A Market Development Plan for a Bio-based Processing Industry

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A Market Development Plan for a Bio-based Processing Industry

Abstract
The prospects for making industrial products from agricultural materials hinge on bio-processors' ability to produce at lower cost than petroleum processors and gain market share. There are several reasons to expect strengthening competition from the agricultural processing sector. First, petroleum inputs have had a price advantage over agricultural inputs for more than a century. But this advantage may be coming to an end; Corn was seven times more expensive than petroleum on a pound basis at the turn of the century and again during World War II. However, the relative price of corn has steadily fallen throughout the post war period as food demands grew slowly while petroleum demands expanded with the industrial economy. The relative price of corn has how fallen to the lowest level since the civil war (Figure 1).

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A Market Development Plan for a Bio-based Processing Industry

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INTRODUCTION

The prospects for making industrial products from agricultural materials hinge on bio-processors' ability to produce at lower cost than petroleum processors and gain market share. There are several reasons to expect strengthening competition from the agricultural processing sector:

First, petroleum inputs have had a price advantage over agricultural inputs for more than a century. But this advantage may be coming to an end. Corn was seven times more expensive than petroleum on a pound basis at the turn of the century and again during World War II. However, the relative price of corn has steadily fallen throughout the post-war period, as food demands grew slowly while petroleum demands expanded with the industrial economy. The relative price of corn has now fallen to the lowest levels since the civil war (Figure 1).

Second, current and prospective technology improvements show potential for processing yield increases. For instance, recombinant organisms may increase concentrations and yields of fermentations that can reduce processing costs. Further, new ligno-cellulose conversion technology may provide higher-value uses for biomass such as wood chips and crop residues.

Third, bio-processors can benefit from the learning curve. An estimate made during the expansion of petrochemical processing industry in the fifties and sixties suggests that costs fell eighty percent when cumulative output doubled (Leibermann). In bio-processing, some cost reductions are already occurring (Hohmann and Rendleman).
Some bio-based products have improved environmental properties, owing to differences in the chemical structure of petroleum and crops (Morris and Ahmed). Inorganic chemicals in petroleum, such as nitrogen and sulfur, are sometimes released into the environment during processing or use, which can cause pollution. In contrast, the oxygen in bio-fuels, for example, can lead to more complete combustion. The quality advantage for bio-based products can take several forms: reduced organic solvent evaporation from paint, degradable soaps and plastic bags, and clean fuel. Increasingly, governments require that externalities be taken into account in the marketplace. European manufacturers now have an incentive to use “clean” materials, for instance, because they are responsible for recycling many of their products. In the United States, standards are adjusted to ensure desired product performance. Recycling incentives and standards both can lead to a price premium for bio-based products. So, market share may be increased with new products that have improved environmental properties. Finally, a bio-based industry is sustainable, based upon recycling carbon dioxide and water, and utilizing energy from the sun.

Overall, the price prospects look encouraging as economic analysts consistently project increasing real prices of petroleum products and declining real prices of agricultural materials. There are risks, however, as strategic reductions in petroleum prices are a possibility (OPEC Bulletin). Yet there is some up-side uncertainty to this investment, as market-growth prospects may be linked to stricter environmental regulations and an increased public desire for a sustainable future.
In this paper, we review business and public sector activities that will encourage the development of a bio-processing industry that uses agricultural materials. First, a production and investment plan that is suitable for a profit-minded business sector is proposed; actual and impending cost advantages for major chemicals are identified. Next, market effects of implementing the capacity expansion plan are considered; on-farm income and government programs; on U.S. energy costs and imports. Finally, public research support to facilitate processing and efficient market interventions are discussed.

BUSINESS PLAN

The business plan for expanding production of bio-based chemicals has an intermediate-run component that is based on glucose conversion. This investment could begin immediately and be active during the next five years because some important technologies are now moving past demonstration. With a significant research commitment, breakthrough technology in recovery processes, the significant impediment to many bio-processes, could make them economically viable. The investments in this first phase are mostly expansions of existing processing facilities. However, new facilities with attendant new jobs would be necessary to significantly expand the glucose conversion industry. A second phase of the investment is based on conversion of cellulose materials such as cornstalks or wood chips into ethanol. This technology is just now entering the demonstration phase, so investment will not begin for five years. The investments in the second phase will be new facilities and new business enterprises.
The specific chemicals chosen for expansion are based on technology, market characteristics, and potential cost of production. Technical problems and research needs are reviewed; potential market demand is considered; cost estimates and projections for a few key commodities are included in subsequent discussions.

A. Glucose conversion

The selected products from the glucose-conversion sector are diversified across uses and some have potential environmental benefits (Table 1). The dominant chemical is styrene, which is used mainly to produce plastic disposable articles such as cups, plates, and forks. Lactic acid polyester can functionally displace polystyrene and some related plastics, with the added feature of controlled degradability. Several solvents, such as butanol, acetone and isopropanol are also included.

The technology situation varies among these products. Lactic acid production is being demonstrated (Archer Daniels Midland, Decatur, IL) and Cargill (Minneapolis, MN) recently started-up a lactic acid polyester pilot plant. The acetic acid biochemical process needs improved recovery technology or concentration improvement. Acetone and butanol production, while favorable stoichiometrically, will require yield and recovery improvements. Concerted research is required to make these processes economically feasible.

Several economic factors influence technology adoption and cost competition between a bio-chemical and a petro-chemical in general. The average cost of a processing firm (ATC) is the sum of plant operation expenditure, a capital replacement allowance and (petroleum or bio-based) material expenses. All cost components can be
expressed per unit processed and then divided by the yield of the industrial product that is obtained from a unit of the material input. Marginal cost includes plant operation and materials. Marginal cost and (average) variable cost are the same in the case of linear processing technology.

Equilibrium in a competitive market occurs when producers recover variable costs \( (c_v) \) and fixed costs that include a normal return on capital \( (c_f) \); firm entry ceases at this point because capital seeks extra-normal returns in other industries.

Suppose that a process becomes available with variable and fixed costs of \( c_v^* \) and \( c_f^* \), respectively. There are three outcomes in the technology competition. First, the new technology is not competitive and will not be adopted if the average total cost (sum of fixed and variable cost) with the new technology \( (ATC^*) \) exceeds average total cost \( (ATC) \) with the old technology. The other extreme occurs when \( ATC^* \) is below variable costs of the old technique; the old plants are shut-down immediately because variable costs cannot be covered. Some adjustment time is required even with the presence of strong profit signals. For instance, the mid-seventies expansion of the high fructose corn syrup processing sector occurred over a five-year period following the development of glucose conversion technology (Carmen).

