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BIOMASS ENERGY PRODUCTION IN THE UNITED STATES: AN OVERVIEW

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Abstract—This paper summarizes reports prepared for the U.S. Environmental Protection Agency (EPA) by researchers at the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL). It also presents conclusions from a Biomass Energy Strategies Workshop conducted at ORNL. The Biofuels Feedstock Development Program (BFDP) has largely concentrated on the development of dedicated biomass feedstocks, referred to as energy crops. Two general types of energy crops have received the most attention—short-rotation woody crops (SRWC) and herbaceous energy crops (HEC). These cropping systems use traditional food production technologies as a means of maximizing the production of biomass per unit of land. Research focuses on the development of new crops and cropping technologies. The reports prepared for EPA and summarized by this article include discussions of crop production technologies, available land, economic considerations and environmental trade-offs. The discussion of other sources of biomass occurs only in the context of the workshop on biomass energy strategies.

[The views expressed in this paper are those of the authors and do not necessarily represent the views of the U.S. Environmental Protection Agency or the U.S. Department of Energy.]

Keywords—biomass energy; herbaceous energy crops; short-rotation woody crops; environmental effects; economics; biomass feedstocks; biomass strategies.

1. INTRODUCTION

Stabilizing the concentration of carbon dioxide (CO_2) in the atmosphere will require a combination of energy conservation and the use of alternative energy sources. Biomass resources, which have been historically important energy supplies, offer a near-term renewable alternative to fossil fuels. Biomass resources include wood wastes and residues from the production of paper and forest products, agricultural residues, long-rotation woody plantings, thinnings, logging residues and specialized wood and herbaceous crops developed specifically for energy production.

Biomass energy is an old form of energy, still used in many areas of the world as a major energy source. However, in the United States, fossil fuels (oil, gas and coal) replaced biomass energy in the early parts of this century because they were inexpensive, readily accessible and offered high B.t.u. contents. In the 1970s, as a result of increases in fossil fuel prices brought on by the oil embargo, the use of biomass and other forms of renewable energy increased. However, increases were limited mostly to the pulp, paper and timber manufacturing industries, and to residential space heating.

To put biomass energy use into the context of the entire U.S. energy budget, Figs 1 and 2 illustrate the historical use of biomass energy by the end-use sector and in relation to overall U.S. energy use. Overall energy use has increased by 167% in the period from 1949 to 1990, wood energy use has increased by 108%, while wood energy use represents 82% of total biomass energy use.[1,2]

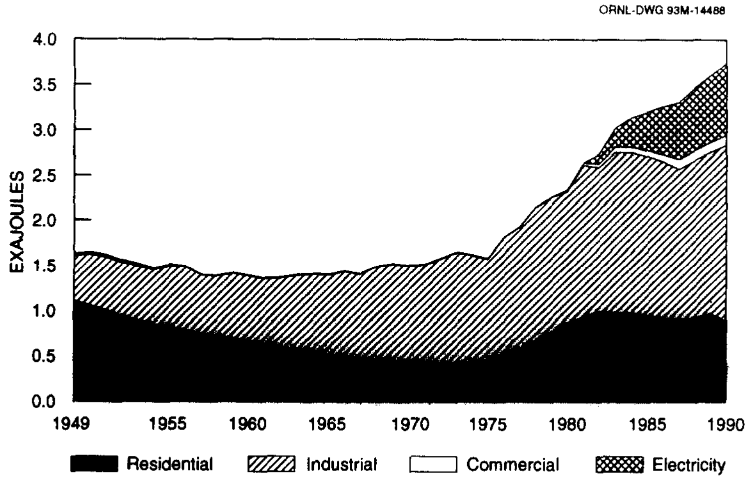

Fig. 1. Historical use of biomass energy by end-use sector.

