from increased haze and visibility loss, were estimated at $0.17 per pound of NO_x. The total damages from both NO_x and the by-product O_3 were summed to obtain $0.82 per pound of NO_x emissions.

Particulates were the final emission discussed in this study. The external costs for this pollutant were primarily derived from health effects and lost visibility. Mortality costs were measured at $0.33 per pound of particulates, while morbidity costs were $0.03. Visibility costs were estimated at $0.83 per pound of particulates. The damage from this pollutant on materials, vegetation, and ecosystems was also examined, although the costs

could not be estimated in dollars. The total costs of particulate damages totaled $1.19 per pound.

The Pace studies are a valuable tool with which to estimate the economic value of the external costs associated with coal combustion. They can also serve as a means of estimating the potential to decrease these externalities when biomass is used as a substitute energy source.

Swezey et al. [118] provide examples by states to monetize externalities (all estimates in 1991 dollars). The state of New York used the control cost approach to estimate the dollar value of total externalities from a coal-fired plant. The control costs, including air emissions (CO_2, NO_x, particulates, and SO_2), water discharges, and land use impact added 1.4 cents per kilowatt-hour to the cost of coal power. Massachusetts and Nevada also used the control cost approach and estimated the total externalities from coal power at 4 cents per kilowatt-hour. The differences between states primarily results from the estimates of the external costs resulting from CO_2. Note that Massachusetts has adopted a full CO_2 offset for wood-burning plants. The result of this was to lower the external costs from wood-fired plants to about 1 cent per kilowatt-hour, which is lower than coal and natural gas, the latter thought to be the "cleanest" fossil fuel.

Cifuentes and Lave [37] estimate the economic value of the damages to human health from the air pollutants released in energy conversion. These estimates are shown in Table 9.4. The numbers show that the damages from particulates are not directly comparable from the two fuels since the particulates from coal conversion appear to be somewhat toxic while the particulates from biomass conversion do not appear to be toxic.

Table 9.4. Marginal benefits of reducing pollutant emissions in the United States regarding health effects of the pollutants [37].

Pollutant Emissions	Marginal benefit	
	Low	High
	(1993 dollars/Ton)	
Particulates	978	3,354
Sulfur Dioxide	304	1,216
VOCs	82	248
Nitrogen Dioxide	102	308

CONCLUSIONS

This chapter has attempted to provide information on the magnitude of the externalities that could result from crop production and energy conversion. Where possible we attempted to compare the dollar value of the externalities generated by alternatives such as biomass crops or corn production and biomass- or coal-fired power plants. Unless these decreased externalities can be reflected in dollar amounts, they may not be recognized by those who make the financial decisions surrounding energy conversion.

To precisely monetize external costs, three functional relationships must be shown: (1) between production or conversion and physical or biological effects (2) between physical or biological effects and external costs, and (3) between external costs and the monetary valuation of these costs. Very few studies have attempted to describe these relationships. Those that have do not provide sufficient information to completely and accurately estimate the monetary value of the reduction in external costs that would result from using biomass as an alternative energy source. Since there is limited information available about the dollar value of the damages, particularly damages per unit of pollution, an attempt was made to describe the type of damage that may result from each externality when it was not possible to estimate the damages in dollars.

The literature review surveying biomass production and conversion into energy uncovered the numerous external costs of those processes; however, these external costs are generally less than alternatives such as row-crop production and energy conversion using coal. The potential to decrease external costs such as soil erosion, water pollution, and chemical use from the replacement of annual row crops with perennial biomass crops is significant, depending on the scale of replacement. Biomass production and conversion could also result in a substantially reduced impact on human health at a local level when compared to corn production and at a global level when compared to coal conversion. This will also depend on the scale of replacement. The potential for the use of biomass as an alternative renewable energy source to decrease global environmental concerns such as the greenhouse effect, ozone depletion, and acid rain, is limited when dealing with small-scale use. Thus generating power with biomass fuels should not be interpreted as resulting in the same level of environmental quality as coal-generated power; rather it means that on a small scale any noticeable change in environmental quality will be localized to Iowa. Noticeable reductions in the greenhouse effect, ozone depletion, and acid rain could only result from large-scale biomass energy conversion.

We must realize that the environmental problems associated with energy conversion cannot ultimately be solved through the use of energy produced from biomass crops. At the same time, the ability of biomass to reduce many of the adverse effects of conventional crop production and energy conversion on humans and our environment, no matter how minute in scale, must be recognized as a positive aspect of using biomass as an alternative energy source.

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Chapter 10

Recommendations and Conclusions

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CHAPTER 10. RECOMMENDATIONS AND CONCLUSIONS

The wide-scale adoption of biomass energy systems in Iowa will require convergence of several favorable conditions. The state must contain a sufficient resource base for the production of large quantities of biomass. The price of biomass as a crop must be high enough to encourage its cultivation by farmers, yet its price as a fuel must be low enough to make it competitive with fossil fuels. The wide dispersion and low density of most biomass resources demands energy conversion processes that are of high efficiency at moderate scales. Ideally, the state will have an appropriately trained work force to support both the production of biomass and its conversion to useful energy. The state should also have suitable physical infrastructure to support a transition to biomass energy systems. Both production and conversion activities must have net benefits to the environment compared to the fossil fuel technologies they would replace, and society must sufficiently value these benefits. The goals of this study were to assess these conditions as they apply to Iowa and to recommend a course of action to encourage the development of biomass energy in the state.

Of the several necessary conditions, the existence of a large biomass resource base is the most readily satisfied. This study estimates that 406 trillion Btus of biomass energy could be produced in the state without appropriating any cropland presently used for food, feed, or fiber production. This large biomass resource consists of a variety of municipal wastes, wood industry wastes, animal wastes, forest and corn crop wastes, and herbaceous energy crops (HEC) and short rotation woody crops (SRWC) grown on land currently in the CRP/WRP programs. However, as Figure 10.1 illustrates, the largest contributors to this resource are corn crop residue (43%) and dedicated crops of HEC and SRWC on CRP/WRP land (44%). Since CRP/WRP land is currently in grass or trees suitable for biomass energy, Iowa effectively has a biomass reserve of 406 trillion Btus that is immediately available. An additional 212 trillion Btus could be established within five to twenty years if the 2.66 million acres of marginal land (LCC IV to VII) presently in crop production or non CRP/WRP pasturage were established in dedicated herbaceous or woody biomass crops. The south central and southeastern regions of Iowa appear to have

the greatest potential for woody and herbaceous biomass production. Agricultural diversification and rural development needs are also greatest for these regions.

Figure 10.1

Large capital investments are not necessarily required to convert existing biomass resources into useful energy. Infrastructure in the state includes large, efficient steam power plants, presently fired on coal, that could be co-fired with biomass. The state also contains highways and trucking firms that could transport biomass to these plants. The 19 largest (>50 MW) coal-fired steam power plants in Iowa co-firing 50% biomass would completely consume the switchgrass crop on the 2.225 million acres of land presently in the CRP/WRP program. A total of 29.6 million tons of coal imported into the state would be displaced by such a cofiring program. Co-firing is not without some technical adjustments, such as in fuel handling, boiler derating, and strategies to avoid ash fouling. Although there appears to be no utility experience in cofiring with biomass, related experience suggests that limitations to such a conversion will not be technical in nature as long as conditions promoting ash-fouling are avoided.

Infrastructure also includes internal combustion engine power plants at many small municipalities, which average only a few megawatts in generating capacity. These plants could be retrofitted with small gasifiers to allow consumption of biomass fuels. Although this may have important local impacts, the state-wide effect on energy consumption would be modest. Even if all 329 of these small plants were converted to biomass, it would only affect 11% of the total electric generating capacity of the state.

Neither does biomass energy development appear to be limited by the absence of a suitable workforce. A significant part of the rural workforce today is farmers who are not able to support themselves with full-time farming and who supplement their income with other work. If additional opportunities in agriculture presented themselves, presumably these part-time farmers would return to their professions full-time. Also, most of the jobs associated with energy conversion facilities are semi-skilled positions of the type familiar to many rural workers.