An intermediate case is probably most common (Figure 1). When \( ATC^* \) is between \( ATC \) and \( c_v \), producers with the new technology cannot force old-technology producers to cease operations by undercutting their price. However, the new technology will now be adapted at replacement time because old technology can no longer earn a normal return \( (Salter) \). In this case the rate of technology adoption should reflect the age distribution of
the old technology. For instance, if plants last 15 years and the age distribution is uniform, 1/15 of the production capacity would be replaced by the new technology each year.

Now consider the prospects for adopting the styrene process. The cost comparison for lactic acid and styrene are given in Table 2. The styrene data are taken from the 1994 SRI report. Lactic acid data are taken from HRA (1991). Some modifications were made to the data. First, the glucose input cost for lactic acid was obtained from a model of the corn milling industry (Landucci et al.), and adjusted for 1994 material costs and co-product returns. Capital costs for both processes were adjusted down to a 10% annual rate of interest, reflecting recent alternative returns on investments. Projected variable costs in the year 2005 are also shown. These estimates reflect changing petroleum and corn prices. The petroleum price assumption; $20/bbl is conservative, reflecting entry points for alternative fuels (OPEC Bulletin). Other projections, such as the World Bank’s, reach $25/bbl. The corn price projection of $2.43 in 2005 is taken by a recent study by the Food and Ag Policy Research Institute (FAPRI 1993).

According to the estimates, lactic acid is not presently competitive because the average total cost ($.27/lb) is higher than the corresponding cost for styrene ($.21/lb). However, the adoption phase may be near due to the improving oil-crop price ratio. Projections suggest that lactic acid costs could reach the threshold of the immediate shutdown phase in about ten years; average total costs for lactic acid will be $.28/lb while styrene variable costs will be $.29/lb. Until then, it would be reasonable to expect that lactic acid gets replacement investment of styrene capacity, say 1/15 of the existing production.
B. Cellulose-ethanol processing

Cellulose-to-ethanol conversion has been possible for some time. However, recent advances also make hemicellulose conversion possible. Thus, an additional one-third of material in wood or corn residues can now be converted. In turn, the potential for yield increase and cost reduction is greatly enhanced. The new technology, utilizing simultaneous saccharification and fermentation (SSF) with a recombinant organism that rapidly ferments both cellulose- and hemicellulose-derived sugars, is just entering the demonstration phase. So, five years will pass before high expectations are confirmed or discarded.

Presently, ethanol occupies a niche in the fuel market. It is mixed in the oxygenated fuels that the EPA requires in urban areas with smog problems. But ethanol is not widely used as a fuel, owing to high production costs with either synthetic or fermentation-based technology. Nonetheless, access to the commodity fuel market is a good possibility with the new cellulose conversion technology. In particular, a recent study suggests that ethanol could have a price comparable to the wholesale gasoline price by processing wood-chips in a large plant (U.S. Dept. of Energy). Ethylene production from ethanol should also be competitive if present estimates of ethanol production costs are accurate. Thus, the largest commodity chemical market will also be accessible.

Now return to the list of target chemicals for the business expansion plan, which are shown in Table 1. The ethanol-based chemicals include ethylene and butadiene. Butadiene is an intermediate chemical that is used in synthetic rubber production. Ethylene is the dominant chemical for plastic manufacturing. The production targets for
bio-based processing include the entire 1993 production of butadiene. A 10% market share of ethylene production is the capacity expansion target because subsequent cost analysis suggests that bio-based processing will be on the competitive margin with the petroleum-based methods. It is assumed that the remaining ethanol supply will be used in the commodity fuel market:

1. Cornstalk-ethanol cost and supply analysis

Midwestern cornstalks are technically suitable as a feedstock in the ligno-cellulosics-ethanol process. Indeed, stover may be a low-valued input that is well-suited to the midwest. Thus, the DOE cost study is now adapted to a corn-stover-based process. The analysis requires several phases: the midwest supply of corn residue; processing yield and material flow adjustments that affect the processing costs; the potential role of transport costs as a limiting factor on the location of a large plant. Each of these factors is considered below.

a. Corn Stover-Supply

Generally, a supply curve identifies the amount of a resource that is available in the market at a given price. In turn, a supply curve is defined by the value of the resource in the best alternative use. The supply price for a new crop is typically given by processing costs (planting, care, harvesting) plus an allowance for land rent — land rent represents the value of the land when it is used in the production of another crop. However, the supply price for cornstalks may be lower than the supply price of a new crop, at least for some
levels of use. It is not necessary to recover land costs that have already been taken into account in corn profit calculations and output decisions.

Presently, the economic value of cornstalks (stover) arises from two sources. First, erosion levels and fertilizer requirements are both reduced when cornstalks are left on the ground. Second, cornstalks provide a low-grade hay when fed to cows. As a first approximation then, the stover supply curve facing ethanol processors in a region is a step function (Figure 3). Initially, it is horizontal at net-harvest cost; processing plants in well-chosen locations in cash-grain areas could acquire stover that is not used by livestock producers at slightly above harvest cost. The second step of the supply function is defined by the higher value that livestock producers are willing to pay when using stover as a feed.

All available stover supplies would be diverted to industrial uses if processors are willing to pay slightly more than the livestock value. The stover supply is vertical at the point where all available supplies are used by industry, provided that the amount of land planted to corn is given.

Estimates for opportunity costs of corn stalk use determine the height of steps in the corn stalk supply curve. Net harvest cost estimates of Table 3 include harvest expenses and fertilizer replacement costs. The harvesting costs are approximated harvesting costs of hay, including fixed machinery replacement costs and variable operation costs. Further, the costs are calculated using a stover tonnage actually harvested that includes an amount left on the field for conservation compliance. The fertilizer cost estimate is based on replacement of the phosphorous and potassium (Claar et al.).
fertilizer replacement, and 30% residue left on the field for conservation compliance gives a stover net harvest cost of $16.5/ton (Table 3).  