According to DOE/EIA,[1] biomass supplied 2.76 exajoules (EJ) of primary energy in 1990, and accounted for ~3.3% of the total U.S. supply in 1990. However, biomass heat and electricity generated by independent power producers, and by many combined heat and power or cogeneration facilities,[3] are omitted from the DOE/EIA estimates. Overend and Chum estimate that the total EJ of biomass energy supplied in the United States in 1990 was 3.54 EJ. Most of the correction to the DOE/EIA data is in the electricity and industrial sectors.

Biomass-fired boilers represented 6500 megawatts (MW) of electricity generation capacity in the United States in 1992[4] (DOE, 1993). Much of this capacity was in the industrial sector, and the remainder was in the utility sector. Electricity generation from biomass in the industrial sector allows industry to avoid solid waste, while capitalizing on opportunities to generate electricity and process steam and heat. The amount of electric power produced by both sectors equaled ~42,000 gigawatt hours (GWh), which represents an energy supply equivalent to nearly 200,000 barrels of oil per day. An annual supply of ~45 teragrams (Tg) of biomass fuels was required[4] (DOE, 1993).

Several sources have projected increasing the use of biomass energy over the next 20–50 years. These estimates are summarized in Table 1. The projections vary a great deal, ranging from a 58–188% increase in bioenergy use by 2010. This reflects the uncertainty in estimating rates of biomass energy technology improvements and acceptance.

The U.S. Department of Energy initiated

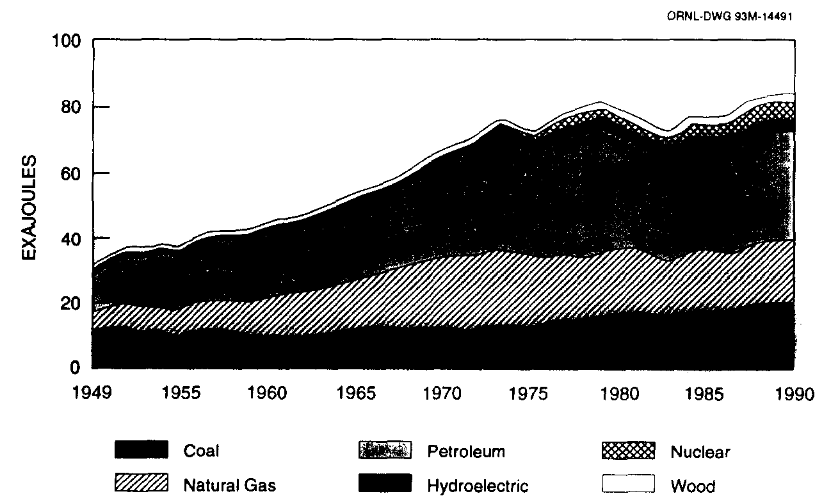

Fig. 2. Historical use of biomass energy in relation to overall energy use in the United States.

Table 1. Estimates of future U.S. biomass energy use (exajoules)

Source	Year				
	Base	2000	2010	2020	2030
Annual Energy Outlook[5]	3.1[a]	4.2	5.3	—	—
Interlaboratory White Paper[6]					
Business As Usual[b]	3.5[c]	4.2	7.1	8.2	10.9
National Premiums[d]	3.5[c]	5.8	8.3	10.0	12.5
R,D&D Intensification[e]	3.5[c]	5.3	10.1	14.0	20.2
National Energy Strategy[7]					
Current Policy	3.1[a]	3.5	4.9	6.0	7.5
National Strategy	3.1[a]	3.7	5.0	8.0	10.2

[a]1989 base year.
[b]Business As Usual—a scenario that represents biomass energy market penetration levels that can be expected given projected conventional energy prices and demand and projected normal progression of biomass energy development.
[c]1988 base year.
[d]National Premiums—a scenario that represents heightened national and regional concerns about the externalities of conventional energy production and consumption, resulting in energy market price premiums for clean energy sources.
[e]R,D&D Intensification—a scenario that makes the same assumptions about energy markets as the Business as Usual case but assumes that federal and other research and development funding is accelerated.

biomass energy research in 1978, viewing it as a viable alternative to fossil fuel and has focused on strategies to implement biomass energy should sources of fossil fuels become unavailable. While the fuel shortages foreseen in the 1970s have not materialized, environmental concerns associated with fossil fuel use are increasingly important.

