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STRATEGIES FOR ACHIEVING A SUSTAINABLE, CLEAN AND COST-EFFECTIVE BIOMASS RESOURCE

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Abstract—Biomass, produced in an economically and environmentally sustainable manner, could realistically be used to supply 50,000 MW (5 quads) of electric capacity by the year 2010, and probably twice that amount by the year 2030.

Since 1992, the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE) have each been independently evaluating the potential for biomass to become a major renewable energy resource over the next four decades, capable of offsetting some of the U.S. dependency on fossil fuels while also offering important environmental and economic benefits. This paper presents EPRI's conclusions, which are more conservative than those of the U.S. DOE, and outlines possible strategies by which EPRI can advance acceptance of biomass as a preferred renewable resource. Copyright © 1996 Elsevier Science Ltd.

1. THE STRATEGY DEVELOPMENT PROCESS

EPRI's conclusion that biomass could become a truly important feedstock for electric generation in the near term grew out of a series of workshops attended by experts from government, academia and industry. The goal of the workshops was an assessment of the overall potential of biomass feedstocks to become a significant sustainable resource for electric power production in the U.S. A corollary goal was to gain consensus regarding the extent to which different sources of biomass would contribute to the total mix of feedstocks. There was agreement that approximately one additional quad of primary energy could be aggregated from available wood and agricultural wastes and forest management practices in a fully sustainable manner. However, if more than 10% of U.S. electric capacity is to be fueled by biomass, the resource would need to be a dedicated one, produced intentionally for energy purposes—a new agricultural crop grown for an economically important market.

Participants in the workshops identified the two major barriers: (1) lack of assurance of a reliable market for a dedicated biomass energy crop, which is significantly influenced by the current costs of fossil fuels, both coal and natural gas; and (2) current federal agricultural policies, particularly with respect to price supports for recognized commodities (or program crops) and the present constraints on the use of the more than 21 Mha of agricultural reserve program lands. Moreover, the very limited federal budget and program support for biomass energy within both the U.S. Departments of Energy and Agriculture over the past 12 years have not reduced the risks which would be experienced both by farmers making biomass/biofuels resource decisions and by electric utilities considering utilization of biomass resources.

EPRI has begun to address the concern about lack of a reliable market by seeking utilities that will commit to using biomass either as a dedicated feedstock or in a cofiring mode. During 1994 EPRI participated as a reviewer and cofunder of seven of the integrated systems economic feasibility studies selected for U.S. DOE support—the seven which involved at least one EPRI member company. EPRI is currently also supporting the development of a model to assess the relative costs and considerations of large-scale biomass fuel production in different regions of the country.

A third barrier that was identified is the lack of consensus as to criteria for environmentally sound development of biomass; however, this concern has been addressed by the National Biofuels Roundtable, organized in 1992 by EPRI and the National Audubon Society. The objectives of the roundtable involved defining principles for sustainable production at a site-specific, a landscape and a regional scale. The report was adopted in the summer of 1994 by the 30 roundtable participants who reflected the views of 24 distinct constituencies.

While there was recognition that forest products, particularly pulp and energy markets, would at times find themselves competing for the same resource, there was also general agreement that over the long term, collaboration between the paper industry and electric utilities would be advantageous. Six or seven paper companies have been growing short-rotation hardwood species for pulp for nearly a decade and, to a considerable extent, have made their way up the developmental learning curve. With only about 70–75% of a tree suitable for pulp, the residual material is available for generating electricity for the paper production process directly or to feed the local utility grid.[1]

2. BIOMASS AS AN ENERGY RESOURCE

Biomass is solar energy which has been stored by means of the photosynthetic capabilities of the chlorophyll molecules present in the leaves of green plants (the larger the leaves, the larger the amount of chlorophyll and, in general, the greater the amount of biomass). Wood has served as the major source of energy for thousands of years, yet today even in industrialized nations it is used mainly for residential or process heating rather than as fuel for electric power production.