Environmental effects, although not necessarily benign, generally favor biomass production and conversion compared to conventional row-crop production and fossil-fuel energy conversion. Some biomass cropping systems, such as for sorghum, tropical corn, and other annual herbaceous species, have the same negative environmental impacts as hybrid corn: soil erosion, nitrate run-off, and high pesticide applications. However, two strongly-favored (perennial) biomass crops, switchgrass and hybrid poplar, can greatly reduce these problems and can even ameliorate problems associated with annual crops if employed in buffer strips along riparian zones. There are some concerns that monocultured biomass can have the same adverse effects on wildlife diversity as conventional row-

cropping. However, with careful attention to cultivation and harvesting practices, perennial biomass crops are generally perceived as superior to present cropping systems.

The relative pollutant emissions from the various energy conversion processes depend as much on the fuel being converted as they do on the process of conversion. By some measures, certain fossil fuels are superior to renewable, biomass fuels. In particular, natural gas is superior to biomass fuels in most respects. When burned, natural gas emits neither sulfur compounds nor fly ash. Careful burner design can eliminate most nitrogen emissions for this gaseous fuel. It is inferior to sustainable use of biomass fuels only with respect to greenhouse gas emissions. Although the greenhouse gas carbon dioxide is formed during combustion of natural gas, the amount, on a heat-release basis, is much less than for other fossil fuels; hence, use of natural gas is often touted as a way to reduce greenhouse warming. However, natural gas itself is a much stronger greenhouse gas than carbon dioxide: accidental leakage of unburned natural gas to the atmosphere is probably the most important environmental concern about this fuel.

Compared to other fossil fuels, though, biomass is superior by most environmental measures. These advantages are particularly important in comparing biomass to coal. Most coals contain between 1% and 10% sulfur, which must be removed before or after the energy conversion process if emissions of acid-rain precursors are to be controlled. In contrast, the sulfur content of biomass is insignificant. Also, most coals contain inherent nitrogen, known as fuel nitrogen, that forms nitrogen oxides during high-temperature conversion processes. The nitrogen content of biomass ranges widely and can be significant in some forms of biomass. For both coal and biomass fuels, the ultimate nitrogen oxide emissions depend strongly on the conversion process and can be controlled by proper process design. Another important constituent of coal is ash, which can range up to 20% or more by weight of coal; most biomass fuels have ash contents of only a few percent. Atmospheric emissions of ash, though, depend on the kind of conversion equipment in use. Emissions of organic compounds, such polycyclic aromatic hydrocarbons or dioxins, are primarily a function of the conversion process rather than the fuel consumed. Finally, coals are expected to emit much larger concentrations of toxic heavy metals, such as mercury and cadmium, into the atmosphere than biomass. The fate of these metals and their environmental influences are just beginning to be understood. However, there is some evidence that metals can become concentrated during the conversion process or once they are emitted into the biosphere. Concentrations of heavy metals in biomass, by contrast, are very small.

Solid disposal problems will be similar between conversion processes using biomass and coal. Potential water pollution problems arising from conversion processes are generally amenable to water treatment processes, whether based on biomass or coal.

Six types of processes were evaluated for the conversion of biomass into useful energy: direct combustion, thermochemical conversion, biochemical conversion, indirect liquefaction, physical extraction, and electrochemical conversion. Economic considerations suggest that new electric generating capacity should be based on integrated gasification/gas-turbine power cycles. Also for economic reasons, plants for liquid fuels should be based on conversion of sugar and starch to ethanol or, better yet, conversion of cellulose to ethanol. Contraints imposed by economies of scale and limits on transporting biomass suggest biomass power plants of about 50-MW electrical generating capacity and liquid-fuel plants of about 5,000 barrels/day.

Although direct-combustion in steam power plants is the best developed of the electrical generation technologies, heat rates are 12,500 Btu/kWh or higher at the 50 MW scale appropriate to biomass power plants. In contrast, one manifestation of gas turbine cycles, the biomass integrated-gasification/steam-injected gas turbine (BIG STIG) cycle, is projected to have heat rates comparable to very large-scale, coal-fired steam power plants (about 10,200 Btu/kWh). These lower heat rates are essential if widely dispersed, low-density biomass is to be used as fuel. This important biomass power cycle is illustrated schematically in Figure 10.2.

Ethanol fuel from corn starch is a well-established process and has become a commercial success with the assistance of state and federal subsidies. However, if production of ethanol fuel in the United States were to expand to provide a larger fraction of U.S. transportation fuels, the market price for fermentation by-products, which has been a key factor in economic viability of the ethanol fuel industry, would drop and the net price of feedstock would increase significantly. For this reason, alternatives to corn as a feedstock are considered essential if ethanol is to play a larger role in the liquid fuels market. Enzymatic processes have been developed to convert cellulose, the major constituent of many woody and herbaceous crops, into ethanol. The conversion yield, on a mass of ethanol per mass of feedstock basis, is comparable for the conventional and advanced conversion processes. However, the larger biomass production yields and lower production costs for cellulose-rich crops compared to starch-rich crops translates into improved conversion economics for the cellulose-to-ethanol process. A schematic of this

Figure 10.2

important biomass to transportation fuels process is shown in Figure 10.3. Much developmental work remains for this advanced conversion process.

Figure 10.4 illustrates the hypothetical impact of biomass energy production on two communities in Iowa. Ottumwa, located in southern Iowa, is surrounded by marginal crop land, which we assume yields 100 bushels/acre of corn or 5 tons/acre of either woody or herbaceous biomass crop. We also assume current technology for producing power and liquid fuels in the Ottumwa area: a 50 MW, direct-fired biomass power plant, capable of supplying the electrical needs of a population of about 25,000 people, and a 5,000 barrel/day corn-to-ethanol plant. The second community is Ft. Dodge, located in some of the richest farmland in the world, capable, we assume, of yielding 150 bushels/acre of corn or 7.5 tons/acre of biomass crop. However, for this community we assume advanced conversion technology for producing power and liquid fuels: a 50 MW, BIG STIG power plant and a 5,000 barrel/day cellulose-to-ethanol plant. A 20-mile radius drawn around each city defines the regional community from which biomass resources can be drawn. Three percent (25,000 acres) of each of these regions is arbitarily assumed to be used for non-agricultural purposes.

The higher productivity of the land around Ft. Dodge and the higher efficiencies of its hypothetical conversion facilities are evident in comparing the pie charts of land use for each community. However, even in Ottumwa 62% of the surrounding land area is still available for the traditional crops of food, feed, and fiber. In the Ft. Dodge area traditional crops take up 83% of the land area. Clearly, opportunities for regional development through biomass energy systems are enormous even while traditional crops dominate production.

The biggest obstacle to widespread adoption of biomass energy systems is economic. A wide gap exists between the price at which farmers are willing to sell biomass as crop and the price at which conversion facilities are willing to buy biomass as fuel or feedstock.

The target price for biomass to be a viable feedstock for energy conversion processes is generally agreed to be about $2.00/MM Btu. For biomass with a nominal higher heating value of 8,000 Btu/lb (dry), this translates to $32.00/ton (dry). The production cost analysis performed in this study examined both herbaceous energy crops and short-rotation woody crops.

The production cost analysis for herbaceous crops examined both annual and perennial crops grown at two places in Iowa: Chariton (southern Iowa) and Ames (central

Figure 10.3

Figure 10.4

Iowa). Although this analysis investiged two scenarios for use of machinery and equipment, the results of the more conservative (and probably more realistic analysis) are presented here. The more optimistic scenario does not alter the conclusions drawn here. Although this analysis includes costs for regional transport of biomass to conversion facilities, it does not include profit or tax considerations.