2. BIOMASS ENERGY STRATEGIES WORKSHOP FINDINGS

The following section reports the findings from a workshop conducted in November 1990 to gather information and recommendations from a cross-section of government and private sector groups with strong interests in all aspects of biomass energy systems. Working groups evaluated constraints to the commercialization of biomass energy and possible solutions. The working groups addressed biomass liquid fuels and biomass-based electricity as whole systems, and energy crop production and environmental issues were addressed as separate topics. Tables 2–5 summarize the constraints and solutions identified by the working groups for the production of liquid biofuels, biomass-based electricity, and energy crops.

2.1. *Liquid biofuels*

There are economics of scale in the production of liquid fuels from biomass. Thus, the availability of large quantities of lignocellulosic feedstock is a very important issue. Quality of feedstock can also affect the economics of the conversion process. Pilot-scale testing, particularly of the simultaneous saccharification and fermentation process components, is needed to predict adequately the economics of conversion systems using dedicated feedstocks. Environmental constraints were not thought to be significant, though more data are needed on environmental emissions. A significant constraint to the large-scale commercialization of alcohol fuels is the large amount of new infrastructure required to store and distribute unblended

Table 2. Production of liquid fuels from energy crops

Constraint	Potential solutions
Resource	
Feedstock availability	Develop high-yielding, low-cost energy crops
Continuous supply of feedstocks	Use multiple feedstocks, develop storage strategies
Feedstock quality	Optimize feedstock quality for specific conversion processes
Technical and Environmental	
Need for pilot-scale testing and demonstration	Find market niches with low-cost feedstocks and/or existing plant infrastructure
Need for additional research and development (R&D)	Continue and augment R&D in progress
Institutional	
Need for financing of initial pilot tests	Support pilot-scale testing as part of R&D
Need for financing of initial commercial facilities	Support construction through government risk-sharing
Need for end-use infrastructure (e.g., fuel distribution and user vehicles)	Institute policies that promote use of flexible-fueled vehicles or dedicated fleets of neat-fueled vehicles

Table 3. Production of electricity from energy crops

Constraints	Potential solutions
Assurance of feedstock supply	Continue research and development for feedstock production programs. Use of feedstock brokers and long-term contracts
Technical risk	Publicly funded demonstrations of advanced high-efficiency generating cycles
Financial risks	Lower cost of debt service, investment tax credits, purchase agreements
Environmental externalities and subsidies to fossil fuels	Internalize externalities, remove hidden subsidies to fossil fuels
Lack of infrastructure for handling biomass	Information dissemination, research on handling systems
Utility/investor bias	Technology transfer and information dissemination

(neat) alcohol fuels. A combination of R&D and policy change is needed to assure that biofuels from cellulosics become a viable technology.

2.2. *Biomass-based electricity production*

The generation of electricity from biomass is a currently existing technology, but there is room for considerable improvement and expansion. Obtaining higher efficiency of conversion through improved combustion technologies and with gas turbines is believed possible now. Expanding the biomass electric industry to a larger scale than currently exists requires an assurance of feedstock supply and

Table 4. Energy crop production for electricity in the Southeast

Constraints	Potential solutions
No demand for new capacity	Convert existing facilities, promote cofiring, fuel switching due to pollution control policies
Perceived supply/cost instability	Education, simulated siting studies, demonstrations, extension efforts, cooperative supply relationships, feedstock diversification
Lack of industry organization	Enlarge biomass constituency, particularly to potential producers; develop program alliances within government agencies
Risk associated with assured feedstock supplies and costs	Research and development, long-term contracts, full net-benefit assessments, government programs and policies, feedstock diversification
Societal resistance	Early education, siting, economic impact analysis
Government regulatory policies	Education, production system adjustments

Table 5. Energy crop production for liquid fuels in the Midwest/Lake Region

Constraints	Potential solutions
Competition with subsidized crops	Modify agricultural policy, education
Risks associated with assured feedstock supplies and costs	Research and development, particularly drought resistance, demonstration, diversification, oversupply and alternative uses
Government policy	Policy changes, education
Perceived economic impacts	Siting, economic impact analysis, education
Lack of industry organization	Involvement of agricultural community

considerable technology transfer to utilities and investors. Putting fossil fuels and biomass feedstocks on a level playing field by internalizing environmental externalities in fossil fuel costs would very likely increase the attractiveness of energy crop biomass feedstocks.