Since the passage of the Public Utilities Regulatory Policies Act in 1978, there has been a significant increase in the amount of electric power generated from biomass in the U.S., largely from the wood wastes produced by paper and wood products industries. The electric generation capacity grew from about 200 MW in 1979 to about 6000 MW in 1992. This 6000 MW excludes the generation of about 1800 MW of power using municipal solid wastes as an energy resource.

About one-third of the power generated is sold to local utility companies, while the remainder serves as self-generation for the industrial facilities creating the wastes. In most instances the acquisition cost of the biomass fuel has been small; thus, the low efficiencies associated with combusting an energy resource with a high moisture content (about 50%) and a low heat content (about 19,500 kJ kg^{-1}) have not proved a deterrent.

As previously stated, EPRI's projection of as much as five quads of biomass-fueled electric capacity, during the next two decades, is predicated on the conclusion that the major biomass feedstock for the 21st Century will not be wood waste materials, but rather will be a whole new facet of U.S. agriculture, lignocellulosic crops. The projected significance and success of these biomass energy crops is based on the results of the trials of short-rotation woody and herbaceous crops being carried out by researchers throughout the country that have been supported since 1978 by the Biofuels Feedstock Development Program at DOE's Oak Ridge National Laboratory (ORNL).

A portfolio of regionally suitable plant species are being selected for high yields, as well as drought, blight and pest resistance. The biomass feedstocks for the 21st Century are likely to include hybrid cottonwood, poplar, silver maple, red alder, black locust, sweetgum, eucalyptus, sycamore trees, willows, switchgrass and reed canary grass. Work is under way in several parts of the country to match species to regional and local climate and soils characteristics. Several site-specific assessments of the environmental and ecological impacts of the plantings are also being undertaken. Development of the model that relates the components of feedstock production costs is expected to be completed by staff in the Department of Agricultural Economics at the University of Minnesota during the spring of 1995. At the same time, there is a growing recognition of the need for effective infrastructures linking feedstock supplies with their markets, but the options associated with operations required for functional infrastructures are not yet well understood.

3. THE ELECTRICITY MARKETS AND BIOMASS PRODUCTION

Over the decade ahead, electric generation planners anticipate a steady load growth of approximately 1.8% per year. Some of that (perhaps 25%) will be met through Demand Side Management (DSM) programs. Better than 60% will be met by new or repowered facilities using single or combined-cycle gas turbine technologies. Much of the rest is expected to be coal-fired and probably built by independent power producers (IPPs) or affiliated power producers (APPs), which are subsidiaries of utilities. Renewable resources, including biomass, will be used largely where there are niche markets, unless there should be a tax or some other significant constraint placed on fossil fuels use. Niche markets need not be inconsequential, however.

Much of the new generation capacity will be needed along the West and Gulf coasts, where natural gas supplies will meet most of the resource requirements, and also along the East coast, where the natural gas infrastructure is more limited. Utilities along the East coast may find biomass (possibly along with natural gas in a hybrid system) an attractive alternative to uncertainty in fuel supplies or major investments in pipelines and gas storage. Along with the need for additional electric capacity will come the requirement of utilities throughout the U.S. heartland to retrofit existing capacity in order to meet the emission reductions mandated by the Clean Air Act. This offers another niche for biomass, co-firing biomass and coal, thus providing emissions credits or offsets to the SO_x (and to a lesser extent the NO_x) emissions coming from existing coal plants. Furthermore, most U.S. electric utilities have committed to the federal Climate Change "Challenge" of voluntarily reducing carbon dioxide emissions. The use of "closed-loop" biomass to displace a fossil fuel is an expedient means of responding to this challenge.

However, biofuels development is a "chicken and egg" phenomenon. Just because there will be markets for biomass feedstocks does not mean that the feedstocks will be available.

At this time, transportation by truck of wood wastes and agricultural residues to a conversion facility more than 80–120 km away is neither economically or environmentally reasonable. Truck transportation costs are largely regulated and are determined by weight and the shipping distance. In cases where barge or rail transportation is possible, biomass fuels may be shipped significantly longer distances to a facility. However, because of the higher costs associated with producing a dedicated energy resource, it will be vital to minimize the portion of cost attributable to transportation.

