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The Economics of Biomass Production in the United States

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Abstract

Biomass crops (e.g. poplar, willow, switchgrass) could become important feedstocks for power, liquid fuel, and chemical production. With successful research programs that boost crop yields and develop appropriate power and chemical conversion technologies, biomass might compete with fossil fuels for a broad range of uses. Compared to fossil fuels, biomass feedstocks can offer significant environmental benefits. For example, biomass crops do not add greenhouse gases to the atmosphere during their life cycle.

This paper presents estimates of the potential production of biomass in the United States under a range of assumptions. Estimates of potential biomass crop yields and production costs from the Department of Energy's (DOE) Oak Ridge National Laboratories (ORNL) are combined with measures of land rents from USDA's Conservation Reserve Program (CRP), to estimate a competitive supply of biomass wood and grass crops. Estimates are made for one potential biomass use--electric power production--where future costs of electricity production from competing fossil fuels set the demand price. The paper outlines the methodology used and limitations of the analysis.

Currently, biomass-based electricity generation is a niche market where electricity is expensive and fuel is cheap or incurs a disposal cost, e.g. waste wood, sawdust, etc. However, if biomass production and usage systems demonstrate themselves to be workable at DOE's projected costs, biomass crops might become competitive for electricity production and other uses. Increases in fossil fuel prices, more rapid advances in gassification-gas turbine power generation technology, or rapid market development for biomass-based co-products such as pulp wood or chemicals could accelerate the production of biomass for electricity generation. Policies that discourage greenhouse gas emissions or encourage biomass production on idle land could also make biomass feedstocks more competitive with fossil fuels for a range of uses.

Biomass crops could be produced on some of the land idled by farm programs in recent years. However, if biomass crop production should expand beyond 30 million acres, then the interaction of biomass with traditional agricultural crops, markets, and programs becomes important. While the outlook for biomass feedstocks for energy and other uses offers promise, the practical viability of biomass production and usage systems needs to be demonstrated. Given the uncertainty about the competitiveness of the biomass industry, projects that successfully demonstrate biomass production and utilization systems hold the key to the future of biomass production in the United States

Background

This paper discusses the economic potential of biomass production and utilization. Biomass crops are being promoted as feedstocks for the production of electric power, liquid fuels, and chemicals. Biomass feedstocks have environmental advantages compared to fossil fuels. For example, they would not add greenhouse gasses to the atmosphere during their life cycle. These crops might be grown on fragile lands and could perform other environmental tasks such as the filtration of fertilizer and pesticide runoff. DOE research suggests that yields of biomass crops such as poplar, willow, and switchgrass could be increased significantly. If new generation efficient gassification systems and turbines were developed for power production, biomass might become competitive with fossil fuels as an energy source. Such a development would benefit farmers by adding energy crops to traditional food and fiber production. Rural communities would benefit from jobs created by biomass production and utilization.

Methodology

The supply of a product is the quantity that will be produced with a unit of resources at a price that is competitive with other uses for the same resources. Given a fixed amount of biomass production, the competitive price is set by the last unit of resources coming into production which just meets production expenses. The potential supply of biomass can be estimated given data on land productivity, biomass production costs, and the cost of land for alternative uses. Since biomass crops have a life cycle of several years, the stream of biomass revenues and costs has to be discounted in order to compare returns from biomass production with alternative investments (Strauss and Wright).

The supply price estimates for biomass on an acre of land can be done by calculating the present value of estimated revenue and costs over a production cycle (n years). Let $p \equiv$ average annual biomass crop price per ton harvested, $y_t \equiv$ biomass yield per acre (in period t), $c_t \equiv$ total production cost per acre (including a competitive return to the land), and $r \equiv$ the discount rate over the crop cycle period. For each acre of biomass, the discounted revenue $\equiv \sum_{t=1 \text{ to } n} [(p^*y_t)/(1+r)^t] = p^* \sum_{t=1 \text{ to } n}[y_t/(1+r)^t]$, since p is defined as an average price over the crop cycle. This discounted revenue from biomass production must equal the discounted cost $\equiv \sum_{t=1 \text{ to } n}[c_t/(1+r)^t]$. Solving for p, $p = \{ \sum_{t=1 \text{ to } n} [c_t/(1+r)^t]\}/\{\sum_{t=1 \text{ to } n} [y_t/(1+r)^t] \}$. The average biomass supply price depends on the ratio of discounted production costs to discounted yields (resource productivity). This calculation was repeated for land units with differing productivity (yields) and value (rental rates).