2.3. *Dedicated feedstock supply systems*

The working group on DFSS felt it necessary to assume that appropriate technologies and markets existed before they could begin productive discussion. Thus, although a lack of markets for DFSS was not specifically identified as a major constraint in Tables 4 and 5, it is in reality the single largest constraint to the expansion of dedicated feedstock production. Since DFSS issues are often region specific, to simplify the discussion, electricity production was limited to the Southeast region, and liquid biofuel production was limited to the Midwest/Lake region.

2.4. *Environmental issues*

The environmental working group identified 14 biomass feedstock issues that were relevant to the development of biomass as a significant energy source to the United States. This group did not explore the many positive environmental attributes of biomass energy systems. Rather they delved into issues that might require some resolution prior to an expansion of biomass energy systems to large-scale commercialization in the United States. The issues were loosely grouped into three areas: (1) issues relevant to the use of exist

Table 6. Cropland in the United States by major use[a]

Use	Million hectares
Cropland used for crops	137
Harvested	124
Failed	3
Summer fallowed	10
Cropland idled	25
Annual programs	11
Long-term programs	14
Total	162

[a]Source—USDA/ERS.[8]

ing biomass; (2) issues relevant to the establishment and maintenance of DFSS; and (3) issues relevant to any use of biomass for energy. The ranking of relative importance of the issues differed, depending on whether the end use was anticipated to be a large biofuel facility in the Midwest or a moderately sized electric generating facility in the Southeast. The biggest problem in both cases was the lack of data needed to predict environmental responses.

The group's primary concern over the use of existing biomass, especially in the Southeast, is that bottomland forest areas will be degraded, either through overharvesting or through conversion to agricultural-type use, and that herbicide use will increase. The primary concern with the establishment of large acreages of DFSS is that the crops may become disease or pest reservoirs. The working group concluded that even though these concerns exist, the wise use of regulations and management alternatives could help mitigate most of the negative environmental impacts that may be associated with increased use of biomass to produce energy. If wisely implemented, DFSS production should present a very positive alternative to the use of fossil fuels for energy.

2.5. *General workshop conclusions*

The group found that the need for complete fuel cycle analysis to evaluate and optimize all components of specific types of bioenergy systems exists. Furthermore, the results should be compared with fossil fuel cycles in order to document the economic and environmental advantages of bioenergy systems. Policy analyses are also necessary to understand the external barriers inhibiting commercialization.

The development of a fully functioning DFSS takes 3–10 years, depending on the feedstock. Investors are reluctant to finance the planting of crops without guaranteed markets, or to finance the building of conversion facilities without guaranteed feedstock supplies. The entire group concluded that in order to move either/or conversion technologies forward, near-term demonstration projects would be necessary. Since the risks are high, both government and industry must support these projects. At the same time, research must proceed, both as part of, and separate from, demonstration projects.

While the Biomass Energy Strategies Workshop participants identified many technological barriers that are yet to be overcome and analyses that are needed to reduce uncertainty, it was determined that technological developments are not enough to stimulate commercialization. Many organizations—federal, state and private—must expend considerable effort to reduce the external barriers that inhibit commercialization. Examples of these barriers are regulations that prohibit certain land uses, subsidies that favor competing energy systems and fuels, and various institutional arrangements that may tend to work against the adoption of bioenergy. It will take creativity, vision and leadership to make the necessary changes and to realize the combined benefits of improved energy security, enhanced rural development and positive environmental effects from bioenergy.