A 75 MW power plant, operating at 30% efficiency, is expected to require nearly 30,000 ha of land, assuming that the biomass production is from short rotation crops yielding 24 green tonnes per hectare per year. Thirty thousand hectares is less than 2% of the land within an area having a radius of 80 km. As the average U.S. farm covers 185 ha and most farmers plant a mix of three or more crops, it is quite possible that as many as (or even more than) 500–1000 farms would ultimately be involved in production of the biomass resources needed for the plant. On the other hand, to put this level of biomass production into perspective, land penetration up to the 7% level would place biomass in the category of a secondary crop, low enough to not be in competition with any of the seven major commodity crops.[4]

Along with the requisite suitable cropland, there will need to be adequate water, efficient harvesting capabilities, and a fuel supply infrastructure to take care of getting the crop from the field to the power plant gate. Well-designed harvesting equipment and the development of an infrastructure are hurdles which can be surmounted. However, water availability is not guaranteed in parts of the western U.S. Thus, Fig. 1, which shows the regions of the U.S. considered suitable for production of different biomass crops, takes into account the fact that there are serious questions still to be answered regarding the adequacy of irrigation water for biomass production in many western states.

4. ENVIRONMENTAL CONSIDERATIONS RELATED TO USE

As evidenced during the National Biofuels roundtable discussions, in the eyes of many environmentalists and environmental policy makers, the most important attribute of biomass is its potential to diminish net U.S. emissions of carbon dioxide. Figure 2, which is adapted from a similar figure in the Council of Agricultural Science and Technology document,[5] illustrates this potential. Although carbon dioxide is a by-product of the combustion of biomass, carbon dioxide is also taken up during the photosynthetic process in the lignin, cellulose and hemicellulose molecules comprising the biomass. Thus, when grown as well as used as a fuel on a sustained basis, biomass is considered to be at the least CO_2-neutral. The conclusion of scientists at the First International Conference on Carbon Dioxide removal held in the Netherlands in March, 1992 was that it is more efficient to use land to grow biomass for energy purposes than to simply sequester CO_2 in forests.

Woody biofuels contain negligible sulfur and, in general, considerably less fuel-bound nitrogen than both coal and oil. However, as in any combustion process, thermal NO_x will be produced. The fluidized bed combustion systems are able to meet the existing federal