Similarly, the feed value of hay can be calculated using some adjustments for total digestible nutrients and protein deficiencies of cornstalks in comparison to hay (Stroben and Ayres). Stover's value as a feed can be calculated from the 1994 hay price at about $35/ton.

The volume of cornstalks that would be available to the processing industry can be approximated using estimates of available cornstalks, cattle populations and forage requirements, and the availability of hay for forage. Specifically, the total stover supply estimate is given by state Table 4. Calculations (not shown) involved multiplying a state's corn area by a stover yield estimate that leaves an allowance for compliance with the conservation reserve program. Similarly, the cattle feed demand estimate in column 2 is the product of cattle population and forage requirement per animal, less hay supply for each state. In turn, the industry supply of column 3 is the supply less feed demand -- about 125 billion lbs would be available at low prices near harvest cost. At prices above the feed price, the entire stover supply of about 200 billion lbs would be available to the processing industry.

A significant share of the U.S. gasoline supply could be provided by ethanol processing from cornstalks. To see this, convert the corn stalk supply to ethanol output as follows:

\[
\frac{203.25 \text{ billion lbs stover} \times 0.3975 \text{ lb ethanol}}{1 \text{ lb stover}} \times \frac{1 \text{ gal ethanol}}{6.6 \text{ lb ethanol}} = 12.24 \text{ billion gal.}
\]
Further, the U.S. gasoline supply for 1994 was 111.0 bil gallon. Hence, ethanol could provide about 11% of the U.S. fuel consumption. Even larger stover supplies and ethanol production are a possibility, if market stover prices encourage farmers to plant more corn.

b. Transportation costs

A large processing plant exploits economies of scale but requires vast amounts of cornstalks (2.903 million tons for a 350 million gallon/year plant). It is estimated that the large plant must use all available cornstalks in a circle within a 50 mile radius, given average corn density in Iowa. The details of these calculations are given in Appendix A. But the basic idea is that the cost of corn stover delivered to the plant increases as the distance from the plant increases. Specifically, the average input cost can be calculated from the formula

\[ AIC = P_0 + 2 \cdot r \cdot t/3 \]

where \( P_0 \) is the harvest cost, \( r \) is the radial distance from the plant, in miles, and \( t \) is the transportation cost, in \$/ton/mile.

Recent quotations from Iowa trucking firms indicate that the transportation rate is between $.1/ton/mile and $.15/ton/mile for short distances. Hence the average cost of all stover drawn from within 50 miles is between $19.8/ton and $21.5/ton. The lower stover cost estimate is used in the processing cost study because the routine of a large plant could reduce the short-haul rate. Beyond that, there may be some offsetting bias in these calculations; on the one hand, distance is measured as the crow flies instead of on a particular road network – it may be understated. On the other hand, the average corn density may understate availability at the sub-state levels because it combines low density
from the cattle grazing areas of the south with high density in the cash-grain areas of the north. Well-chosen plant locations would probably be in cash grain areas, where stover could be acquired near harvest costs. In any event, these calculations suggest that transport costs are not a major barrier to operation of large scale plant.

c. Processing costs

The DOE study is the reference point for cost estimates on cornstalk processing. However, several adjustments were required. In particular, ligno-cellulose content of corn stover is only one-half of that for wood chips, so the one-half of electrical plant capacity that was sold as a byproduct credit is removed. Also, the 10% gasoline mixing operation was eliminated so that estimates now refer to a pure ethanol basis. Regarding financial matters, the capital allowance was calculated at a 10% return and 15 year amortization period. Also, input price and capital outlays were updated to a 1993 basis. Finally, cornstalk harvesting costs of Table 3 are used for feedstock costs. But adjustments for stover transport costs from Appendix A are also included; the average input cost estimate for stover is slightly less than the DOE's woodchip cost estimate. The revised material flows and cost estimates are shown in Table 5.

The bottom line is an overall production cost for ethanol of $.46/gal. Ethanol production at this cost would be competitive with gasoline, without subsidies.

d. Overall cost evaluation
A fully developed ethanol processing technology based on corn stover could compete in today's market and displace some petrochemical products. Supporting cost comparisons are given in Table 6. First, petro-based ethanol would shut down, as the variable costs exceed total costs of the cellulose process. Grain-based production of ethanol would probably also cease, according to a variable-cost estimate (Katsen). So, ethanol supplies up to the amount defined by midwestern corn stalk supplies could be produced. Further, ethanol's production costs using corn stalks are below the price of gasoline.

As of 1993, petroleum-based ethylene still has a cost advantage over ethylene produced from corn stalks and ethanol; total costs are $0.10/lb from petroleum and $0.14/lb from stover. However, the cost advantage could erode with rising petroleum prices; petro-ethylene costs will be $0.14/lb by 2005 while bio-ethylene costs will remain stable, according to our projections. Further, the production cost from petroleum is highly variable, owing to variability in the by-product revenues; over the 1978-1993 period the standard deviation of average total costs in the petro-process was $0.06/lb (Figure 3).

Hence, bio-based ethylene is moving onto the margin of competition. Petro-chemical processors will not all leave the market but bio-processors should be able to establish a respectable market share. Furthermore, the fixed costs will be low ($0.01/lb) in a large-scale operation that already processes ethanol. Consequently, periods of inactivity during adverse market conditions would have manageable costs. Before new ligno-cellulose conversion technology was on the horizon, the ethylene market was considered inaccessible (Lipinsky).
C. A capacity adjustment schedule

Consideration of cost advantages and production barriers lead to a schedule for expanding production of target chemicals. The production schedule given below is useful for identifying research needs, investment requirements and raw material demands.

The target chemicals are classified according to the anticipated rate of adoption and the start of the adoption period in Table 1. The rate of adoption estimate is based on the cost advantage; rapid adoption of a new technology (say 5 years) will occur when the cost advantage points towards shut-down of petro-processing. Slow adoption will occur when the bioprocessing costs preclude new petro-investment without displacing existing capacity. The starting point for process adoption is defined by technical production barriers, such as low yields or incompletely understood chemical processes.

Consider the glucose conversion sector. There will be delays in the adoption of some chemicals. For instance, a five year delay is required for new chemistry that would permit acetone production. But some of the other chemicals are ready now. It is assumed that all market-ready chemicals follow the adoption rate of lactic acid. That is, 1/15 of capacity is moved into the bio-processing sector each year, as lactic acid is a better investment than styrene.