3. SUMMARY OF REPORTS ON ENERGY CROP TECHNOLOGY STATUS

The following sections are summaries of a set of papers that ORNL staff prepared in 1991/92 for EPA under contract. EPA's goal was to learn more about the technology development status of dedicated biomass energy crops in order to evaluate their potential for carbon mitigation strategies. This brief summary of those papers provides a quick overview of the technology status of energy crop development in 1992. New information is rapidly being obtained and may not be totally captured by this review.

3.1. *Land availability*

Energy crop production systems use technologies developed to cultivate traditional agricultural crops. Consequently, most U.S. lands currently in food crop production could produce high-yield biomass energy crops. The U.S. Department of Agriculture (USDA) reported 162 Mha of cropland in the United States in 1991 (Table 6). Of this base, 137 Mha were either used to produce crops, were planted but not harvested, or were summer fallowed. The remaining 25 Mha were idled either through annual acreage reduction programs or through the Conservation Reserve Program.[8] Graham[9] evaluated U.S. cropland for its potential to be converted to intensive biomass production. Of the 162 Mha of cropland in the United States, 131 Mha have been identified as capable of cultivating energy crops, and, of that total, 91 Mha could produce 5 Mg ha^{-1} yr^{-1}. (All yields are reported on a dry weight basis.)

The agricultural needs of the United States in the next century will require much of the acreage capable of supporting energy crops. The Soil Conservation Service (SCS) optimistically projected that 88 Mha of land in agricultural production will be required to meet the domestic and export demand in 2030.[10] These projections indicate that 74 Mha currently in cropland may not be required to meet future U.S. agricultural needs. However, about 75% of the lands projected to be surplus are in the Great Plains or Mountain regions, areas generally not desirable for energy crop production because of low rainfall levels. Only about 16 Mha would be in regions well suited to energy crop cultivation. On the basis of this, it is estimated that 8–16 Mha of cropland could be converted to biomass production in the near future without displacing conventional crops in any significant way. Energy crop production could extend beyond 16 Mha without significant crop displacement if the additional land for energy crops was drawn from pastureland or former cropland currently in long-term set-aside programs. Actual conversion of any type of land to energy crop production will depend heavily on the probability of there being a profit in it for the landowners. This in turn will be related to federal programs for food crops and other agricultural and land-use policies.

3.2. *Dedicated feedstock supply systems*

DOE's BFDP has the goal of making biomass energy a cost-effective, environmentally sound energy option for the United States. Species of plants are selected for their rapid growth, wide site adaptability, pest resistance and disease resistance. Wright[11] reports that four major categories of plant species are being considered: woody; thin-stemmed perennial; thick-stemmed perennial; and annuals. Some of the desirable species identified thus far are listed in Table 7. Each cropping system offers characteristics that make it relatively more suitable for specific locations and conversion technologies. Mixed cropping systems will be desirable in many locations.

Woody crops have been developed that yield on average between 10 and 17 Mg ha^{-1} yr^{-1}. This is 2–3 times the yields normally achieved by traditional forest management. Much higher yields have been observed under selected conditions. In general, woody

Table 7. Desirable energy crop species

Woody crops:	
Populus spp.	poplars, cottonwoods & hybrids
Eucalyptus spp.	eucalypts
Acer saccharinum	silver maple
Liquidambar styraciflua	sweetgum
Platanus occidentalis	sycamore
Robinia pseudoacacia	black locust
Salix spp.	willows
Herbaceous crops:	
Panicum virgatum	switchgrass
Elytrigia spp.	wheatgrasses
Pennisetum purpureum	napiergrass or elephantgrass
Saccharum spp.	energy cane
Sorghum bicolar	sorghum

biomass converts to thermal energy and gasification more efficiently than herbaceous energy crops. Wood feedstock has a lower moisture content, lower ash, lower nitrogen and higher energy values per ton than herbaceous biomass. Other desirable attributes include potential for storage on the stump and infrequent soil disturbance from establishment and harvest.