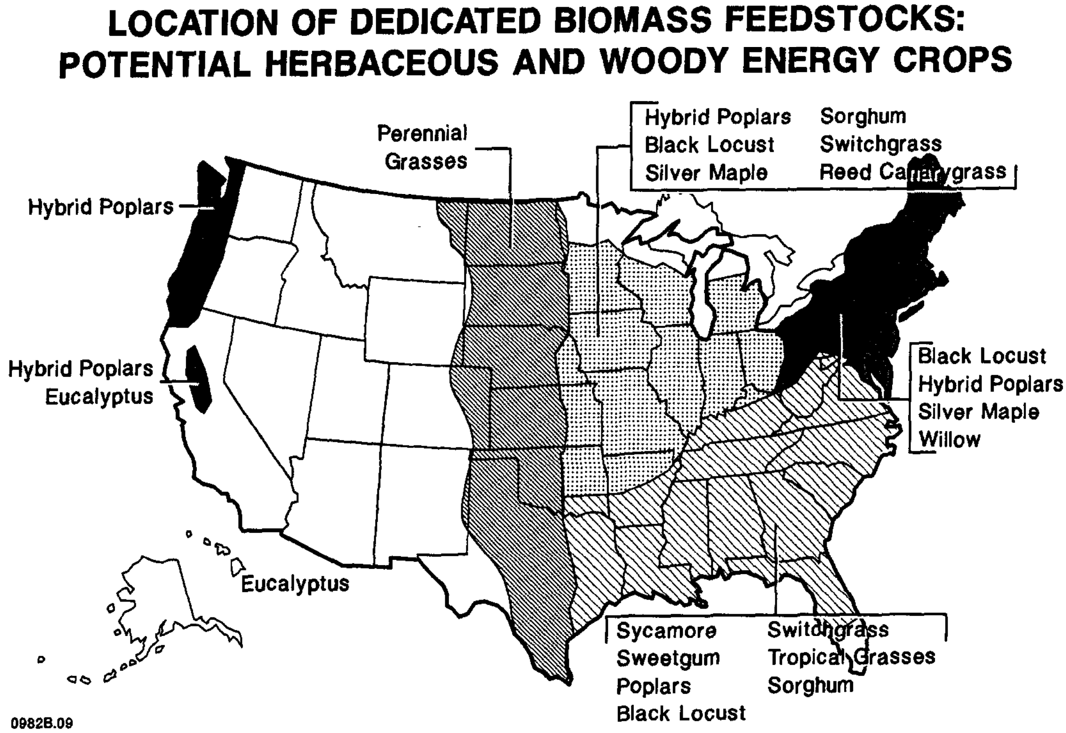

Fig. 1. Location of dedicated biomass feedstocks: potential herbaceous and woody energy crops.

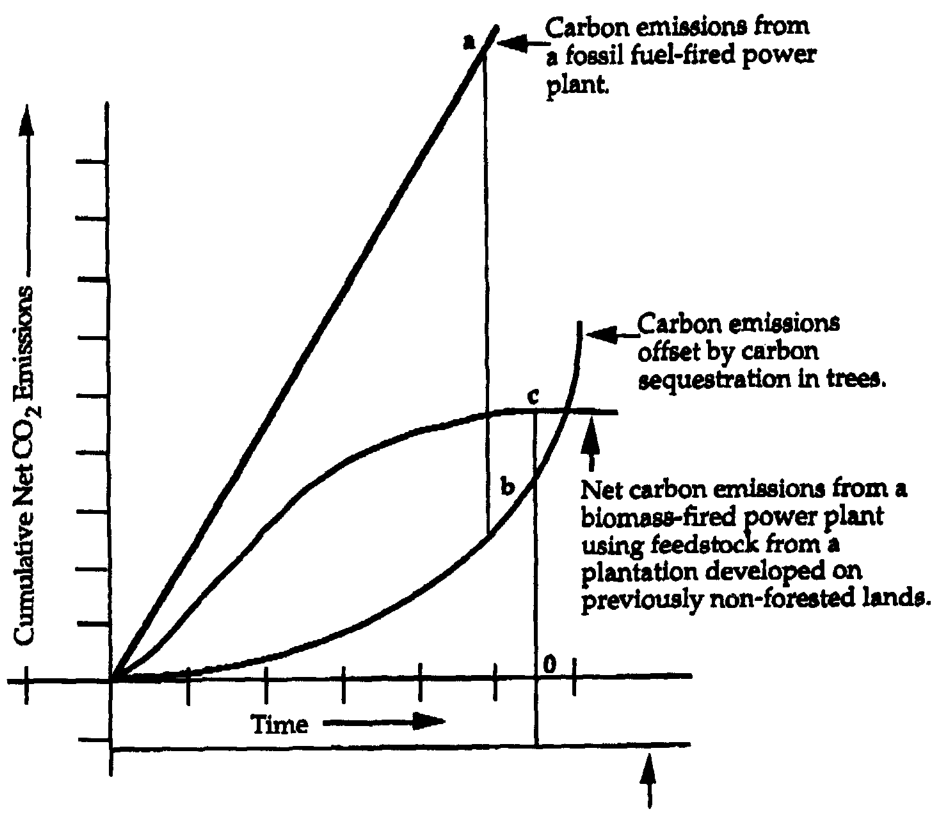

Fig. 2. Schematic representation of the paths of cumulative net emissions of CO_2 as a function of time for a fossil fuel-fired electric power plant and accompanying carbon sequestration using dedicated crops.[5]

NO_x standards so long as large amounts of herbaceous feedstocks, harvested during the rapid growth phase, are not used. With stoker–grate or pile–burner combustion systems, or in cases such as with herbaceous species with significant fuel-bound nitrogen, NO_x emissions can be readily controlled by urea or ammonia injection. Particulate emissions are controlled by baghouses or electrostatic precipitators.