The quantity of biomass produced on a unit of land is simply the area times the average annual yield. The total quantity q supplied to the market at a price p is the sum of production on all land where the equivalent discounted price $<= p$ (p is the marginal price for the last unit of land to go into production at that price). Land units were ranked by their estimated "break even" price p, and production was summed over all units of land with an equal or lower price. This calculation gives the total quantity of biomass produced at each price level (current prices), i.e. the potential biomass supply.

Data for the Estimation of the Potential Biomass Supply in the United States

A data set for four potential biomass production regions in the United States was created. Acreage was broken down into land units by land capability class (Walsh and Graham, 1995) and average land rental values from the 12th sign-up of USDA's Conservation Reserve Program (Osborn, Liacuna, and Linsenbigler, 1992). Data on potential biomass yields and production costs by land class was assembled by ORNL for land suitable for biomass (crop, CRP, and pasture land with medium to high conversion potential) in the four regions shown in Figure 1. Calculations assume that biomass yields, production budgets, and CRP land rents applied to all land in a unit. Switchgrass was the representative grass crop while poplar was the wood crop for all regions except for willows in the North East. The yield scenarios (labeled by year) represented judgments about the potential success of biomass research programs: 2000 - yields attainable with current technology, 2005 - yields with improved management and clonal and varietal selection, and 2020 - yields that could be achieved with a sustained multi-regional genetic improvement program. Table 1 summarizes the data set used for estimation of the potential biomass supply in the U.S.

Figure 1: Biomass Production Regions

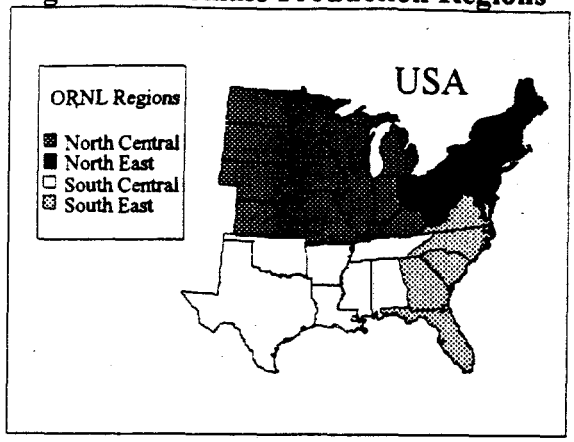

Table 1: Potential Biomass Crops, Suitable Acreages, and Average Yields 1/

	Grass Crops					Wood Crops				
Region	Crop	Million Acres	Yield Scenarios (Dry Tons/Acre) 2000	2005	2020	Crop	Million Acres	Yield Scenarios (Dry Tons/Acre) 2000	2005	2020
North Central	Switch grass	200	4.2	4.8	6.0	Poplar	177	3.1	5.1	7.1
North East	Switch grass	36	3.7	4.3	5.3	Willow	36	4.2	6.4	8.1
South Central	Switch grass	64	5.1	5.9	7.4	Poplar	41	2.6	4.6	6.8
South East	Switch grass	22	6.0	6.9	8.6	Poplar	22	3.0	5.0	7.3

1/ Production cycles assumed in ORNL biomass crop budgets were: switchgrass - 10 years, poplar - 7 years, and willow - 22 years. Regions included suitable acreage with adequate rainfall. Acreages shown overlap for grass and wood crops. The number of land class/rental observations were: North Central - 182, North East - 91, South Central - 61, and South East - 60. Land data included 12 land capability classes/subclasses with different potential yields assigned to each. Crop budgets were assigned to land classes by ORNL (5 switchgrass budgets, 3 poplar budgets, and 1 willow budget). Average CRP 12th sign-up rents (and standard deviations) in dollars/acre for the regions are: North Central -74 (41), North East - 78 (24), South Central - 49 (19), and South East - 42 (19).

Figure 2 shows a sample ORNL switchgrass crop budget and associated average yield scenarios for 2000, 2005, and 2020 for the North Central region. Budgets included variable cash, labor, and operating capital costs of production. This data was combined with a 6.5 percent discount rate and a CRP rental rate for the land unit (representing the required return from the land to cover ownership costs, profits, and taxes) to calculate an annualized farmgate price (cost) per ton that would allow normal returns for the land owner, given estimated revenues and costs. Budgets did include some variation in production costs associated with different yields (e.g. harvesting, transportation).