Thin-stemmed perennials, specifically warm-season grasses, offer excellent soil holding capacity and the ability to maintain growth under drought conditions. Average yields of thin-stemmed perennials in preliminary species comparison trials ranged from 4.0 to 14.0 Mg ha^{-1} yr^{-1}. More recent results[12] indicate the potential to reach 20 Mg ha^{-1} yr^{-1} in several locations. Thin-stemmed perennials require lower agronomic inputs, are adapted to a wider range of soil and climate conditions, and are overall a lower risk crop. These crops have a high initial moisture content before harvesting, but field drying normally reduces moisture level prior to baling. One drawback of thin-stemmed perennials is that harvest, handling and storage losses are relatively high. The major advantage of these grasses is that a full-scale DFSS can be available within 2 years of planting.

Thick-stemmed perennials, such as energy cane and napiergrass, can produce yields from 12.2 to 32.4 Mg ha^{-1} yr^{-1}. However, these species are very sensitive to frost and are limited to the extreme southern regions of the United States. Thick-stemmed perennials do require high inputs. However, in the appropriate locations the high yields can offset the high inputs required. Though sugar cane production technology can be used for production of these species, new, lower cost harvest and handling techniques should be developed.

Annual crops currently considered for DFSS include sorghum and sudangrass. Annual crops exist in a wide range of genotypic variations. Thus, they can be easily modified to suit physiologic conditions in several regions. Yields from annuals vary greatly from 10 to 20 Mg ha^{-1} yr^{-1}, and higher yields of up to 37 Mg ha^{-1} yr^{-1} are reported on some sites. Although these yields may drop considerably in droughty years, they may still equal yields of many SRWC and perennial grass species. Annuals can often produce higher yields than other energy crops; input costs are also higher. Annual crops offer the advantage of fitting into diversified farm management systems. Cropping systems could include both energy and food production sequentially grown on the same land in the same year. A major disadvantage of annual cropping systems are the high-input requirements and potential for soil erosion losses.

Table 8. Factors influencing the applicability of energy crop systems

System	Range in production yields[a] ($Mg\ ha^{-1}\ yr^{-1}$)	Advantages	Disadvantages
Woody crops	10–17	Good conversion characteristics, moderate storage/harvest losses, on-stump storage, preexisting markets, good yields	5–10 year payback period, management practices and equipment different from those of row crop agriculture
Thin-stemmed perennials	4–14	Drought tolerant, low agronomic input, low risk, annual income, farm integration simple	High handling/storage losses, high ash content, high transportation costs
Thick-stemmed perennial	12–32	High yields, annual income, sugars easily converted to ethanol	Limited range, high input cost, high transportation costs
Annuals	10–20	High yields, drought tolerant, simple integration into traditional agriculture	High storage losses, high year-to-year yield variations, high transportation costs, high erosion losses

[a]Small plot experimental yields have indicated the potential for much higher yields in the woody crops and thin-stemmed perennials. Production yields are based on larger plot sizes.

Additional disadvantages are: (1) that harvest occurs in the fall when many other farm crops are harvested; and (2) that storage is in the form of silage.

All of the energy crop DFSS have characteristics that favor them in specific circumstances. Table 8 summarizes many of these characteristics. Herbaceous systems can be harvested every year, thus returning income to the landowner on a regular basis. Herbaceous systems use standard farming equipment and familiar management techniques. Woody systems, although harvested only once every 5–8 years, require less intermediate management. Markets for woody biomass currently exist for paper and other pulp products. These markets could make the transition from traditional agriculture to energy crops less risky.

3.3. *Environmental issues*

The strongest argument for developing DFSS is the ability to improve environmental quality by providing an alternative to fossil fuels (especially coal), thus reducing the emissions of greenhouse gases.[13,14] The energy characteristics of coal and biomass are similar. Coal and biomass are solid fuels that are easily converted to thermal energy. Both have potential for conversion to gaseous and liquid fuels. While the combustion of biomass releases carbon to the atmosphere, the net change in atmospheric CO_2 is small or zero because the release of carbon is offset by new growth of biomass.