Costs of herbaceous crop production were generally lower in southern Iowa because of the lower land costs in this part of the state. The crop with the lowest production costs in both locations was sweet sorghum, with a cost of $36.91 for Chariton and a cost of $42.44 in Ames. Although the Chariton cost is within 15% of the target selling price, it does not include profit for the farmer. Furthermore, sorghum is not the ideal fuel for most of the energy conversion schemes targeted for development. The high moisture content of sweet sorghum makes it unsuitable for off-farm transport and processing. Although on-farm fermentation of sugar pressed from sweet sorghum is a relatively simple operation, economies of scale are lost and profitable conversion operation is problematic. The high moisture content of sweet sorghum also makes it unsuitable for electric power generation. Finally, this annual crop shares the same environmental disadvantages during production as hybrid corn.

Among the perennial herbaceous crops examined in this study, switchgrass had the lowest costs at both sites. In southern Iowa the cost was $44.19 while in central Iowa the cost was $53.36. The lower of these two costs is still $2.85/MM Btu, well above fuel prices assumed in any of the analyses for conversion processes.

Short-rotation woody biomass can yield 5–7 dry tons/acre in Iowa. The cost of production (including harvesting and transportation) is estimated to be between $2.35 and $3.00/MM Btu. Under these circumstances, it will be difficult for operators of conversion facilities to convince Iowa farmers to sell them biomass feedstock at $2.00/MM Btu. The exception is corn stalks, which can be baled and delivered to a conversion plant for about $0.50/MM Btu. Even when profit and tax are added, farmers may be able to offer corn stalks as boiler fuel at a competitive price.

Biomass energy conversion companies will also find it difficult to sell their products, be they transportation fuels or electricity, even if they are able to obtain biomass feedstock at an optimistically low price of $2.00/MM Btu. Table 10.1 summarizes the costs of several biomass fuels or biomass-derived fuels and compares them to the costs of several fossil fuels. Biomass, with the possible exception of corn stalks, can neither compete with the low-value market for coal nor the high-value market for natural gas.

Table 10.1. Cost comparison of fuels in Iowa.

Fuel	Cost* (per MM Btu)
Transportation	
Diesel	$5.10
Gasoline	$5.60
Methanol from natural gas	$16.13
Biodiesel (from vegetable oil)	$11.30–$22.30
Ethanol from cellulose	$19.20
Ethanol from corn	$12.50–$27.90
Methanol from biomass	$15.40–$33.20
Heat and power	
Corn stalks	$0.50
Wyoming subbituminous coal	$1.00
Natural gas	$2.00–$5.00
Hybrid poplar	$2.40–$3.00
Switchgrass	$2.90–$3.50
Liquefied petroleum gas	$4.90–$8.50

*Moisture-free, ash-free, higher heating value basis.

Western subbituminous coal, much of it from the Powder River Basin of Wyoming, resembles biomass fuel in many important respects. It is has high volatile content, high moisture content (often approaching 30%), high alkali content, and low sulfur content. It has some of the same advantages as biomass (low sulfur emissions) and some of the same disadvantages (some boiler derating and increased ash fouling of boiler tubes). Generally, the two fuels can be processed in similar manners. However, the delivered cost of western coal to Iowa is as low as $1.00/MM Btu compared to the delivered cost of Iowa-grown dedicated biomass crops of between $2.85 and $3.00/MM Btu. On this basis, Iowa biomass cannot compete with Wyoming coal. Environmental considerations have been suggested as a means for bringing the cost of coal closer to that of biomass. This point will be subsequently discussed.

In general, direct comparisons between natural gas and biomass cannot be made. Natural gas is a high-value feedstock that can be used for both chemical synthesis and energy conversion in relatively simple reactors and engines. Biomass is also a versatile

feedstock but requires considerably more equipment and processing to use it. For example, whereas natural gas can be fired directly in a gas-turbine engine, biomass must first be converted to gas in a gasifier. The lower price of biomass feedstock is generally overshadowed by the higher capital cost of the biomass energy conversion system.

Advanced thermodynamic cycles have been offered as a means for improving the economics of biomass power. Indeed, the heat rate for a BIG STIG power plant of 50 MW capacity is comparable to that for a much larger steam power plant. Under the optimistic assumption of $2.00/MM Btu biomass feedstock, the resulting cost of electricity is about $0.05/kWh, which is comparable to that for a new, coal-fired steam plant. Although this system is attractive for new electric generating capacity in the state, it cannot compete with existing capacity which may produce electricity for as little as $0.02/kWh.

Transportation fuels from biomass will also have a difficult time competing with petroleum-derived gasoline. A well-designed ethanol plant producing 5,000 barrels/day would cost about $140 million and have a conversion cost of about $0.87/gallon. However, since the heating value of ethanol is only 70% that of gasoline, this conversion cost is equivalent to gasoline selling for $1.24/gallon before tax, transportation, and profit. The current production cost for gasoline is only $0.70/gallon.

Environmental and socioeconomic impacts of using energy resources are increasingly being considered by utilities and state regulatory agencies as part of integrated resource planning. These nonmarket-related factors are known as externalities. Although a wide variety of potential factors not captured by traditional markets can be considered, most states have focused on environmental externalities, especially air emissions from power plants. As of 1992, 29 states required some form of externality evaluation in resource planning, although most of these evaluations are qualitative in nature.

Attempts to quantify environmental externalities by a process called monetization have met with a great deal of controversy but have been adopted by six states. There are three approaches to monetization. The damage costs approach is based on the actual economic damage to the environment produced by the production or conversion process. However, more often than not, the economic value of such damage is unknown and, in some instances, even the extent or severity of environmental effects of a suspected pollutant is unknown. The control cost approach is based on the costs of removing the suspected pollutant from the process stream and is generally favored. For example, New York calculates externalities for air emissions from a new coal-fired power plant ranging from $0.00005/kWh for particulates to $0.0055/kWh for nitrogen oxides. The mitigation cost

approach measures the dollar cost of compensating for damage once it occurs. It is relevant to such strategies as planting trees to off-set carbon dioxide emissions from power plants.

Externality adders would appear to be an excellent method for moving the advantage in cost of energy from fossil fuels to biomass. Nevertheless, the current low price of many fossil fuels can offset the advantage this controversial accounting method gives to biomass. For example, relatively expensive natural gas used in combined cycles yields the lowest priced electricity for new generation capacity in much of the United States, as calculated by conventional economic measures. Recent experience in New York and Boston suggests that inclusion of environmental externalities in resource planning simply improves the attractiveness of natural-gas based projects. Few, if any, renewable energy projects are selected in competitive bidding even with environmental attributes considered.

Even western coal may remain cheaper than biomass when externality adders are applied. The advantage of biomass with respect to sulfur emissions is not so large in comparison with western coal as it is for other coals. Indeed, the restrictions on sulfur emissions mandated by the Clean Air Act of 1992 set off a rush not for advanced "clean coal" technology but for low-sulfur, western coal, referred to as "compliance coal" for its ability to bring boilers into compliance with federal law.

More compelling, it would seem, is the advantage in greenhouse emissions that sustainable biomass use offers compared to western coal. Sustainable use of biomass implies that it is grown at a rate equal to its consumption such that no net carbon dioxide accumulates in the atmosphere. In contrast, each pound of western coal results in about 2.75 lb of carbon dioxide accumulation in the atmosphere. Assuming that these two fuels could be used interchangeably in an existing boiler, an estimate of the externality valuation of carbon dioxide necessary to induce a utility to switch from western coal to biomass can be made. If western coal can be delivered for $1.00/MM Btu and biomass can be delivered at $2.85/MM Btu, then the externality valuation would have to be at least $16.15/ton of carbon dioxide emitted. Germany is contemplating a valuation of only $6/ton and valuations adopted by New York, California, New Jersey, and Wisconsin are all less than $15/ton based on the cost to plant trees to offset carbon dioxide emissions. Clearly, western coal will not be driven from the market by current externalty valuations on sulfur dioxide and carbon dioxide.