In the ligno-cellulose-processing sector, no production occurs until after five years, as we await the completion of successful demonstration. Afterwards, rapid displacement of synthetic and corn-based ethanol will occur due to cost advantages. Cellulose-based ethanol, priced at cost in a competitive market will be available in sufficient volume to eliminate the quota rents created by oxygenated fuel mixing regulations. In contrast, slow
Adoption is assumed in the other commodity markets. A 10% share of the ethylene market is consistent with the status of cost competition. Ethanol supplies for the fuel market are defined by the midwest corn stover supply, less allocations for ethylene and butadiene. Ultimately a market demand and price study should be conducted to determine suitable allocations to ethanol, ethylene and gasoline markets. Further a more thorough analysis of alternative feedstocks for cellulose conversion is still needed.

Estimates of anticipated production adjustments for every chemical in the production plan of Table 1 are given in Appendix D.

ADJUSTMENTS IN RESOURCE USE

In turn, the capacity adjustments for chemicals places changing demands on particular resources; product yields define resource adjustments for corn, grain, stover, and petroleum. A summary of estimates for adjustments in demands is given in Table 7. Examination suggests that the development of a bio-processing sector reorients the resource markets towards renewable agricultural resources and away from the fixed petroleum resource. Contraction of the petroleum processing sector should help offset our dependence on imported oil. Expansion of the bio-processing sector should create new demands for underutilized resources.

The oil demand reduction would be about 150 mil barrels after ten years of adjustment and 350 mil bbl at the end of the 20 year adjustment period from the last column of Table 7. The projected demand reduction compares favorably to the World Bank projection that U.S. oil imports will increase by 770 mil bbl (105 million tons) during
the next decade. The cornstalk-based sector could stem one-fifth of the increase even at
the conservative adjustment rate assumed in capacity expansions. More rapid
development of the cornstalk sector, or the development of other ligno-cellulose
feedstocks, such as wood residues, could offset projected oil import increases even further.

The estimated adjustments for corn reflect several effects. First, there is an
expanding corn demand associated with chemicals and solvents. Next, expanding stover
processing of ethanol begins in year 6. In turn, the expansion of the new ethanol
technology displaces the older corn-using technology and reduces the demand for corn.
Hence, the estimate for corn demand adjustment is cyclical, expanding to about 250 mil
bushels during the first five years, then declining towards zero, and ultimately expanding
to about 420 million bushels by the end of the 20-year adjustment period. The ultimate
corn demand expansion of 420 million bushels compares favorably to the growth in corn
exports to the centrally planned economies during the 70’s.

Cellulose conversion creates a new market for a resource. Even during the
downward phase of the corn demand cycle then; the overall resource demand for corn
producers should remain stable, as stover demand increases offset corn demand
reductions.

SOCIAL BENEFITS AND COSTS

Consumers will be the ultimate beneficiaries in the upcoming competition between
petroleum processing and biological processing because they will pay lower prices for
plastics, solvents and fuel. There are also gains and losses in the raw-material-using
sectors. The agricultural-demand expansion allows us to remove some idle land from government programs, which should make it possible to reduce government commodity program payments. Similarly, a cornstalk-based ethanol sector creates value with a new use for an underutilized resource. In the petro-processing subsector, the picture is mixed because consumer gains and producer losses from lower prices are offsetting. Below we elaborate on the magnitude and nature of these benefits and costs.

Commodity programs

U.S. commodity programs jointly offer a producer subsidy equal to the difference between a government-set target price and require producers to set aside a fraction of their cropland in order to qualify for subsidy payments. The government can manage supplies for stable farm income and reduced government expenditures by reducing the target price and set-aside rate during a period of expanding demand. If the demand expansion is slightly larger than the supply increase, the market price rises. Then government subsidy obligations reduce because the spread between the target and market prices shrinks and fewer producers participate. Farm income remains stable as producers substitute market receipts for government program payments.

The estimates of Table 8 are based on analyses of the corn market. Specifically, foreign adjustments to changing market conditions are taken from Westhoff et al. Producer response to program provisions are given by Adams. Further, period-0 prices and policy conditions are taken from existing policy and normal market conditions.
The estimates suggest that implementing the chemical production schedule can contribute to a resolution of the corn sector's surplus problem. During the first seven years of the adjustment schedule, production expands and government payments are cut in half. A reversal would be required when the contraction in corn-based ethanol offsets other expansions; there would be little change in production, farm income, or government programs during this period. But over the entire 20-year period, government payments could be reduced drastically with stable farm income. Government programs could still be present if farm income maintenance is a requirement. However, other sources of demand growth, such as expanding trade, might also mitigate the need for farm programs.

B. Derived demand and factor returns for cornstalks

If the new cellulose-conversion technology develops, the energy market will create a third source of value for cornstalks. As a first approximation, suppose that ethanol substitutes freely for gasoline in the large world market. Then the residual demand for cornstalks is the gasoline price less non-feedstock processing costs, which is expressed as a value per unit of cornstalks. The horizontal line (D_e) in sidebar #2 indicates a perfectly elastic demand for stover from the large energy market.

Using 1994 data for wholesale gasoline prices, stover-ethanol processing costs and ethanol yield, an estimate of the demand-price for stover can be calculated. The details of these calculations are as follows. First, subtract the stover processing costs from the wholesale gasoline price ($0.60/gal - $0.300/gal). The residual value for stover is $0.30/gal. This residual value is the maximum amount that the processor is willing to pay for the input.
Next apply the stover-ethanol yield (see Appendix B) to obtain the processors' maximum bid for stover:

\[
\$0.30 \times 1 \text{ gal ethanol} = \$0.30/\text{gal ethanol} \\
0.0083 \text{ tons stover/ton stover}
\]

The estimate of \(\$36/\text{ton}\) is slightly higher than the livestock value of stover, suggesting that the energy market can bid stover away from livestock uses.

To calculate net economic benefit from this new technology, notice the demand curve, \(D_e\) in 3. The height of this demand curve indicates processor net returns from processing the last unit of input. Meanwhile, the height of the supply curve indicates the opportunity cost of using the next unit. So the net benefit for one unit of the input is the vertical difference between demand and the supply curve. Adding up gives the areas \(U\) plus \(L\) as measures of returns over harvest cost and returns over livestock opportunities foregone. The details of benefit calculations are in Appendix C. An annual return of \(\$1.2\) billion is indicated for the fully developed technology. This estimate may be conservative, since it is based on the soft energy market conditions and gasoline prices of 1994.