Figure 2: Switchgrass Production Budget Spreadsheet For a North Central Region Unit of Land With ORNL Yields and CRP Land Rent

	A	B	C	D	E	F	G
2	Switchgrass Budget	2000-YR. 1 ESTAB. COST	2000-YRS. 2-10 ANNUAL MAINT. & HARV. COST	2005-YR. 1 ESTAB. COST	2005-YRS. 2-10 ANNUAL MAINT. & HARV. COST	2020-YR. 1 ESTAB. COST	2020-YRS. 2-10 ANNUAL MAINT. & HARV. COST
3	VARIABLE CASH COSTS						
4	Seed	14.63		14.63		14.63	
5	Fertilizer	30.76	21.91	31.80	22.19	33.86	25.03
6	Chemicals	13.06		13.06		13.06	
7	Fuels/Lube	4.41	0.38	4.41	0.38	4.41	0.38
8	Repairs	8.29	0.55	8.29	0.55	8.29	0.55
9	Harvest		17.61		18.55		20.90
17	COSTS OF OWNED RESOURCES						
18	Capital Replacement	7.60	10.03	7.60	10.69	7.60	12.34
19	Oth. Nonland Capital	3.65	4.51	3.65	4.80	3.65	5.53
21	Labor	9.60	13.54	9.60	14.67	9.60	15.45
24	**Present Value (PV) Cost Calc. (1993 $/Acre)**						
25	Discount rate (%)	6.5%	Assumed Transport Cost ($/T):				
26	Annual land rental rate-CRP data:	74	3.00	PV-2000	PV-2005	PV-2020	
27	A=R. 4-8, C. B,D,F	Estab. cost-yr. 1		71.15	72.19	74.27	
28	B=R. 4-8, C. C,E,G	Maint. harv. cost-2-10		269.24	277.36	311.91	
29	C=R.18-19,21; All	Cap. lab. depr.-1-7		207.75	221.60	242.63	
30	D=R.26, C.B.D,F	Land rental cost-1-10		566.55	566.55	566.55	
31	= A + B + C + D	10 Y. Farm C.(93 $/A)		1114.69	1137.70	1195.36	
32	Yield Assum.-ORNL:	Average (dry tons/acre)	Transport costs-yrs. 2-10				
33	2000	3.69	70.25				
34	2005	4.22	80.34				
35	2020	5.27	100.33				
36							
37	**Annualiz. Farm C./Ton (93 $/Ton)**		Annualized Delivered Cost (93$/T)				
38	2000	47.60	50.60				
39	2005	42.48	45.48				
40	2020	35.74	38.74				

Calculations of annualized cost of switchgrass production, given ORNL budgets, yields, and land rental costs from CRP data sources.

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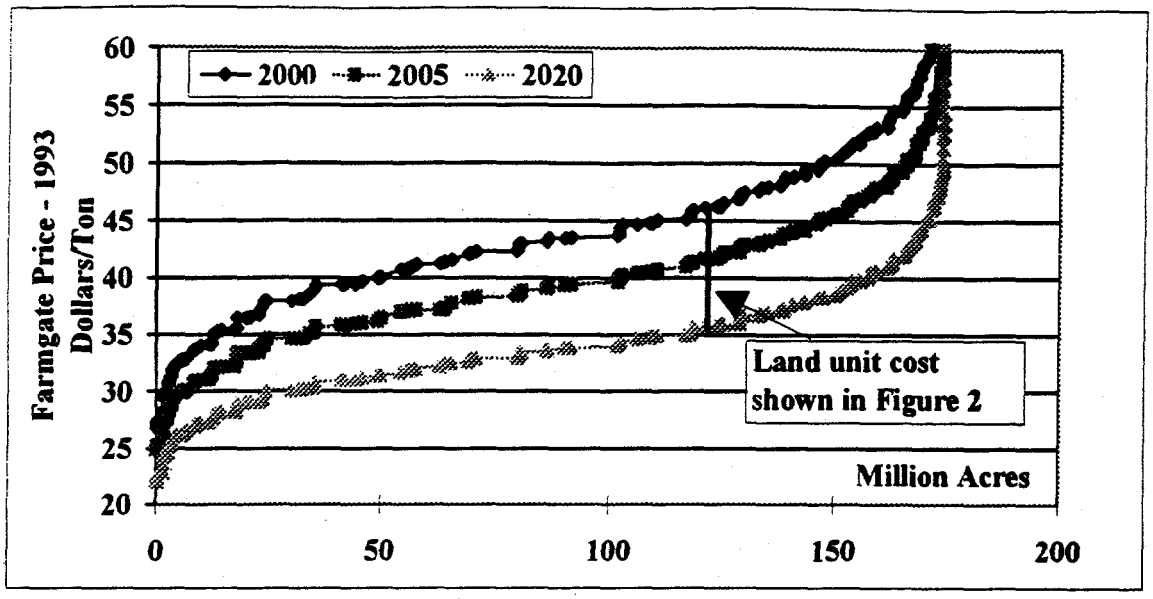
Shaded areas show budget data used. Underlined numbers are resulting annualized farm costs.