Carbon monoxide is the one remaining concern in engineering a conversion facility to use biomass as a power generation resource; however, so long as the oxidation process is complete, CO emissions will not be a problem, nor will emissions of the aromatic hydrocarbons associated with incomplete combustion.

The residual ash remaining after combustion of biomass has value. The quantity of ash is only about one-tenth to one-fifth that produced by coal combustion. As it is largely made up of nutrients required for plant growth, potassium, calcium, iron and silicon at high pH, biomass ash can generally be used as a soil amendment on nearby agricultural lands or where dedicated biomass crops are grown.

5. THE ENVIRONMENTAL CONSIDERATIONS RELATED TO PRODUCTION

While excessive use of chemicals or inappropriate siting of biomass crops on significant slopes will result in environmental damage, the participants in the National Biofuels Roundtable were in agreement that production of dedicated biomass feedstocks, carried out intelligently and taking into account lessons to be learned from sustainable agriculture, can be environmentally sound. Since energy crops as well as weeds are a sink for soil moisture and nutrients, it is likely that some use of chemicals, both fertilizers and herbicides, will be required if production is to be both sustainable and economically viable. However, the use of chemicals can be minimized. Short-rotation woody crops and herbaceous perennials do not compare with annual row crops in terms of the rates of soil erosion and surface water siltation.

Biomass production, carried out with foresight and good judgment, also presents numerous opportunities to improve degraded lands, remediate some existing pollution problems, restore some former wetlands, and create different spatial and temporal patterns in regional landscapes in support of both biodiversity and the protection of watersheds.

6. THE POTENTIAL LAND BASE FOR DEDICATED BIOMASS CROPS

The 1987 Census of Agriculture reported that there were slightly more than two million farms in the U.S., with 386 Mha classified as farmland. The agronomists and economists who prepared the Second RCA Appraisal of Soil, Water and Related Resources for the U.S. Department of Agriculture estimated the total privately owned land base within the U.S. that is suitable for crop production to be between 165 and 180 Mha. Annually, between 120 and 135 Mha are planted either for major crops or for vegetables, fruits, tree nuts, or farm gardens. ORNL researchers have stated that, of the total acreage, at least 125 Mha would be suitable for lignocellulosic energy crops.[2]

Because of the "green revolution", with annual increases of nearly 2% in agricultural productivity over the past 60 years, only one-third of the land which was needed to feed one American in 1930 is needed to feed one today. The U.S. Department of Agriculture's Second RCA Appraisal predicted that over the next 40 years, there will be a 30% further decline in the need for cropland, even if there is growth in the grain export markets of 50%.[4] This suggests that there could well be more than 40 Mha of cropland available for new markets or new products. A recent contractor report for the Office of Technology Assessment[3] projects that, with appropriate incentives, energy crops could be grown on 34 Mha. The U.S. DOE's current biomass developmental strategy states that somewhere between 14 and 80 Mha of under-utilized land could be made available for energy crops. EPRI has elected to adopt a relatively conservative estimate of 20 Mha, the equivalent of 5 quads of energy as electricity, over the coming two decades.

At present about 22 Mha of lands, which had been previously in crops, are in federally supported land reserve programs. In 1992, more than 7.6 Mha were in acreage reduction programs (ARP) (12.4 Mha in 1991), which are lands set aside to curtail production of particular crops. Participation in the ARP provides farmers with eligibility for deficiency payments (subsidies). USDA staff from the Office of Energy report that for the 1990–1991 crop year, total deficiency payments associated with the seven program crops (wheat, cotton, corn, barley, sorghum, oats and rice) were \$6.788 billion.