Other externalties can be explored, such as adders for heavy metal emissions or credits for rural development. However, externality valuations become harder to justify as

environmental effects become uncertain or if the valuations simply pit one state against another and become barriers to interstate commerce. Externalities must avoid the appearance of a means to justify a particular end.

Recommendations for improving the prospects for biomass energy in Iowa must be formulated with careful regard for the present economic barriers to its use. Biomass is not presently competitive with western coal in existing steam power plants. Nor is it presently competitive with natural gas for new electrical generating facilities that might be anticipated for the state. Transportation fuels from biomass, whether ethanol, methanol, or biodiesel, are not presently competitive with petroleum-derived gasoline without significant state and federal tax incentives. Environmental externalities do not appear to be large enough to change this assessment. Efforts within the state should focus on demonstrating technologies that could quickly and economically replace fuel supplies that are most susceptible to disruption and price escalation in the future.

Although coal might seem the most desirable fuel to replace on environmental grounds, the supplies from Wyoming and other states in the west are probably as secure and free of price uncertainties as any alternatives that can be contemplated. On the other hand, the last 25 years have amply demonstrated the pitfalls of relying on foreign sources of petroleum for transportation fuels. Although price and supply have remained stable for the last 15 years, events ranging from the Gulf War to the rise of Islamic fundamentalism as a potent political force in the Mideast suggest the importance of alternative sources of transportation fuels.

The technology for converting starch or sugar to ethanol is commercially mature, and adequate market impetus should exist for private industry to support incremental improvements in the process. However, if a national crisis were to develop that required substantial expansion of U.S. production of ethanol, conversion of corn to ethanol could not provide the necessary supply or price. Degradation of cropland as a result of expanded and more intensive corn production would probably be unacceptable. Conversion of cellulose to ethanol must be commercially developed if biomass is to be an important source of transportation fuels. Pilot-scale experience with cellulose to ethanol processes, although unlikely to be cost-effective at the present, would provide invaluable engineering and economic data for eventual commercialization. Since much of the process duplicates the conventional corn to ethanol process, such a pilot plant could be built in conjunction with an existing ethanol plant in Iowa.

Natural gas, although supplied from the North American continent, might also prove susceptible to price escalations and even supply disruptions. Tremendous pressures are building on the supply of natural gas in the United States. It is widely used in residential and commercial applications as a clean and convenient fuel. Utilities have targeted natural-gas fired combined cycle gas turbine power plants as the least-cost option for future electric generating capacity. Both industry and utility operators of coal-fired and fuel-oil fired boilers are scrutinizing it as a method for reducing sulfur emissions at the lowest capital cost. Natural gas can also be used as "reburning" fuel in a low-cost process for reducing nitrogen oxide emissions from coal-fired boilers. The auto industry is investigating compressed natural gas as one approach to meeting California mandates for low-emission vehicles. Electric utilities recognize natural gas as an inexpensive and quick method to meet the Clinton administration's call for voluntary reductions in carbon dioxide emissions. Indeed, Vice President Gore hails natural gas as the solution to many of the United State's environmental problems. Although the supply is large, the demand for natural gas can be expected to apply upward pressures on the price of natural gas over the next several years.

When the price of natural gas for utilities reaches $4/MM Btu, the Electric Power Research Institute predicts that demand for coal gasification plants will develop. These plants will convert coal into a clean-burning gas to substitute for natural gas in combined cycle gas turbine power plants. Such integrated (coal) gasification combined cycle plants have been demonstrated at sizes up to 100 MW. Coal gasification technology stands ready for escalations in natural gas prices. Biomass could also be used in such plants. The low sulfur content and high volatile content of biomass are advantages in gasification, even when compared to western coal. However, the technology has not been demonstrated at the same scale as it has been for coal. A biomass gasification demonstration plant, operated in conjunction with an existing gas turbine facility in Iowa, would be an important step in positioning Iowa for the introduction of biomass power.

In addition, Iowa should explore niche markets for biomass as they appear. Niche markets usually represent the application of low-cost biomass supplies to a specific energy application. Examples in Iowa include use of baled corn stalks for boiler fuel, conversion of municipal yard waste into heat or power, use of waste seed corn to fire cement kilns, use of waste seed corn or corn cobs in grain drying, the use of crop residues to replace expensive liquified petroleum gas ($4.90–$8.50/MM Btu in central Iowa) for grain drying, use of switchgrass as reburning fuel in coal-fired cyclone burners to reduce nitrogen oxide

emissions, the conversion of manure to biogas via digestion for on-farm energy demand, and expanding opportunities to convert landfill gas and municipal sewage gas to useful power. Niche markets provide opportunities for demonstrating biomass technology in cost-effective settings. However, technology appropriate to niche markets is not always relevant to the technologies anticipated for large-scale biomass energy projects of the future.

Finally, opportunities for significantly increasing yields of biomass grown in Iowa should be continually explored. The experience of the forest industry in the Pacific Northwest is especially relevant in this regard where concerted research efforts in the last ten years have increased hybrid popular yields by 100% and reduced unit production costs.

The potential for biomass energy in Iowa is enormous. However, neither economic nor environmental factors are able to justify its wide-scale application at the present. Iowa's strategy should be to target for demonstration those technologies that could replace vulnerable supplies of conventional fuels as well as to support cost-effective niche market applications. Opportunities to improve biomass yields should also be explored. With patient preparation, Iowa will be ready to assume the leadership role in biomass energy expected of it.

Appendixes

APPENDIX A

CHAPTER 3, PART 1: BUDGETS FOR EACH BIOMASS CROPPING SYSTEM AND SPECIES

Table 3.A1. Estimated establishment year budget for alfalfa, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa	ton	40.00	2.51	100.40
Total income				100.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	160.00	40.00
Potassium	lb	0.17	625.00	106.25
Fungicides				
Eptom	pt	2.81	3.00	8.43
Herbicides				
Lorsban 4E	pt	1.81	1.00	1.81
Seed				
Alfalfa seed	lb	2.50	12.00	30.00
Transportation				
Haul to plant	ton	4.15	2.51	10.42
Operator labor				
Tractors	hour	6.00	2.29	13.73
Diesel fuel				
Tractors	gal.	0.83	8.60	7.13
Repair and maintenance				
Implements	acre	5.47	1.00	5.47
Tractors	acre	11.35	1.00	11.35
Interest on op. cap.	acre	18.07	1.00	18.07
Total direct expenses				252.66
Return above direct expenses				-152.26
Fixed expenses				
Implements	acre	16.88	1.00	16.88
Tractors	acre	15.72	1.00	15.72
Total fixed expenses				32.60
Total specified expenses				285.25
Return above total specified expenses				-184.85
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-299.85

Table 3.A2. Estimated annual budget for alfalfa, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa	ton	40.00	4.40	176.00
Total income				176.00
Direct expenses				
Herbicides				
Lorsban 4E	pt	1.81	2.00	3.62
Transportation				
Haul to plant	ton	4.15	4.40	18.26
Operator labor				
Tractors	hour	6.00	2.32	13.94
Diesel fuel				
Tractors	gal.	0.83	8.07	6.69
Repair and maintenance				
Implements	acre	5.88	1.00	5.88
Tractors	acre	11.49	1.00	11.49
Interest on op. cap.	acre	1.52	1.00	1.52
Total direct expenses				61.40
Return above direct expenses				114.60
Fixed expenses				
Implements	acre	12.57	1.00	12.57
Tractors	acre	15.28	1.00	15.28
Total fixed expenses				27.86
Establishment cost	acre	59.97	1.00	74.96
Total specified expenses				164.22
Return above total specified expenses				11.78
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-103.22