Figure 2 shows the calculations for an observation with a CRP rent of 74 dollars per acre that is expected to yield 3.7 tons per acre of switchgrass in 2000, 4.2 tons in 2005, and 5.3 tons in 2020. When similar spreadsheet calculations were performed for all rental observations in the North Central region, they were sorted by price (annualized farmgate cost). Then total acreage and production was cumulated for all land units with equal or lower prices. This process yielded a supply estimate with the lowest "break even" farmgate price per ton (left axis) verses the total acreage of land used (bottom axis) shown in Figure 3. The left part of the supply response scenario estimates shows the minimum price needed to bring switchgrass into production in competition with existing land use while the right part of the figure indicates the price that would be needed to bring all of the

land in the North Central region into switchgrass production. The point representing the results of the spreadsheet calculation shown in Figure 2 is marked with a vertical line.

Figure 3: Potential Switchgrass Supply for the North Central Region



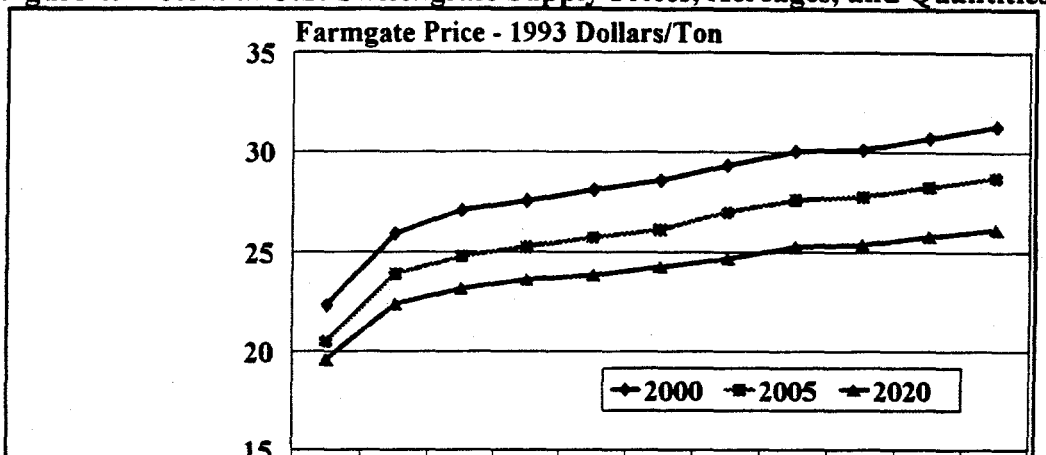
When the supply estimate is presented in terms of total acreage in a region, the scenarios with increased yields move the supply prices downward, i.e. they lower supply costs. Improved yields in 2005 with a modest research program lower costs at the line shown in Figure 3 from $47.60 per ton to $42.48, a reduction of $5.12 per dry ton or 11 percent. By 2020 with a long term research program, the costs are lowered to $35.74 per ton, down $11.86 or 25 percent from the costs projected in 2000. This calculation shows that given production costs and a variety of land prices and productivity; a) there is some land available that could produce switchgrass at a low price, e.g. $30 or less per ton, b) if research programs could successfully increase yields, switchgrass at $30 per ton would be competitive on more acreage (or at any of the acreages shown in Figure 3, the competitive price would be reduced). The calculation of a national biomass supply estimate follows the same methodology, combining land data from the four regions shown in Figure 1.

There is an important caveat about this type of analysis. The land rent distribution comes from a survey with existing crop production patterns in place. For example, the North Central region shown in Figure 1 has over 60 million acres in corn production, accounting for almost 80 percent of corn production land in the U.S. While Figure 3 suggests that all of this land could be converted to switchgrass production if prices approached $60 per ton, the resulting removal of 80 percent of U.S. corn production would raise feed grain, livestock, and food prices dramatically. In turn this would raise the prices required to maintain all of this land in switchgrass production. Therefore the supply estimates using this methodology are appropriate for smaller acreages or biomass on idle land that is not competing with mainstream crops (e.g. the 50 million acres in conservation and crop set-aside programs in recent years). If biomass crops were to seriously compete with traditional food and fiber crops, a full multi-commodity global market analysis would be needed to analyze the interaction of biomass crops with the existing farm economy.