The benefit would accrue entirely to resource (stover) owners if the processing market were perfectly competitive. In the real world, there are locational advantages that would accrue to processors. So one would expect this benefit to be split between the two groups.

Finally, it is a straightforward matter to calculate the number of large plants required and the initial corresponding investment. The estimate of initial investment is \(\$12.2\) bil, which is about a 10% annual return on investment.
There are reasons for caution in interpreting potential returns and income. First, the technology has not been verified yet. Second, even if it is, the costs and returns are in the distant future and often receive heavy discounting in financial reasoning. Finally, the market price adjustments associated with alternative feedstocks, such as wood chips, and reduced fuel prices would be associated with a new fuel source have not been taken into account.

C. Petroleum

The processing displacement in petroleum may be large enough to change market conditions. Specifically, the oil equivalent supply associated with cornstalks and corn grain was calculated at 105,104 million pounds at the end of the 20 year adjustment period. The oil equivalent of the new supply (349 million barrels) is about 6% of U.S. petroleum consumption.

Some approximations for market effects and benefits are presented in Table 9. These estimates are based on the review of petroleum market elasticities and oil extraction cost functions provided by Yücell. Yücell's assumption that OPEC follows oligopoly pricing is also retained. But the estimates are based on linear demand. Also, single period oligopoly pricing that conforms to the actual 1992 pricing and exports defines OPEC behavior in the present simulations.

The estimates indicate a reduction in U.S. petroleum prices of about $0.8/bbl. The presence of new bio-fuel supplies (reduced processing demand for petroleum) causes this downward price pressure. In response, fuel and chemical processors expand consumption
of the sum of petroleum and bio-based inputs. Also, OPEC reduces the amount it supplies to the U.S. market in response to downward price pressure.

From the surplus estimates, fuel and chemical processors and consumers in the United States are beneficiaries; the consumer surplus estimate for the petroleum market is about $5.0 bil. In contrast, the U.S. suppliers of petroleum would experience a decline in profits as the excess of revenues over extraction cost falls—the profit reduction estimate is about $3.2 bil. Nonetheless, there is an overall U.S. gain, as consumer surplus exceeds the profit loss by $1.7 bil.

D. Overall net benefit for the United States

There are three main benefits associated with the investment in the bio-processing sector. At the end of the 20 year adjustment period, reduced commodity program payments are on the order of $4 bil. Additionally, the increased returns to cornstalk owners would be about $1.2 bil. The net gain from the petroleum market is also about $1.7 bil.

Overall, the benefit analysis suggests that a fully developed bio-processing industry would contribute to national income in the United States, as the overall benefit is about $6.9 bil annually. However, these estimates should be viewed as preliminary—they are approximations that are based on readily available data and market response estimates.

RESEARCH AND POLICY

Private initiatives should guide most development in the bio-based processing sector. But some essential activities may not obtain the necessary emphasis in the private
sector. So there is a limited role for public-sector activity. For instance, research on the science underlying production processes or commercialization barriers is often conducted in the public sector; individual firms sometimes consider basic research to be high cost. Further, benefit recapture is sometimes limited by competition and incomplete patent protection. The private sector may also under-value returns that accrue in the distant future, especially when risk figures prominently in private-sector financial decisions:

Specific research for the bio-processing sector should develop:

1. Organisms that have been shown to ferment both C5 and C6 sugars to ethanol.
2. Organisms that efficiently utilize the C5 and C6 sugar syrups from lignocellulose to produce other target chemicals than ethanol, such as butanol, acetone, etc.
3. Organisms or enzymes that utilize ethanol as a substrate to produce the target chemicals.
4. Organisms that produce significantly increased product concentrations with high yield.
5. Processes to efficiently recover and isolate the target chemicals from the fermentation broths or enzymic process streams.

Cornstalks are a competitive feedstock in the ethanol process because the land-cost-recovery of energy crops in commercial agricultural areas is avoided. Accordingly, agronomic research for feedstocks should focus on residues, plant by-products and crops in marginal agricultural areas that have low land rents. Some specific projects include:

1. Evaluate the cost of alternative feedstocks, such as wood residues, and cornstalks in rotations that alternatively include and exclude residue harvest.
2. Investigate the technical feasibility of substituting grain and ligno-cellulose material through corn breeding. Economics research could improve our limited understanding of the potential for market growth, the technology development that would best exploit it, and government interventions, if any, that would facilitate private-sector activities.

For instance, studies of the major industrial product markets should be conducted. These studies should include statistical demand analysis, pricing studies, and patterns of import protection. Access to potential markets depends on the extent of competition and our ability to accommodate the changing demands associated with the business cycle. Also, the market and general equilibrium effects of new cellulose conversion technology should be studied.

A more controversial issue is whether the government should provide incentives to the bioprocessing sector and the particular form it should take. The main argument for public action stems from the risk of price reductions in the petroleum market. The policies that have been proposed are a capital subsidy and an input (corn) subsidy. This policy comparison deserves economic research for some important cases. However, some practical considerations may point towards the capital subsidy. Subsidies can become open-ended commitments that are difficult to terminate after the justification becomes obsolete. Experience also shows that commodity subsidies can be blunt instruments; they are often not limited to intended beneficiaries. In contrast, capital subsidies have a sunset defined by the debt on the plant. Further, targeting might be achieved with explicit risk reduction criteria.
Finally, wide fluctuations in production from year-to-year are characteristic of agricultural markets, even though there is enough production capacity for expansion of an industry that uses agricultural materials. It could be that food and industrial demands can co-exist in a harmonious fashion, with expansions in food demand occurring at the same time as contractions in industrial processing. But it is also conceivable that joint fluctuations in agricultural production and industrial demand could at times magnify price changes. This is a researchable issue in economics that deserves some attention.
REFERENCES


Stanford Research Institute International PEP Yearbook, PEP Report 33C: (Section 8) SHW, 1993.