When the total range of atmospheric pollutants from fuel combustion is considered, the relative advantage of biomass energy systems depends on the specific technology employed. The low-efficiency biomass combustion technologies largely in use today emit greater levels of particulates and volatile organic compounds (VOC) than most coal-fired power systems. However, most of the pollutants result from incomplete fuel combustion. For both economic and ecological reasons, new biomass energy combustion and gasification systems should have greatly improved efficiencies which would result in their becoming very clean energy sources. Refineries built for the production of liquid fuels from biomass will also require high efficiency in their conversion processes to become economically feasible. Since these new biomass energy

Table 9. Typical environmental impacts of selected food crops and energy crop production systems

Cropping system	Soil erosion rates[16] (Mg ha^{-1} yr^{-1})	N–P–K[17,18] application rates (kg ha^{-1} yr^{-1})	Herbicide[17,18] application rates (kg ha^{-1} yr^{-1})
Annual crops			
Corn	21.8[a]	135–60–80	3.06
Soybeans	40.9[a]	20–45–70	1.83
Perennial crops			
Herbaceous energy crops	0.2	50–60–60	0.25
Short-rotation woody crops	2.0	60–15–15	0.39

[a]These numbers are from data collected in the early 1980s; thus, it is anticipated that new tillage practices may be resulting in lower values.

systems do not yet exist, actual air and water emissions cannot be determined.

Large dedicated feedstock production systems also do not yet exist, but probable characteristics of such systems can be deduced from evaluation of food crop and plantation forestry production systems and extrapolation from experimental plantings. According to Ranney and Mann,[15] DFSS will be managed using many of the techniques developed for traditional food crops, including intensive site preparation, chemical fertilizers, pesticides and mechanized harvesting. Many of the environmental problems associated with food crop production stem from these practices and also exist, to some extent, with DFSS.

Environmental impacts of current DFSS are anticipated to be lower than those associated with current row crop production and greater than those on fallowed, pasture, or set-aside lands. Environmental problems potentially associated with DFSS include soil erosion, ground and surface water pollution, fossil fuel use, air quality, sustainability of site productivity, biodiversity, and wildlife habitat manipulation. Most of these problems can be avoided with appropriate site selection and technology implementation. Potential rates of erosion, fertilizer application and herbicide use are outlined in Table 9.

Soil erosion depletes nutrients on-site and causes nonpoint water pollution off-site. Perennial energy crops (trees and grasses) stabilize the soil better than row crops and are similar to or slightly less effective than fallowed, set-aside, or pasture lands. Pimentel *et al.*[16] estimated the average erosion rates for U.S. croplands as 18.1 Mg ha^{-1} yr^{-1}. Erosion rates for herbaceous and woody biomass systems are expected to be much lower; estimates average 0.2 Mg ha^{-1} yr^{-1} for perennial herbaceous systems and 2 Mg ha^{-1} yr^{-1} for SRWC. The rates could vary considerably across region and crop type.

Erosion rates for SRWC systems will vary during and after establishment of the crop. During the 2 year establishment period, when little ground cover exists, erosion from SRWC systems will be comparable with erosion from crop systems. After root systems develop and canopy closure occurs (often within 2 years), erosion rates will be substantially lower, similar to those of hay lands. Erosion rates for hay lands were estimated to be 0.2 Mg ha^{-1} yr^{-1}.

Fertilizers and herbicides will be used in energy crop systems to improve productivity. Test data indicate that energy crop application rates of fertilizer and herbicides will be lower than those of most row crop agriculture systems. Table 9, drawn from the paper by Ranney and Mann[15] (this volume) summarizes

Table 10. Typical costs of supplying energy crops in the Midwest and Southeast

Region/crop	($/Mg)		($/GJ)	
	1989	2010	1989	2010
Midwest				
Hybrid poplar chips	68	47	3.45	2.37
Sorghum	48	33	2.74	1.88
Switchgrass (corn site)	68	48	3.88	2.73
Switchgrass (oats)	60	43	3.42	2.45
Southeast				
Energy cane	52	33	2.98	1.87
Switchgrass	62	38	3.54	2.17

typical fertilizer and herbicide application rates and erosion levels for food crop and energy crop systems. The timing of fertilizer and herbicide treatments will affect their rates of movement off-site. For instance, application of chemicals early in a woody crop rotation, when the soil is relatively exposed, would potentially increase their movement off-site.