Table 3.A3. Estimated annual budget for intercrop alfalfa/sweet sorghum, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa/sweet sorghum	ton	40.00	6.20	248.00
Total income				248.00
Direct expenses				
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	6.20	25.73
Operator labor				
Tractors	hour	6.00	2.40	14.42
Diesel fuel				
Tractors	gal.	0.83	8.32	6.91
Repair and maintenance				
Implements	acre	6.28	1.00	6.28
Tractors	acre	11.78	1.00	11.78
Interest on op. cap.	acre	1.56	1.00	1.56
Total direct expenses				71.96
Return above direct expenses				176.04
Fixed expenses				
Implements	acre	14.83	1.00	14.83
Tractors	acre	15.71	1.00	15.71
Total fixed expenses				30.54
Establishment cost	acre	59.97	1.00	74.96
Total specified expenses				177.46
Return above total specified expenses				70.54
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-44.46

Table 3.A4. Estimated annual budget for intercrop alfalfa/sorghum x Sudan grass hybrid, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa/sorghum x Sudan	ton	40.00	6.10	244.00
Total income				244.00
Direct expenses				
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sorghum x Sudan seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	6.10	25.32
Operator labor				
Tractors	hour	6.00	2.40	14.42
Diesel fuel				
Tractors	gal.	0.83	8.32	6.91
Repair and maintenance				
Implements	acre	6.28	1.00	6.28
Tractors	acre	11.78	1.00	11.78
Interest on op. cap.	acre	1.51	1.00	1.51
Total direct expenses				70.45
Return above direct expenses				173.55
Fixed expenses				
Implements	acre	14.83	1.00	14.83
Tractors	acre	15.71	1.00	15.71
Total fixed expenses				30.54
Establishment cost	acre	59.97	1.00	74.96
Total specified expenses				175.95
Return above total specified expenses				68.05
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-46.95

Table 3.A5. Estimated establishment year budget for reed canary grass, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass	ton	40.00	2.31	92.40
Total income				92.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	125.00	26.25
Herbicides				
2,4-D	pt	2.31	2.00	4.62
Seed				
Reed canary grass seed	lb	4.50	9.00	40.50
Transportation				
Haul to plant	ton	4.15	2.31	9.59
Operator labor				
Tractors	hour	6.00	2.31	13.87
Diesel fuel				
Tractors	gal.	0.83	8.69	7.21
Repair and maintenance				
Implements	acre	5.36	1.00	5.36
Tractors	acre	11.46	1.00	11.46
Interest on op. cap.	acre	6.92	1.00	6.92
Total direct expenses				149.75
Return above direct expenses				-57.35
Fixed expenses				
Implements	acre	17.76	1.00	17.76
Tractors	acre	15.89	1.00	15.89
Total fixed expenses				33.64
Total specified expenses				183.40
Return above total specified expenses				-91.00
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-206.00

Table 3.A6. Estimated annual budget for reed canary grass, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass	ton	40.00	3.33	133.20
Total income				133.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	200.00	42.00
Transportation				
Haul to plant	ton	4.15	3.33	13.82
Operator labor				
Tractors	hour	6.00	1.61	9.66
Diesel fuel				
Tractors	gal.	0.83	5.81	4.82
Repair and maintenance				
Implements	acre	4.14	1.00	4.14
Tractors	acre	7.94	1.00	7.94
Interest on op. cap.	acre	4.78	1.00	4.78
Total direct expenses				111.14
Return above direct expenses				22.06
Fixed expenses				
Implements	acre	11.56	1.00	11.56
Tractors	acre	10.87	1.00	10.87
Total fixed expenses				22.43
Establishment cost	acre	20.60	1.00	22.89
Total specified expenses				156.46
Return above total specified expenses				-23.26
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-138.26

Table 3.A7. Estimated annual budget for intercrop reed canary grass/sweet sorghum, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass/ sweet sorghum	ton	40.00	4.35	174.00
Total income				174.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	200.00	42.00
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	4.35	18.05
Operator labor				
Tractors	hour	6.00	2.75	16.49
Diesel fuel				
Tractors	gal.	0.83	9.71	8.06
Repair and maintenance				
Implements	acre	7.30	1.00	7.30
Tractors	acre	13.47	1.00	13.47
Interest on op. cap.	acre	6.30	1.00	6.30
Total direct expenses				140.93
Return above direct expenses				33.07
Fixed expenses				
Implements	acre	19.21	1.00	19.21
Tractors	acre	18.21	1.00	18.21
Total fixed expenses				37.42
Establishment cost	acre	59.97	1.00	22.89
Total specified expenses				201.24
Return above total specified expenses				-27.24
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-144.24

Table 3.A8. Estimated annual budget for intercrop reed canary grass/sorghum x Sudan grass hybrid, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass/sorghum x Sudan grass	ton	40.00	4.41	176.40
Total income				176.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	200.00	42.00
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sorghum x Sudan seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	4.41	18.30
Operator labor				
Tractors	hour	6.00	2.75	16.49
Diesel fuel				
Tractors	gal.	0.83	9.71	8.06
Repair and maintenance				
Implements	acre	7.30	1.00	7.30
Tractors	acre	13.47	1.00	13.47
Interest on op. cap.	acre	6.26	1.00	6.26
Total direct expenses				140.09
Return above direct expenses				36.31
Fixed expenses				
Implements	acre	19.21	1.00	19.21
Tractors	acre	18.21	1.00	18.21
Total fixed expenses				37.42
Establishment cost	acre	59.97	1.00	22.89
Total specified expenses				200.40
Return above total specified expenses				-24.00
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-139.00

Table 3.A9. Estimated establishment year budget for switchgrass, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Switchgrass	ton	40.00	3.32	132.80
Total income				132.80
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Herbicides				
Atrazine 4L	pt	1.58	2.50	3.95
Seed				
Switchgrass seed	lb	3.50	7.00	24.50
Transportation				
Haul to plant	ton	4.15	3.32	13.78
Operator labor				
Tractors	hour	6.00	1.56	9.38
Diesel fuel				
Tractors	gal.	0.83	6.01	4.99
Repair and maintenance				
Implements	acre	3.46	1.00	3.46
Tractors	acre	7.77	1.00	7.77
Interest on op. cap.	acre	4.68	1.00	4.68
Total direct expenses				96.49
Return above direct expenses				36.31
Fixed expenses				
Implements	acre	12.71	1.00	12.71
Tractors	acre	10.87	1.00	10.87
Total fixed expenses				23.58
Total specified expenses				120.07
Return above total specified expenses				12.73
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-102.27

Table 3.A10. Estimated annual budget for switchgrass, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Switchgrass	ton	40.00	4.57	182.80
Total income				182.80
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	100.00	21.00
Transportation				
Haul to plant	ton	4.15	4.57	18.97
Operator labor				
Tractors	hour	6.00	0.86	5.18
Diesel fuel				
Tractors	gal.	0.83	3.14	2.60
Repair and maintenance				
Implements	acre	2.24	1.00	2.24
Tractors	acre	4.25	1.00	4.25
Interest on op. cap.	acre	3.80	1.00	3.80
Total direct expenses				82.01
Return above direct expenses				100.79
Fixed expenses				
Implements	acre	6.51	1.00	6.51
Tractors	acre	5.85	1.00	5.85
Total fixed expenses				12.36
Establishment cost	acre	20.60	1.00	11.36
Total specified expenses				105.73
Return above total specified expenses				77.07
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-37.93

Table 3.A11. Estimated establishment year budget for big bluestem, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Big bluestem	ton	40.00	2.55	102.00
Total income				102.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Herbicides				
2,4-D	pt	2.31	2.50	5.78
Seed				
Switchgrass seed	lb	9.00	12.00	108.00
Transportation				
Haul to plant	ton	4.15	2.55	10.58
Operator labor				
Tractors	hour	6.00	1.64	9.87
Diesel fuel				
Tractors	gal.	0.83	6.47	5.37
Repair and maintenance				
Implements	acre	3.38	1.00	3.38
Tractors	acre	7.96	1.00	7.96
Interest on op. cap.	acre	8.23	1.00	8.23
Total direct expenses				183.13
Return above direct expenses				-81.13
Fixed expenses				
Implements	acre	12.10	1.00	12.10
Tractors	acre	11.48	1.00	11.48
Total fixed expenses				23.58
Total specified expenses				206.72
Return above total specified expenses				-104.72
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-219.72