Footnotes

1. Reported cost data on bio-processes are adjusted for uniformity and for comparisons that indicate decisionmakers' tradeoffs. The cost data also conform to procedures of Donaldson and Culberson, facilitating comparison to petrochemical processes. In particular, variable costs include materials and utilities. Labor costs are also included when available. Fixed costs are limited to capital costs, which are calculated as the annual payment on a 15 year, 10% interest, fixed annual payment mortgage on the entire plant cost. Other expenditures are excluded from fixed costs; overhead is excluded because there is no opportunity cost; insurance reflects a decision to offset risks of the profit stream—it should be considered elsewhere. In principle, expenses such as labor for plant maintenance or taxes on the plant could be included, but individual situations vary and data was not uniformly available.

Cost data for some petrochemical processes (styrene, ethylene, ethanol) are developed using Donaldson and Culberson's estimates of input requirements, yields, and plant costs. First, input requirements are combined with recent price data for an estimate of material and utility expenditure. Then capital expenditure data are updated with a price index for plant and equipment, and annual payment is given for a 15 year mortgage.

2. Consumers benefit by the amount they are willing to pay for the price reduction. In practice, the change in consumer surplus is taken as an approximation to the change in willingness to pay. In turn, consumer surplus is calculated as the area below the demand curve and above the price line.

3. Production costs for several energy feedstocks in a Midwest location are reported by Hallam and Colletti on p. 173. These cost estimates are at least three times the harvest cost for cornstalks.

4. Donaldson and Culberson report data for an ethylene plant that has a 44 million lb. capacity (p. 106), which gives a fixed cost of $0.035/lb for estimated capital costs in 1994. The fixed cost estimate of Table 3 is $0.009/lb, which applies to a 1.3 bil lb capacity ethylene plant that matches the ethanol capacity of 350 mil gallon from Table 5. The fixed cost estimate for the large plant is based on Donaldson and Culberson and the "0.6 factor rule" (Johnston). To wit, when the capacity output for a plant increases (from \( q_s \) to \( q_e \)), the capital cost increase (from \( c_s \) to \( c_e \)) is less than proportionate at
\[
\frac{c_e}{c_s} = \left( \frac{q_e}{q_s} \right)^{0.6}.
\]
Table 1. Some target chemicals, prospects for adoption, and capital requirements

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>acetic acid</td>
<td></td>
<td>3658</td>
<td>15 years</td>
<td>1350</td>
<td>378</td>
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<td>acetone</td>
<td></td>
<td>2462</td>
<td>5 years</td>
<td>1221</td>
<td>342</td>
<td></td>
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<tr>
<td>butanol</td>
<td></td>
<td>1328</td>
<td>15 years</td>
<td>1157</td>
<td>324</td>
<td></td>
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<tr>
<td>maleic anhydride</td>
<td></td>
<td>424</td>
<td>15 years</td>
<td></td>
<td>230</td>
<td>60</td>
</tr>
<tr>
<td>meth. eth. ketone</td>
<td></td>
<td>556</td>
<td>15 years</td>
<td>484</td>
<td>126</td>
<td></td>
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<tr>
<td>isopropanol</td>
<td></td>
<td>1236</td>
<td>15 years</td>
<td>1084</td>
<td>303</td>
<td></td>
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<tr>
<td>butanediol</td>
<td></td>
<td>200</td>
<td>15 years</td>
<td>196</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>adipic acid</td>
<td></td>
<td>760</td>
<td>15 years</td>
<td>230</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>styrene</td>
<td>[lactic acid]</td>
<td>10063</td>
<td>15 years</td>
<td>2208</td>
<td>882</td>
<td></td>
</tr>
</tbody>
</table>

Chemicals produced from glucose

Chemicals produced from cornstalks

<table>
<thead>
<tr>
<th>Ethanol</th>
<th></th>
<th>5 year</th>
<th>5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>glucose</td>
<td></td>
<td>7708</td>
<td></td>
</tr>
<tr>
<td>synthetic</td>
<td></td>
<td>1077</td>
<td></td>
</tr>
<tr>
<td>gasoline [ethanol]</td>
<td></td>
<td>777000</td>
<td>5 year</td>
</tr>
<tr>
<td>ethylene</td>
<td></td>
<td>41220</td>
<td>5 year</td>
</tr>
<tr>
<td>butadiene</td>
<td></td>
<td>3091</td>
<td>5 year</td>
</tr>
</tbody>
</table>
### Table 2. Production costs for styrene and lactic acid in 1993

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Year</th>
<th>Average variable costs ($/lb)</th>
<th>Average fixed costs in ($/lb)</th>
<th>Average total costs ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>styrene*</td>
<td>1993</td>
<td>0.18</td>
<td>0.03</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>0.29</td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>lactic acid*</td>
<td>1993</td>
<td>0.2</td>
<td>0.072</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>0.21</td>
<td></td>
<td>0.28</td>
</tr>
</tbody>
</table>

*Adapted from Donaldson and Culberson

*Adapted from HRA, Inc.
Table 3. Costs of corn stover harvest, 1993 data

<table>
<thead>
<tr>
<th>Operation</th>
<th>Fixed cost</th>
<th>Variable Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reported</td>
<td>per ton</td>
<td>Reported</td>
</tr>
<tr>
<td>Rake</td>
<td>$2.43/acre</td>
<td>$1.215/ton</td>
<td>$1.52/acre</td>
</tr>
<tr>
<td>Baler</td>
<td>$3.14/bale</td>
<td>$6.28/ton</td>
<td>$2.05/bale</td>
</tr>
<tr>
<td>Total direct:</td>
<td></td>
<td>7.495</td>
<td>4.86</td>
</tr>
<tr>
<td>a. assume 2 ton/acre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. assume 2 bales/ton</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Indirect fertilizer replacement costs

| Application rate | Price  |          | |
|------------------|--------|----------|
| p₂o₅ 13 lb/acre  | $150/ton | 0.075 | 0.4875 |
| k₂o 71 lb/acre  | $206/ton | 0.103 | 3.6565 |

Total indirect: 4.144

Total direct and indirect: $16.50/ton

Sources: Duffy and Judd
Claar et al.
Table 4. Corn stover: net supply available for industrial processing, 1993 data