The Conservation Reserve Program (CRP) currently has 14.4 Mha enrolled, at an annual cost to the U.S. taxpayer of \$1.7 billion. CRP lands are considered to be highly vulnerable to either rain or wind erosion. They are withdrawn from row crop production for at least 10 years and are planted in protective cover with either grass or trees. USDA's Natural Resources Conservation Service staff have called attention to the marked congruence of the locations of CRP lands and locations which ORNL has indicated give promise of high yields for energy crops.

7. THE ECONOMICS OF BIOFUELS PRODUCTION

A decade ago, DOE set its objective for biofuels production cost at \$1.90/GJ. However, after rigorous reevaluation of projected yields and all the costs associated with biofuels production, the figure has been revised upward to the \$2.25 and \$2.40 range, which, at least for the short-term, is more realistic. Cost-competitiveness will be influenced by regional characteristics, including weather, soils quality, and land rentals. Results coming from some herbaceous species trials indicate that, while corn generally is a more profitable crop than switchgrass on prime farmland in Iowa, biofuels may give higher returns than row crops on lower-quality croplands. Also, land quality may be more critical in corn production than in energy crop production.

Figure 3 shows that presently less than 50% of biomass production costs are area-dependent costs, i.e. are associated with the land area growing the crop. Besides land rental, these costs include site preparation, planting, herbicide and/or pesticide treatments, fertilization, and cultivation. The remaining costs are yield-dependent, and include harvesting, chipping, collection and transportation. At this time, ORNL analyses indicate that harvesting and handling costs alone comprise 30–40% of total production costs. With improvements in crop productivities, the area-dependent costs might be cut dramatically. Currently at about \$28 per dry tonne (\$25/ton), ORNL researchers expect that, within the decade ahead, harvesting costs could be cut to \$18 per dry tonne (\$15/ton). Transportation costs are largely fixed by trucking tariffs; however, investments in improved designs and more appropriately sized harvesting and collection equipment will certainly result in significant reductions in harvesting and handling costs. Best estimates at this time suggest that improvements in yield-dependent operations would decrease these costs from more than \$26 per dry tonne to \$20–\$23 per dry

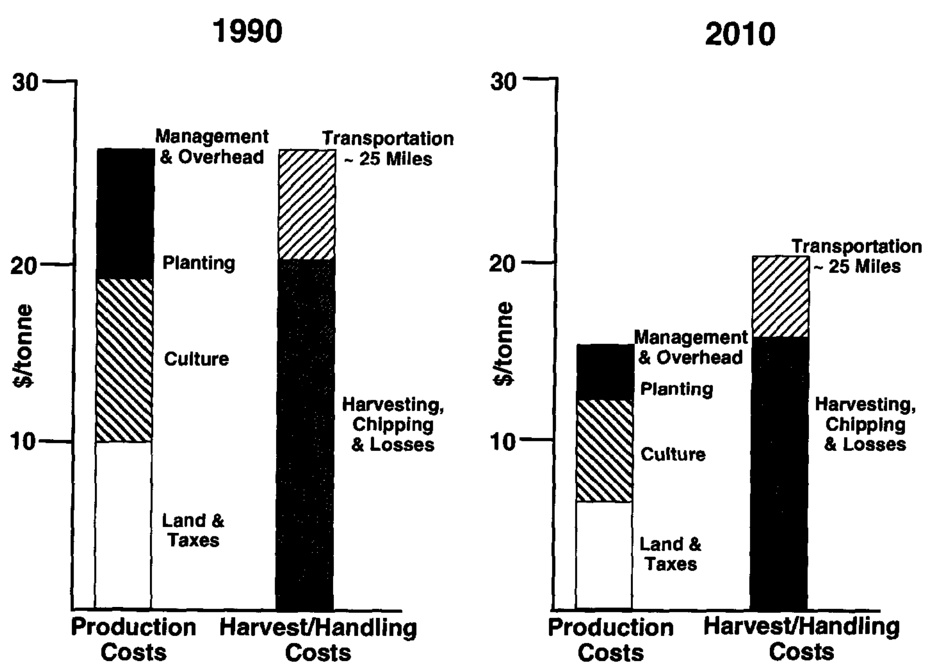

Fig. 3. Estimated biomass production, harvesting and handling costs in 1990 and 2010 (1993 dollars).

tonne. That would bring the total cost of the feedstock down to about \$30 per dry tonne or \$1.90 GJ^{-1}, plus contingencies.