Energy crop research has examined the potential for using multispecies energy systems in a few locations. Using nitrogen fixing species could reduce the need for fertilizer applications. Several nitrogen-fixing energy crops are being evaluated. Similar to food crops, energy crops are susceptible to pest outbreaks. Multispecies production systems could reduce the risks associated with pests and could also aid in increasing biodiversity of plant and animal species in a predominantly agricultural area. Research on multispecies production systems is very limited, but indicates that the development of such systems to the point of cost-effectiveness will be a significant challenge.

Energy crop production systems are expected to have small direct negative impacts on ambient air quality and large positive impacts when used to offset fossil fuel emissions. The conversion of agriculture sites to energy crop plantings should result in lower emissions of pollutants and greenhouse gases. Conversion of fallowed and idled sites will cause slight increases in these emissions. Air pollutants associated with production systems include NO_x, N_2O, methane, natural VOC, dust and pollen. NO_x is emitted from fossil fuel combustion in vehicles used to establish, harvest, and transport crops. All pollutants except NO_x are expected to approximate natural background levels.

3.5. *Economics of DFSS*

In most cases, the costs of producing electricity from DFSS are greater than the corresponding fossil fuel generation costs. In part, this difference stems from the differing scales of operation and from the current price of fossil fuels at $1.50/GJ or less for coal and natural gas. DFSS is currently more costly than fossil fuels as a delivered feedstock. The establishment of a carbon tax on fossil fuels or other market incentives could alter this cost discrepancy. While the environmental costs associated with fossil fuel use lend support to increasing the use of biomass energy, these benefits are difficult to quantify. Currently, few market incentives exist to induce power producers to account fully for their environmental impacts.

A number of factors influence the costs of producing biomass energy crops, including species used, cropping system, treatments, and regional and microsite variability. Typical costs for producing DFSS as described by Turhollow[19] are presented in Table 10. With the conversion efficiencies available today in the United States, DFSS may need to be available at ~$1.50/GJ or less to make production of electricity or liquid fuels a competitive alternative. However, such prices would not offer the landowners any incentive to produce DFSS. Current production costs for

DFSS biomass range between \$2.74 and \$3.88/GJ.

Focusing on cost competition between fossil and biomass feedstocks, however, does not fully recognize the advantages offered by integrated biomass energy systems. Integrated systems use local labor and environmentally sound land-management techniques to produce feedstocks that are inherently lower in pollutants than fossil fuels. If these benefits are valued by society, then ways will likely be found to reward such benefits financially. Additionally, integrated biomass-to-electric systems can use waste heat to dry the feedstocks, may require less pollution control equipment, may be able to capitalize on the greater reactivity of biomass to increase conversion efficiency, and can land-apply ashes to recycle nutrients. Integrated biomass-to-liquid fuels systems may benefit by selecting feedstocks either for increased conversion efficiency or co-product potential, and effluents may also be land-applied to recycle nutrients. As biomass energy systems become more fully developed and integrated, it is highly likely that they will become very competitive with fossil fuel systems.

4. CONCLUSION

Development of biomass feedstock supply systems using energy crops has progressed to the point of indicating that production of energy from biomass is technically feasible. Also, it is close to economic viability in some situations where government programs are available to reduce land rents or where favorable climates, genetically improved crops, and efficient conversion technologies are available. The nearness of biomass energy technologies to economic feasibility emphasizes the need to consider carefully all environmental risks and benefits, refining the concepts appropriately. The range of available DFSS technologies offers the latitude for improvement of environmental benefits without seriously detracting from economic viability.

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