Biomass Supply Estimates for the United States

Figure 4 shows supply estimates for switchgrass on the lowest cost 50 million acres. The downward shift of supply prices in each scenario results from the yield increases assumed to follow from stepped-up research programs. The numbers in the table below the acreage show the total switchgrass production expected with each scenario. For example, a price of 28 dollars per dry ton would encourage production of 128 million tons on 20 million acres in the scenario for 2000. For 2005, 20 million acres could produce 146 million tons at a price of 26 dollars per ton. The 2020 scenario suggests the same 20 million acres could produce 159 million tons for less than 24 dollars per dry ton. The small amounts that could be produced under 25 dollars per ton with research progress, constitute a niche market that might develop.

Figure 4: Potential U.S. Switchgrass Supply Prices, Acreages, and Quantities

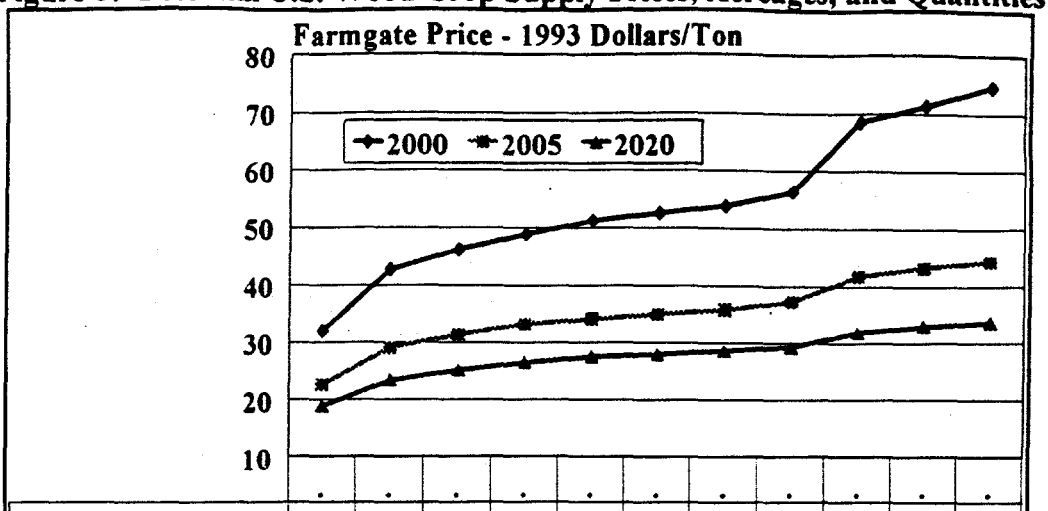


Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons -2000	0	29	54	85	128	148	176	193	215	258	280
Million Tons -2005	0	33	77	105	146	164	200	223	231	295	301
Million Tons - 2020	0	51	92	117	159	198	238	262	277	318	352

The quantities supplied in these estimates are very sensitive to price. This is consistent with the long run methodology used for the estimates and is appropriate for land currently idle. Experience with long-run multi-crop estimates suggests that each quantity produced would require higher prices if biomass production significantly displaced existing crops.

Estimates for U.S. wood crop production on 50 million acres are shown in Figure 5. The interpretation is the same as for Figure 4. The left part of the estimates at lower prices represent lower costs associated with willow production (relative to poplar). The supply estimates in these two figures include much of the same land. Therefore an additional calculation is needed in terms of a common energy metric, allowing either grass or wood production, to determine how much of each particular biomass crop is produced. Since wood and grass crops have different energy contents per ton, a combined estimate can be made by converting wood and grass tonnage to common energy units and prices.