<table>
<thead>
<tr>
<th>State</th>
<th>Stover supply (bil lb)</th>
<th>Stover feed demand (bil lb)</th>
<th>Low-cost supply (bil lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>42.91</td>
<td>4.34</td>
<td>38.57</td>
</tr>
<tr>
<td>IN</td>
<td>22</td>
<td>2.71</td>
<td>19.29</td>
</tr>
<tr>
<td>IA</td>
<td>48</td>
<td>16.63</td>
<td>31.37</td>
</tr>
<tr>
<td>KS</td>
<td>8.26</td>
<td>22.55</td>
<td>-14.29</td>
</tr>
<tr>
<td>KY</td>
<td>5.66</td>
<td>5.16</td>
<td>0.49</td>
</tr>
<tr>
<td>MN</td>
<td>16.15</td>
<td>3.18</td>
<td>12.97</td>
</tr>
<tr>
<td>MO</td>
<td>7.65</td>
<td>12.08</td>
<td>-4.43</td>
</tr>
<tr>
<td>NE</td>
<td>27.82</td>
<td>17.92</td>
<td>9.9</td>
</tr>
<tr>
<td>OH</td>
<td>13.39</td>
<td>0.07</td>
<td>13.32</td>
</tr>
<tr>
<td>SD</td>
<td>4.21</td>
<td>7.98</td>
<td>-3.77</td>
</tr>
<tr>
<td>WI</td>
<td>7.24</td>
<td>11.01</td>
<td>-3.78</td>
</tr>
</tbody>
</table>

Total supply (bil) 203.25 125.91

Total ethanol supply: 203.25 bil lbs stover x $\frac{0.3975 \text{ lb}}{1 \text{ gal}} \times \frac{1 \text{ gal}}{6.6 \text{ lb}} = 12.24 \text{ bil gallon}

U.S. gasoline supply: (1993) 111.0 bil gal

Ethanol's share of fuel market: 11.0%
Table 5. Production cost estimate for corn stover to ethanol plant

<table>
<thead>
<tr>
<th>Material</th>
<th>Units per gallon</th>
<th>1993 price</th>
<th>Unit expense ($/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood/stover, st</td>
<td>0.0083</td>
<td>19.805</td>
<td>0.164384</td>
</tr>
<tr>
<td>Sulfuric-acid, lb</td>
<td>0.297</td>
<td>86.2 $/ton</td>
<td>0.012801</td>
</tr>
<tr>
<td>Lime, lb</td>
<td>0.219</td>
<td>40 $/ton</td>
<td>0.00438</td>
</tr>
<tr>
<td>Ammonia, lb</td>
<td>0.4704</td>
<td>200 $/ton</td>
<td>0.04704</td>
</tr>
<tr>
<td>Nutrients, lb</td>
<td>0.0181</td>
<td>0.115 $/lb</td>
<td>0.002082</td>
</tr>
<tr>
<td>Corn liquor, lb</td>
<td>0.0633</td>
<td>0.133 $/lb</td>
<td>0.008419</td>
</tr>
<tr>
<td>Corn oil, lb</td>
<td>0.0039</td>
<td>0.2067 $/lb</td>
<td>0.000806</td>
</tr>
<tr>
<td>Glucose, lb</td>
<td>0.037</td>
<td>0.129 $/lb</td>
<td>0.004773</td>
</tr>
<tr>
<td>Catalyst</td>
<td>1</td>
<td>0.01 $/unit</td>
<td>0.01</td>
</tr>
<tr>
<td>Disposal, ton</td>
<td>-0.00034</td>
<td>20 $/ton</td>
<td>-0.0068</td>
</tr>
<tr>
<td>Water, mgal</td>
<td>0.01987</td>
<td>0.002 $/gal</td>
<td>0.00004</td>
</tr>
<tr>
<td>Total materials</td>
<td></td>
<td></td>
<td>0.247924</td>
</tr>
<tr>
<td>Labor, man yrs</td>
<td>41</td>
<td>29800 $/yr</td>
<td>0.003494</td>
</tr>
<tr>
<td>Foremen, man yrs</td>
<td>9</td>
<td>34000 $/yr</td>
<td>0.000875</td>
</tr>
<tr>
<td>Supervisors, man yrs</td>
<td>1</td>
<td>40000 $/yr</td>
<td>0.000114</td>
</tr>
<tr>
<td>Total materials + labor</td>
<td></td>
<td></td>
<td>0.252407</td>
</tr>
<tr>
<td>Capital allowance</td>
<td></td>
<td></td>
<td>0.211426</td>
</tr>
<tr>
<td>(10% return, 15 yr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>amortization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total production cost</td>
<td></td>
<td></td>
<td>0.463834</td>
</tr>
<tr>
<td>Total processing cost (net</td>
<td></td>
<td></td>
<td>0.299449</td>
</tr>
<tr>
<td>of stover)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethanol output:</td>
<td>349.72 mil gal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input requirement:</td>
<td>2.902676 mil ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant cost</td>
<td>562.357 mil $</td>
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<td></td>
</tr>
</tbody>
</table>
Table 6. Some production cost comparisons for ethanol and ethylene

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Year</th>
<th>Average Variable Cost</th>
<th>Average Fixed Cost</th>
<th>Average Total Cost</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Petro&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1993</td>
<td>0.765</td>
<td>0.329</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Bio (stalks)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1993</td>
<td>0.253</td>
<td>0.211</td>
<td>0.464</td>
<td></td>
</tr>
<tr>
<td>Bio (corn)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1994</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>1994</td>
<td></td>
<td></td>
<td></td>
<td>0.592</td>
</tr>
</tbody>
</table>

| Ethylene        |      |                       |                    |                    |       |
| Petro<sup>b</sup> | 1993 | 0.021                 | 0.08               | 0.102              |       |
| Petro<sup>b</sup> | 2005 | 0.059                 | 0.08               | 0.139              |       |
| Bio<sup>b</sup>  | 1993 | 0.13                  | 0.009              | 0.139              |       |