Contingencies, such as provision for low-growth years, however, must also be considered. Therefore, crop insurance will need to be factored in, along with additional acreage to cover storage losses. In order to accomplish the ecological trade-offs deemed necessary for any sustainable system, some land will not be actually directed to energy crop production, but will be used as environmental corridor, barrier, filter, or conserve. These combined contingencies are likely to bring the final costs of delivered feedstock up to \$2.25–\$2.40 GJ^{-1}. Nevertheless, if the projected cost reductions can be realized, biofuels will be competitive with either coal or natural gas in many scenarios. Furthermore, it is worth noting that a tax of \$1 GJ^{-1} on fossil fuels would provide a benefit of nearly \$21 per dry tonne for biomass.

It is not envisioned that any existing forest lands will be converted to dedicated biomass crop production, at least in the next decade or so. The costs of land clearing most likely would be prohibitive, and environmental issues would certainly be controversial. However, in some forest–prairie transitional areas, it may be ecologically sound to consider conversion of land which may be in the process of reverting to forest. This possibility deserves consideration.

8. BIOFUELS AS AN ADJUNCT TO RURAL ECONOMIES

As indicated above, the land base devoted to agriculture in the U.S. has been shrinking for the past several years. Crop productivities continue to increase. With a decrease in beef markets, pastureland requirements are 25% lower than they were a decade ago. Moreover, the character of the farm economy has changed dramatically over the past eighty years. Analyses presented by Dr Stewart Smith, senior economist of the Joint Economic Committee of Congress at a symposium on "Agricultural Industrialization and Family Farms" during October, 1992 indicate that the annual income of the agricultural sector has declined from \$36.5 billion (in 1990 dollars) in 1910 to \$28 billion in 1990. Yet during that time frame, the total value of U.S. agriculture has increased from \$83 billion to \$302 billion. Agribusiness is now the dominant component and beneficiary of farming. Most of the new technologies and intensive management practices adopted by U.S. agriculture during the past four decades, have shifted economic benefits away from the farm to the non-farm sectors. Commodity programs and subsidies have further encouraged the specialization which has fostered substantial structural changes, with a dramatic shift away from small and medium-sized farms.

Biofuels production offers rural America an exceptional opportunity. The development of biomass crops could provide jobs in the small- and medium-sized farms component of the agricultural sector, in a fuels handling/management infrastructure, in extension service and farm practices development, and at the conversion facilities. This would not be a multi-million dollar new industry, but rather a multi-billion dollar new industry. The cost of electric generation using higher efficiency conversion technologies and dedicated biomass crops will be approximately 6¢ $(kW\ h)^{-1}$. If the developed capacity is 5 quads, or 50,000 MW, the economic value of that energy is about \$24 billion per year. Realistically, as much as 50% of this \$24 billion would be directly associated with feedstock production and delivery. A \$12 billion addition to the farm sector economy could increase the U.S. rural economy by 42%.

9. CONCLUSIONS

The large-scale development of biomass as an energy resource must be approached from a total fuel cycle perspective, with recognition of the importance of locating and scaling the production of the fuels resource to the site and size of the generating facility.

The time has come for electric power producers to begin to create alliances with those other parties that will be integral to sustainable development of a reliable, renewable feedstock as well as those that will be involved in commercialization of the next generation of electric power plants.

Thoughtful planning and collaborative programs will be essential if public acceptance is to be forthcoming. Furthermore, proposed projects and local policies will need to take into account specific regional factors such as climate, resource competition, electric capacity requirements, regulatory issues, the availability of transportation and transmission routes, as well as public values and attitudes. Commercialization of biomass power may well serve to meet a variety of important national environmental, energy and economic goals; the accomplishment of these important objectives will take place on an incremental and locality-specific basis.[6]

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