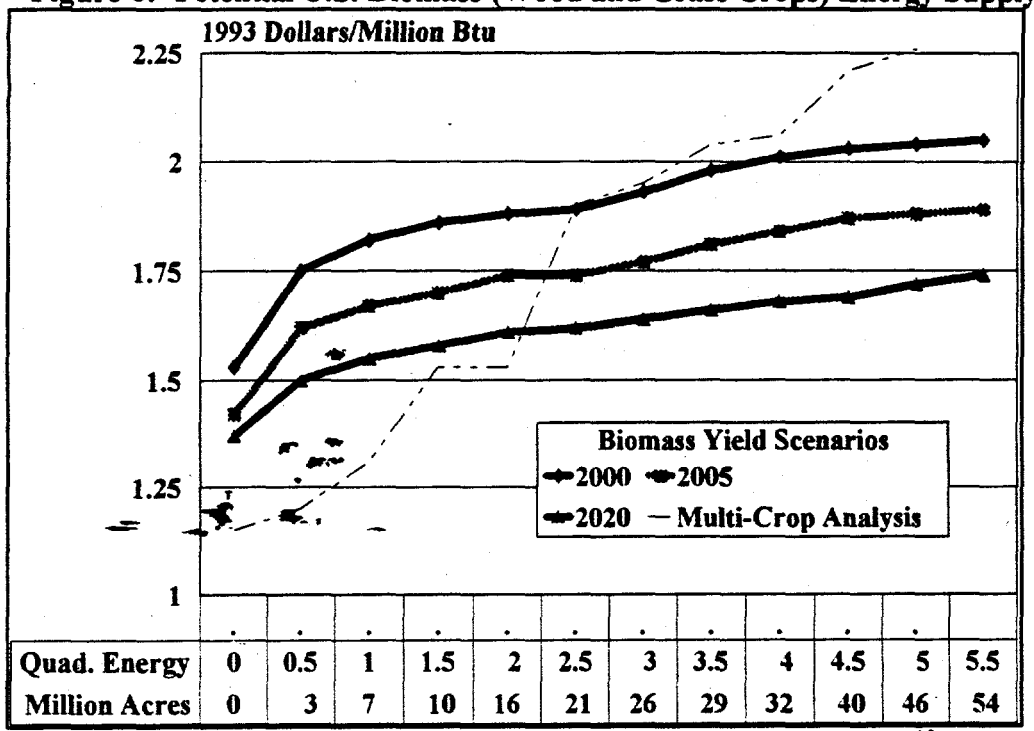
Figure 5: Potential U.S. Wood Crop Supply Prices, Acreages, and Quantities



Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons -2000	0	28	47	62	80	92	107	149	166	186	213
Million Tons -2005	0	37	70	99	128	149	190	224	253	272	287
Million Tons - 2020	0	46	83	139	180	235	261	288	330	350	380

Assuming wood and grass crops contain 16.5 and 14.5 million Btu of energy per dry ton, respectively, the tonnage and prices shown above (with transport costs added) were converted to energy units. Ranking the data for about 50 million acres by energy prices and cumulating the energy content gives the national biomass supply in Figure 6.

Figure 6: Potential U.S. Biomass (Wood and Grass Crops) Energy Supply



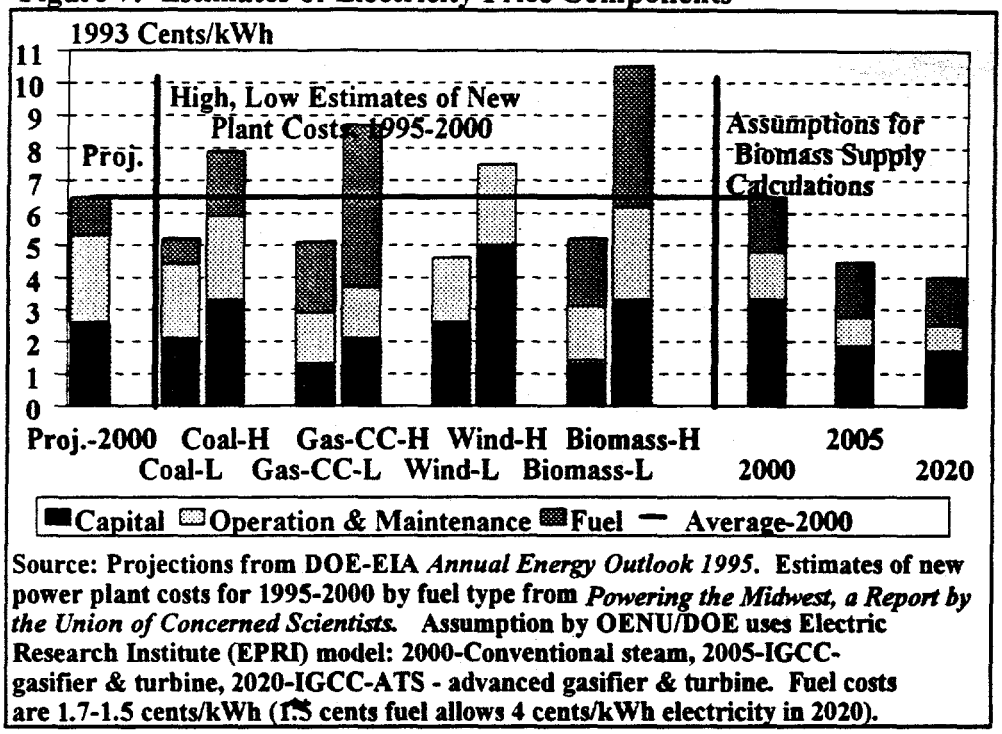
Quad. Energy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Million Acres	0	3	7	10	16	21	26	29	32	40	46	54