Table 3.A12. Estimated annual budget for big bluestem, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Big bluestem	ton	40.00	3.83	153.20
Total income				153.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	100.00	21.00
Transportation				
Haul to plant	ton	4.15	3.83	15.89
Operator labor				
Tractors	hour	6.00	0.86	5.18
Diesel fuel				
Tractors	gal.	0.83	3.14	2.60
Repair and maintenance				
Implements	acre	2.24	1.00	2.24
Tractors	acre	4.25	1.00	4.25
Interest on op. cap.	acre	3.77	1.00	3.77
Total direct expenses				78.91
Return above direct expenses				74.29
Fixed expenses				
Implements	acre	6.51	1.00	6.51
Tractors	acre	5.85	1.00	5.85
Total fixed expenses				12.36
Establishment cost	acre	20.60	1.00	24.40
Total specified expenses				115.67
Return above total specified expenses				37.53
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-77.47

Table 3.A13. Estimated establishment year budget for alfalfa, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa	ton	40.00	2.06	82.40
Total income				82.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	160.00	40.00
Potassium	lb	0.17	625.00	106.25
Lime	ton	6.00	5.00	30.00
Fungicides				
Eptom	pt	2.81	3.00	8.43
Herbicides				
Lorsban 4E	pt	1.81	1.50	2.71
Seed				
Alfalfa seed	lb	2.50	14.00	35.00
Transportation				
Haul to plant	ton	4.15	2.06	8.55
Operator labor				
Tractors	hour	6.00	2.40	14.42
Diesel fuel				
Tractors	gal.	0.83	9.06	7.52
Repair and maintenance				
Implements	acre	5.81	1.00	5.81
Tractors	acre	11.91	1.00	11.91
Interest on op. cap.	acre	21.52	1.00	21.52
Total direct expenses				292.12
Return above direct expenses				-209.72
Fixed expenses				
Implements	acre	18.34	1.00	18.34
Tractors	acre	16.56	1.00	16.56
Total fixed expenses				34.89
Total specified expenses				327.01
Return above total specified expenses				-244.61
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-324.61

Table 3.A14. Estimated annual budget for alfalfa, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa	ton	40.00	3.47	138.80
Total income				138.80
Direct expenses				
Herbicides				
Lorsban 4E	pt	1.81	2.00	3.62
Transportation				
Haul to plant	ton	4.15	3.47	14.40
Operator labor				
Tractors	hour	6.00	2.32	13.94
Diesel fuel				
Tractors	gal.	0.83	8.07	6.69
Repair and maintenance				
Implements	acre	5.88	1.00	5.88
Tractors	acre	11.49	1.00	11.49
Interest on op. cap.	acre	1.46	1.00	1.46
Total direct expenses				57.48
Return above direct expenses				81.32
Fixed expenses				
Implements	acre	12.57	1.00	12.57
Tractors	acre	15.28	1.00	15.28
Total fixed expenses				27.86
Establishment cost	acre	64.92	1.00	81.16
Total specified expenses				166.49
Return above total specified expenses				-27.69
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-107.69

Table 3.A15. Estimated annual budget for intercrop alfalfa/sweet sorghum, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa/sweet sorghum	ton	40.00	4.29	171.60
Total income				171.60
Direct expenses				
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	4.29	17.80
Operator labor				
Tractors	hour	6.00	2.40	14.42
Diesel fuel				
Tractors	gal.	0.83	8.32	6.91
Repair and maintenance				
Implements	acre	6.28	1.00	6.28
Tractors	acre	11.78	1.00	11.78
Interest on op. cap.	acre	1.49	1.00	1.49
Total direct expenses				63.97
Return above direct expenses				107.63
Fixed expenses				
Implements	acre	14.83	1.00	14.83
Tractors	acre	15.71	1.00	15.71
Total fixed expenses				30.54
Establishment cost	acre	64.92	1.00	81.16
Total specified expenses				175.67
Return above total specified expenses				-4.07
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-84.07

Table 3.A16. Estimated annual budget for intercrop alfalfa/sorghum x Sudan grass hybrid, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Alfalfa/sorghum x Sudan	ton	40.00	5.16	206.40
Total income				206.40
Direct expenses				
Herbicides				
Paraquat	pt	4.46	0.40	1.78
Seed				
Sorghum x Sudan seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	5.16	21.41
Operator labor				
Tractors	hour	6.00	2.40	14.42
Diesel fuel				
Tractors	gal.	0.83	8.32	6.91
Repair and maintenance				
Implements	acre	6.28	1.00	6.28
Tractors	acre	11.78	1.00	11.78
Interest on op. cap.	acre	1.48	1.00	1.48
Total direct expenses				66.52
Return above direct expenses				139.88
Fixed expenses				
Implements	acre	14.83	1.00	14.83
Tractors	acre	15.71	1.00	15.71
Total fixed expenses				30.54
Establishment cost	acre	64.92	1.00	81.16
Total specified expenses				178.21
Return above total specified expenses				28.19
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-51.81

Table 3.A17. Estimated establishment year budget for reed canary grass, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass	ton	40.00	2.47	98.80
Total income				98.80
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	125.00	26.25
Herbicides				
2,4-D	pt	2.31	2.00	4.62
Seed				
Reed canary grass seed	lb	4.50	11.00	49.50
Transportation				
Haul to plant	ton	4.15	2.47	10.25
Operator labor				
Tractors	hour	6.00	2.31	13.87
Diesel fuel				
Tractors	gal.	0.83	8.69	7.21
Repair and maintenance				
Implements	acre	5.36	1.00	5.36
Tractors	acre	11.46	1.00	11.46
Interest on op. cap.	acre	7.37	1.00	7.37
Total direct expenses				159.87
Return above direct expenses				-61.07
Fixed expenses				
Implements	acre	17.76	1.00	17.76
Tractors	acre	15.89	1.00	15.89
Total fixed expenses				33.64
Total specified expenses				193.52
Return above total specified expenses				-94.72
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-174.72

Table 3.A18. Estimated annual budget for reed canary grass, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Reed canary grass	ton	40.00	4.73	189.20
Total income				189.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	200.00	42.00
Transportation				
Haul to plant	ton	4.15	4.73	19.63
Operator labor				
Tractors	hour	6.00	1.61	9.66
Diesel fuel				
Tractors	gal.	0.83	5.81	4.82
Repair and maintenance				
Implements	acre	4.14	1.00	4.14
Tractors	acre	7.94	1.00	7.94
Interest on op. cap.	acre	4.83	1.00	4.83
Total direct expenses				117.00
Return above direct expenses				72.20
Fixed expenses				
Implements	acre	11.56	1.00	11.56
Tractors	acre	10.87	1.00	10.87
Total fixed expenses				22.43
Establishment cost	acre	17.47	1.00	19.41
Total specified expenses				158.84
Return above total specified expenses				30.36
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-49.64

Table 3.A19. Estimated establishment year budget for switchgrass, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Switchgrass	ton	40.00	3.14	125.60
Total income				125.60
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Herbicides				
Atrazine 4L	pt	1.58	2.50	3.95
Seed				
Switchgrass seed	lb	3.50	7.20	25.20
Transportation				
Haul to plant	ton	4.15	3.14	13.03
Operator labor				
Tractors	hour	6.00	1.56	9.38
Diesel fuel				
Tractors	gal.	0.83	6.01	4.99
Repair and maintenance				
Implements	acre	3.46	1.00	3.46
Tractors	acre	7.77	1.00	7.77
Interest on op. cap.	acre	4.70	1.00	4.70
Total direct expenses				96.47
Return above direct expenses				29.13
Fixed expenses				
Implements	acre	12.71	1.00	12.71
Tractors	acre	10.87	1.00	10.87
Total fixed expenses				23.58
Total specified expenses				120.05
Return above total specified expenses				5.55
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-74.45