Note: Btu ≡ British thermal unit of energy. One Quad. of energy ≡ 10^{15} Btu.
As a point of reference, the U.S. consumed about 80 Quad. of energy in 1988.

The steeper (dashed) line in Figure 6 shows an alternative biomass supply estimate by McCarl using a multi-crop model (Adams, et. al.) for 2020. At lower prices, the McCarl analysis includes waste wood. As the biomass acreage climbs above 30 million acres and biomass crops compete with existing ones, the multi-crop methodology suggests that higher prices would be needed to cause biomass to displace existing crop production.

Regardless of the estimated biomass supply in energy terms, additional assumptions about technology are required if biomass is to be evaluated exclusively for use as a fuel for electric power generation. Figure 7 summarizes some technical cost assumptions as three components of electricity prices. DOE and Electric Power Research Institute (EPRI) electric power cost assumptions for the three scenarios are shown at the right and are compared to other estimates using various energy sources, including biomass. Lower cost estimates in 2005 and 2020 basically assume greater cost and production efficiency using new generation gassification-gas turbine systems to convert biomass to electricity.

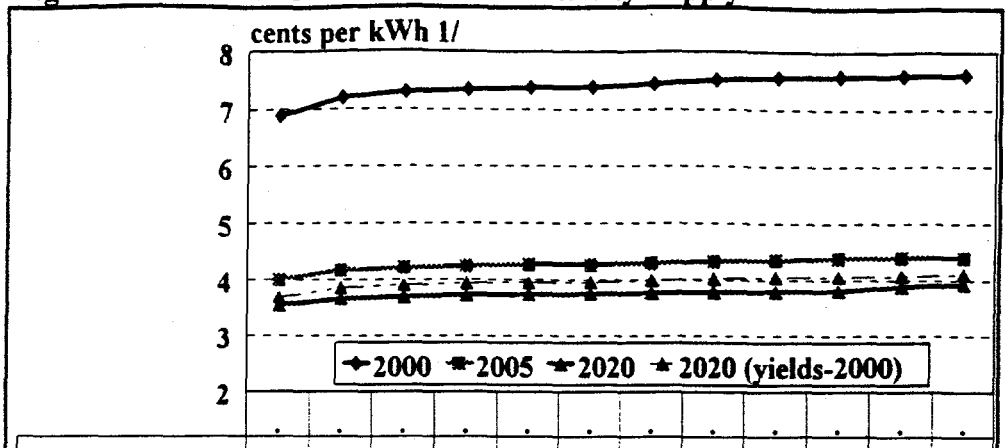
Figure 7: Estimates of Electricity Price Components



Source: Projections from DOE-EIA *Annual Energy Outlook 1995*. Estimates of new power plant costs for 1995-2000 by fuel type from *Powering the Midwest, a Report by the Union of Concerned Scientists*. Assumption by OENU/DOE uses Electric Research Institute (EPRI) model: 2000-Conventional steam, 2005-IGCC-gasifier & turbine, 2020-IGCC-ATS - advanced gasifier & turbine. Fuel costs are 1.7-1.5 cents/kWh (1.5 cents fuel allows 4 cents/kWh electricity in 2020).

Since capital and operation and maintenance costs make up over half of the electricity price, their reduction with new technology is crucial to the attainment of a 4 cents per kWh biomass based electricity price that is thought to be competitive with power production from other fuels in 2020 such as coal and natural gas. The power cost assumptions in Figure 7 are combined with the biomass energy supply estimates in Figure 6 to produce the potential biomass-based electricity supply for the three scenarios in Figure 8. An additional alternative scenario for 2020 assuming yields from 2000 gives electricity price estimates only 0.2 cents per kWh higher on average. Therefore the required cost reduction for competitive electricity production in 2020 in Figure 8 comes almost entirely from the new lower-cost electricity generation technology. If these cost assumptions hold true and if biomass production does not crowd out existing crops, then up to 50 million acres of competitive biomass crops might exist in the future.