Table 3.A20. Estimated annual budget for switchgrass, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Switchgrass	ton	40.00	4.69	187.60
Total income				187.60
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	100.00	21.00
Transportation				
Haul to plant	ton	4.15	4.69	19.46
Operator labor				
Tractors	hour	6.00	0.86	5.18
Diesel fuel				
Tractors	gal.	0.83	3.14	2.60
Repair and maintenance				
Implements	acre	2.24	1.00	2.24
Tractors	acre	4.25	1.00	4.25
Interest on op. cap.	acre	3.80	1.00	3.80
Total direct expenses				82.51
Return above direct expenses				105.09
Fixed expenses				
Implements	acre	6.51	1.00	6.51
Tractors	acre	5.85	1.00	5.85
Total fixed expenses				12.36
Establishment cost	acre	7.45	1.00	8.27
Total specified expenses				103.14
Return above total specified expenses				84.46
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				4.46

Table 3.A21. Estimated establishment year budget for big bluestem, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Big bluestem	ton	40.00	1.77	68.00
Total income				68.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Herbicides				
2,4-D	pt	2.31	2.50	5.78
Seed				
Switchgrass seed	lb	9.00	12.00	108.00
Transportation				
Haul to plant	ton	4.15	1.70	7.06
Operator labor				
Tractors	hour	6.00	1.64	9.87
Diesel fuel				
Tractors	gal.	0.83	6.47	5.37
Repair and maintenance				
Implements	acre	3.38	1.00	3.38
Tractors	acre	7.96	1.00	7.96
Interest on op. cap.	acre	8.20	1.00	8.20
Total direct expenses				179.58
Return above direct expenses				-111.58
Fixed expenses				
Implements	acre	12.10	1.00	12.10
Tractors	acre	11.48	1.00	11.48
Total fixed expenses				23.58
Total specified expenses				203.16
Return above total specified expenses				-135.16
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-215.16

Table 3.A22. Estimated annual budget for big bluestem, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Big bluestem	ton	40.00	3.55	142.00
Total income				142.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	32.00	8.00
Potassium	lb	0.17	94.00	15.98
Nitrogen	lb	0.21	100.00	21.00
Transportation				
Haul to plant	ton	4.15	3.55	14.73
Operator labor				
Tractors	hour	6.00	0.86	5.18
Diesel fuel				
Tractors	gal.	0.83	3.14	2.60
Repair and maintenance				
Implements	acre	2.24	1.00	2.24
Tractors	acre	4.25	1.00	4.25
Interest on op. cap.	acre	3.76	1.00	3.76
Total direct expenses				77.74
Return above direct expenses				64.26
Fixed expenses				
Implements	acre	6.51	1.00	6.51
Tractors	acre	5.85	1.00	5.85
Total fixed expenses				12.36
Establishment cost	acre	21.52	1.00	23.91
Total specified expenses				114.01
Return above total specified expenses				27.99
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-52.01

Table 3.A23. Estimated annual budget for sweet sorghum, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sweet sorghum	ton	40.00	7.08	283.20
Total income				283.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	100.00	12.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	7.08	29.38
Operator labor				
Tractors	hour	6.00	2.56	15.39
Diesel fuel				
Tractors	gal.	0.83	11.37	9.44
Repair and maintenance				
Implements	acre	5.24	1.00	5.24
Tractors	acre	16.84	1.00	16.84
Interest on op. cap.	acre	6.67	1.00	6.67
Total direct expenses				136.70
Return above direct expenses				146.50
Fixed expenses				
Implements	acre	13.75	1.00	13.75
Tractors	acre	26.83	1.00	26.83
Total fixed expenses				40.57
Total specified expenses				177.27
Return above total specified expenses				105.93
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-9.07

Table 3.A24. Estimated annual budget for sorghum x Sudan grass hybrid, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sorghum x Sudan grass	ton	40.00	6.46	258.40
Total income				258.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	100.00	12.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	6.46	26.81
Operator labor				
Tractors	hour	6.00	2.56	15.39
Diesel fuel				
Tractors	gal.	0.83	11.37	9.44
Repair and maintenance				
Implements	acre	5.24	1.00	5.24
Tractors	acre	16.84	1.00	16.84
Interest on op. cap.	acre	6.37	1.00	6.37
Total direct expenses				132.78
Return above direct expenses				125.62
Fixed expenses				
Implements	acre	13.75	1.00	13.75
Tractors	acre	26.83	1.00	26.83
Total fixed expenses				40.57
Total specified expenses				173.35
Return above total specified expenses				85.05
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-29.95

Table 3.A25. Estimated annual budget for doublecrop rye/sweet sorghum, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	1.80	72.00
Sweet sorghum	ton	40.00	5.22	208.80
Total income				280.80
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	162.00	34.02
Seed				
Rye seed	lb	0.31	100.00	31.00
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	7.02	29.13
Operator labor				
Tractors	hour	6.00	3.13	18.77
Diesel fuel				
Tractors	gal.	0.83	12.93	10.74
Repair and maintenance				
Implements	acre	6.55	1.00	6.55
Tractors	acre	19.57	1.00	19.57
Interest on op. cap.	acre	8.68	1.00	8.68
Total direct expenses				184.44
Return above direct expenses				96.36
Fixed expenses				
Implements	acre	18.39	1.00	18.39
Tractors	acre	30.21	1.00	30.21
Total fixed expenses				48.60
Total specified expenses				233.05
Return above total specified expenses				47.75
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-67.25

Table 3.A26. Estimated annual budget for doublecrop rye/sorghum x Sudan grass hybrid, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	1.59	63.60
Sweet sorghum	ton	40.00	4.89	195.60
Total income				259.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	162.00	34.02
Seed				
Rye seed	lb	0.31	100.00	31.00
Sweet sorghum seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	6.48	26.89
Operator labor				
Tractors	hour	6.00	3.13	18.77
Diesel fuel				
Tractors	gal.	0.83	12.93	10.74
Repair and maintenance				
Implements	acre	6.55	1.00	6.55
Tractors	acre	19.57	1.00	19.57
Interest on op. cap.	acre	8.60	1.00	8.60
Total direct expenses				181.08
Return above direct expenses				78.12
Fixed expenses				
Implements	acre	18.39	1.00	18.39
Tractors	acre	30.21	1.00	30.21
Total fixed expenses				48.60
Total specified expenses				229.68
Return above total specified expenses				29.52
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-85.48

Table 3.A27. Estimated annual budget for sweet sorghum in rotation, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sweet sorghum	ton	40.00	6.68	267.20
Total income				267.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	50.00	6.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	6.68	27.72
Operator labor				
Tractors	hour	6.00	2.29	13.73
Diesel fuel				
Tractors	gal.	0.83	10.36	8.60
Repair and maintenance				
Implements	acre	4.94	1.00	4.94
Tractors	acre	15.46	1.00	15.46
Interest on op. cap.	acre	6.23	1.00	6.23
Total direct expenses				124.43
Return above direct expenses				142.77
Fixed expenses				
Implements	acre	11.41	1.00	11.41
Tractors	acre	25.00	1.00	25.00
Total fixed expenses				36.41
Total specified expenses				160.85
Return above total specified expenses				106.35
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-8.65

Table 3.A28. Estimated annual budget for rye/sweet sorghum in rotation, Ames, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	2.35	94.00
Sweet sorghum	ton	40.00	5.78	231.20
Total income				325.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	100.00	21.00
Seed				
Rye seed	lb	0.31	100.00	31.00
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	8.13	33.74
Operator labor				
Tractors	hour	6.00	3.01	18.08
Diesel fuel				
Tractors	gal.	0.83	12.47	10.35
Repair and maintenance				
Implements	acre	6.21	1.00	6.21
Tractors	acre	19.01	1.00	19.01
Interest on op. cap.	acre	8.31	1.00	8.31
Total direct expenses				173.69
Return above direct expenses				151.51
Fixed expenses				
Implements	acre	16.93	1.00	16.93
Tractors	acre	29.37	1.00	29.37
Total fixed expenses				46.31
Total specified expenses				219.99
Return above total specified expenses				105.21
Allocated cost items				
Land	acre	115.00	1.00	115.00
Residual returns				-9.79