Figure 8: Potential Biomass Based Electricity Supply

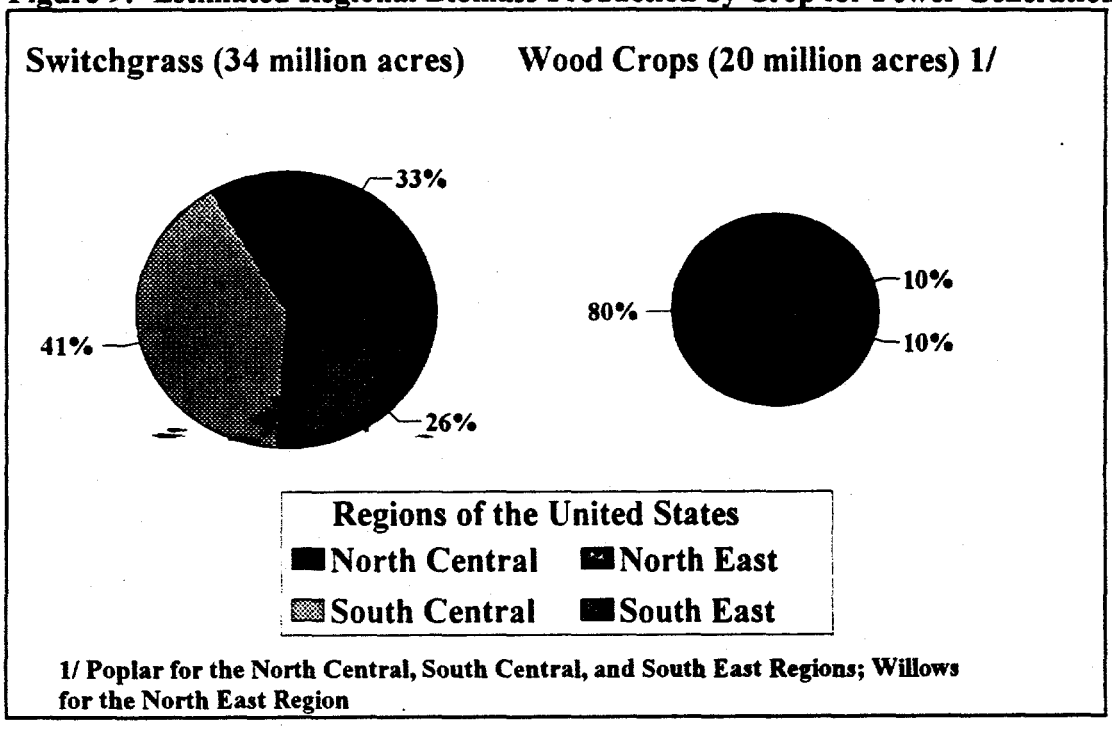


Quad. Energy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Million Acres	0	3	7	10	16	21	26	29	32	40	46	54
Billion kWh-2000	0	36	73	109	145	181	218	254	290	327	363	399
Billion kWh-2005	0	57	115	172	230	287	345	402	460	517	575	632
Billion kWh-2020	0	65	130	195	260	325	390	455	519	584	649	714

1/ Scenarios include fuel, capital, operating & maintainence costs:
2000 - (1.7, 3,31, 1,48); 2005 - (1.6, 1.86, .90); 2020 - (1.5, 1.70, .80)

These calculations and underlying assumptions lead to a distribution of biomass supply by region and crop shown in Figure 9. Willows could become a major wood crop in the North East while switchgrass could be a major biomass crop in the other regions. Low cost power technology and improved feedstock production systems are keys to this future.

Figure 9: Estimated Regional Biomass Production by Crop for Power Generation



1/ Poplar for the North Central, South Central, and South East Regions; Willows for the North East Region

To summarize, biomass crops could become feedstocks for industrial uses, given optimistic assumptions about the success of research programs for production and utilization. The successful development of a new generation of efficient power generation technology could make biomass generated electricity a reality. Some low cost biomass production and biomass wastes such as wood, make a niche biomass power market possible now. Successful biomass research programs, rising fossil fuel prices, and/or biomass incentive policies could expand the biomass industry. However, the optimistic U.S. biomass scenarios assume that improved production, harvesting, delivery, and utilization systems implied by crop budgets and power/utilization cost estimates are in place. Much hard engineering, organizational, and research work will be required to demonstrate the workability of these systems. Future biomass farmers and processors need to see practical and successful demonstration projects on the ground that before they begin to participate on a large scale.

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