Table 3.A29. Estimated annual budget for sweet sorghum, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sweet sorghum	ton	40.00	7.28	291.20
Total income				291.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	100.00	12.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	7.28	30.31
Operator labor				
Tractors	hour	6.00	2.56	15.39
Diesel fuel				
Tractors	gal.	0.83	11.37	9.44
Repair and maintenance				
Implements	acre	5.24	1.00	5.24
Tractors	acre	16.84	1.00	16.84
Interest on op. cap.	acre	8.79	1.00	8.79
Total direct expenses				139.66
Return above direct expenses				151.54
Fixed expenses				
Implements	acre	13.75	1.00	13.75
Tractors	acre	26.83	1.00	26.83
Total fixed expenses				40.57
Total specified expenses				180.23
Return above total specified expenses				110.97
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				30.97

Table 3.A30. Estimated annual budget for sorghum x Sudan grass hybrid, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sorghum x Sudan grass	ton	40.00	6.36	254.40
Total income				254.40
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	100.00	12.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	6.36	26.39
Operator labor				
Tractors	hour	6.00	2.56	15.39
Diesel fuel				
Tractors	gal.	0.83	11.37	9.44
Repair and maintenance				
Implements	acre	5.24	1.00	5.24
Tractors	acre	16.84	1.00	16.84
Interest on op. cap.	acre	8.38	1.00	8.38
Total direct expenses				134.37
Return above direct expenses				120.03
Fixed expenses				
Implements	acre	13.75	1.00	13.75
Tractors	acre	26.83	1.00	26.83
Total fixed expenses				40.57
Total specified expenses				174.95
Return above total specified expenses				79.45
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-0.55

Table 3.A31. Estimated annual budget for doublecrop rye/sweet sorghum, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	1.72	68.80
Sweet sorghum	ton	40.00	5.22	179.20
Total income				248.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	162.00	34.02
Seed				
Rye seed	lb	0.31	120.00	37.20
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	6.20	25.73
Operator labor				
Tractors	hour	6.00	3.13	18.77
Diesel fuel				
Tractors	gal.	0.83	12.93	10.74
Repair and maintenance				
Implements	acre	6.55	1.00	6.55
Tractors	acre	19.57	1.00	19.57
Interest on op. cap.	acre	9.49	1.00	9.49
Total direct expenses				188.05
Return above direct expenses				59.95
Fixed expenses				
Implements	acre	18.39	1.00	18.39
Tractors	acre	30.21	1.00	30.21
Total fixed expenses				48.60
Total specified expenses				236.65
Return above total specified expenses				11.35
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-68.65

Table 3.A32. Estimated annual budget for doublecrop rye/sorghum x Sudan grass hybrid, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	1.72	68.80
Sweet sorghum	ton	40.00	4.47	178.80
Total income				247.60
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	162.00	34.02
Seed				
Rye seed	lb	0.31	120.00	37.20
Sweet sorghum seed	lb	0.35	7.00	2.45
Transportation				
Haul to plant	ton	4.15	6.19	25.69
Operator labor				
Tractors	hour	6.00	3.13	18.77
Diesel fuel				
Tractors	gal.	0.83	12.93	10.74
Repair and maintenance				
Implements	acre	6.55	1.00	6.55
Tractors	acre	19.57	1.00	19.57
Interest on op. cap.	acre	9.17	1.00	9.17
Total direct expenses				186.65
Return above direct expenses				60.95
Fixed expenses				
Implements	acre	18.39	1.00	18.39
Tractors	acre	30.21	1.00	30.21
Total fixed expenses				48.60
Total specified expenses				235.25
Return above total specified expenses				12.35
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				-67.65

Table 3.A33. Estimated annual budget for sweet sorghum in rotation, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Sweet sorghum	ton	40.00	7.15	286.00
Total income				286.00
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.12	50.00	6.00
Herbicides				
Dual	pt	7.88	2.00	15.76
Seed				
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	7.15	29.67
Operator labor				
Tractors	hour	6.00	2.29	13.73
Diesel fuel				
Tractors	gal.	0.83	10.36	8.60
Repair and maintenance				
Implements	acre	4.94	1.00	4.94
Tractors	acre	15.46	1.00	15.46
Interest on op. cap.	acre	8.56	1.00	8.56
Total direct expenses				128.71
Return above direct expenses				157.29
Fixed expenses				
Implements	acre	11.41	1.00	11.41
Tractors	acre	25.00	1.00	25.00
Total fixed expenses				36.41
Total specified expenses				165.12
Return above total specified expenses				120.88
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				40.88

Table 3.A34. Estimated annual budget for rye/sweet sorghum in rotation, Chariton, Iowa, 1993.

Item	Unit	Price	Quantity	Amount
		(dollars)		(dollars)
Income				
Winter rye	ton	40.00	1.93	77.20
Sweet sorghum	ton	40.00	5.78	274.00
Total income				351.20
Direct expenses				
Fertilizer				
Phosphorus	lb	0.25	58.00	14.50
Potassium	lb	0.17	47.00	7.99
Nitrogen	lb	0.21	100.00	21.00
Seed				
Rye seed	lb	0.31	120.00	37.20
Sweet sorghum seed	lb	0.50	7.00	3.50
Transportation				
Haul to plant	ton	4.15	8.78	36.44
Operator labor				
Tractors	hour	6.00	3.01	18.08
Diesel fuel				
Tractors	gal.	0.83	12.47	10.35
Repair and maintenance				
Implements	acre	6.21	1.00	6.21
Tractors	acre	19.01	1.00	19.01
Interest on op. cap.	acre	8.91	1.00	8.91
Total direct expenses				183.18
Return above direct expenses				168.02
Fixed expenses				
Implements	acre	16.93	1.00	16.93
Tractors	acre	29.37	1.00	29.37
Total fixed expenses				46.31
Total specified expenses				229.49
Return above total specified expenses				121.71
Allocated cost items				
Land	acre	80.00	1.00	80.00
Residual returns				41.71

APPENDIX B

CHAPTER 8: SUMMARY OF ENVIRONMENTAL EFFECTS OF BIOMASS PRODUCTION AND CONVERSION

Production:

Fertilizer:

Table A.1. Summary of fertilization rates for biomass energy feedstock crops and traditional agricultural crops (kg / ha).

Crop Type	Uplands			Former Wetlands		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Populus Spp., sweetgum, sycamore, silver maple	245	71	71	0-136	0-27	0-27
Switchgrass, wheatgrass	441	327	327	218	218	218
Corn	621	316	370	621	316	370
Soybean	82	278	398	82	278	398

Sediment:

Table A.2. Average annualized erosion rates for biomass energy feedstock crops and traditional agricultural crops. Values are for mature stands. Negative values indicate sediment accretion.

Crop Type	Uplands	Former Wetlands
Trees	7.5	-15.5
Perennials	12	-16.4
Energy cane	12	-15.5
Sorghum	76	16.5
Corn	27	27

Nitrogen retention:

Table A.3. Nitrogen retention by different vegetation types. Values for poplar and grass are for filter strips.

Vegetation Type	Percent Nitrogen Retention
Row crops	8
Poplar	99
Grass	84

Conversion:

Table A.4. Comparison of emission rates for two conversion technologies. Numbers in parentheses represent metric tons per year for a 50-MW power plant. Combustion values are uncontrolled emission rates.

Pollutant	Combustion (FBC stack emissions)	Gasification
NOx	0.08 - 0.10 lb/MBTU (174 -225)	< 0.12 lb/MBTU
SO_2	0.1 - 0.5 lb / MBTU (215-1075)	0.12 - 0.50 lb / MBTU
Particulates	2.0 lb / MBTU (4300)	