<sup>a</sup> Source: R. Katsen
<sup>b</sup> Based on Donaldson and Culberson with adjustment for a large plant. See footnote 3.
<sup>c</sup> Source: U.S. Dept. of Energy
<table>
<thead>
<tr>
<th>Year</th>
<th>Cornstalk demand expansion (mil lb)</th>
<th>Corn demand expansion (mil bu)</th>
<th>Oil demand reduction (mil bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0.00</td>
<td>51.51</td>
<td>4.03</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.00</td>
<td>103.02</td>
<td>6.07</td>
</tr>
<tr>
<td>Year 3</td>
<td>0.00</td>
<td>154.53</td>
<td>12.10</td>
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<tr>
<td>Year 4</td>
<td>0.00</td>
<td>206.04</td>
<td>16.13</td>
</tr>
<tr>
<td>Year 5</td>
<td>0.00</td>
<td>257.55</td>
<td>20.17</td>
</tr>
<tr>
<td>Year 6</td>
<td>13566.67</td>
<td>210.16</td>
<td>47.56</td>
</tr>
<tr>
<td>Year 7</td>
<td>27133.33</td>
<td>162.77</td>
<td>74.94</td>
</tr>
<tr>
<td>Year 8</td>
<td>40700.00</td>
<td>115.37</td>
<td>102.33</td>
</tr>
<tr>
<td>Year 9</td>
<td>54266.67</td>
<td>67.98</td>
<td>129.72</td>
</tr>
<tr>
<td>Year 10</td>
<td>67833.33</td>
<td>85.87</td>
<td>153.53</td>
</tr>
<tr>
<td>Year 11</td>
<td>81400.00</td>
<td>144.98</td>
<td>175.09</td>
</tr>
<tr>
<td>Year 12</td>
<td>94966.67</td>
<td>204.09</td>
<td>196.64</td>
</tr>
<tr>
<td>Year 13</td>
<td>108533.33</td>
<td>263.20</td>
<td>218.20</td>
</tr>
<tr>
<td>Year 14</td>
<td>122100.00</td>
<td>322.31</td>
<td>239.75</td>
</tr>
<tr>
<td>Year 15</td>
<td>135666.67</td>
<td>381.42</td>
<td>261.31</td>
</tr>
<tr>
<td>Year 16</td>
<td>149233.33</td>
<td>389.02</td>
<td>278.83</td>
</tr>
<tr>
<td>Year 17</td>
<td>162800.00</td>
<td>396.62</td>
<td>296.35</td>
</tr>
<tr>
<td>Year 18</td>
<td>176366.67</td>
<td>404.22</td>
<td>313.87</td>
</tr>
<tr>
<td>Year 19</td>
<td>189933.33</td>
<td>411.81</td>
<td>331.39</td>
</tr>
<tr>
<td>Year 20</td>
<td>203500.00</td>
<td>419.41</td>
<td>348.92</td>
</tr>
</tbody>
</table>

Total stover supply: 203.50 bil lb
Ethanol yield: 0.40 lb/lb stover
Ethanol supply (capacity): 80.89 bil lb
Table 8. Consequences of reduced corn target price and set aside

<table>
<thead>
<tr>
<th>Year of production schedule</th>
<th>Target price ($/bu)</th>
<th>Market price ($/bu)</th>
<th>Set aside rate</th>
<th>Production (mil bu)</th>
<th>Corn net income (mil $)</th>
<th>Government expenditure (mil $*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.75</td>
<td>2.07</td>
<td>0.100</td>
<td>8209.4</td>
<td>10460.0</td>
<td>4251.0</td>
</tr>
<tr>
<td>7</td>
<td>2.66</td>
<td>2.15</td>
<td>0.070</td>
<td>8405.6</td>
<td>9551.1</td>
<td>2043.5</td>
</tr>
<tr>
<td>11</td>
<td>2.73</td>
<td>2.17</td>
<td>0.094</td>
<td>8207.4</td>
<td>9691.4</td>
<td>2466.7</td>
</tr>
<tr>
<td>15</td>
<td>2.69</td>
<td>2.40</td>
<td>0.082</td>
<td>8228.0</td>
<td>9852.7</td>
<td>277.1</td>
</tr>
<tr>
<td>20</td>
<td>2.64</td>
<td>2.41</td>
<td>0.064</td>
<td>8376.9</td>
<td>10029.5</td>
<td>144.5</td>
</tr>
</tbody>
</table>

Table 9. The effect of new supply on the petroleum market

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>1992 baseline</th>
<th>Increased supply</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markets effects:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand, oil equivalent</td>
<td>mil bbl</td>
<td>6271</td>
<td>6509</td>
<td>295</td>
</tr>
<tr>
<td>U.S. oil supply</td>
<td>mil bbl</td>
<td>4160</td>
<td>4160</td>
<td>0</td>
</tr>
<tr>
<td>New supply</td>
<td>mil bbl</td>
<td>0</td>
<td>349</td>
<td>349</td>
</tr>
<tr>
<td>Imports</td>
<td>mil bbl</td>
<td>2110</td>
<td>1999</td>
<td>-138</td>
</tr>
<tr>
<td>Oil price</td>
<td>$/bbl</td>
<td>18.47</td>
<td>17.69</td>
<td>0.78</td>
</tr>
<tr>
<td>Surpluses:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>mil $</td>
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<td>69318</td>
<td>4971</td>
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<td>U.S. petro suppliers</td>
<td>mil $</td>
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<td>28092</td>
<td>-3237</td>
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<td>Net U.S. gain:</td>
<td></td>
<td></td>
<td></td>
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<td>OPEC petro suppliers</td>
<td>mil $</td>
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<td>27964</td>
<td>-3179</td>
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Appendices
Appendix A: The cost of corn-stover acquisition for a large plant.

1. The production function:

\[ Q = A \cdot d \cdot y \]

and \( A = \pi r^2 \)

\[ Q = (\pi r^2) \, dy \]

Let \( \tilde{Q} \) = plant capacity. Then the maximum distance from the plant needed is

\[ r^* = \sqrt{\frac{\tilde{Q}}{\pi d y}} \]

Example: 349.72 mil gal ethanol x 0.0083 s.t. stover = 2.903 mil s.t. stover gal

Iowa average corn density → \( y = 2 \) ton stover/acre

\[ d = 187.62 \text{ acre/mi}^2 \]

\[ r = 49.62 \text{ mi}^2 \]

Conclusion: The large plant needs to pull material from a 50 mile radius for average Iowa corn densities.

Note:

\[ \frac{1 \text{ lb stover}}{.3975 \text{ eth gal eth}} \times \frac{6.6 \text{ lb eth}}{1 \text{ s.t. stover}} \times \frac{1 \text{ s.t. stover}}{2000 \text{ lb stover}} = \frac{.0083 \text{ s.t. stover gal eth}}{1 \text{ s.t. stover}} \]

2. The expenditure function:

At a given radius from the plant, the production in a ring is obtained at a price that is defined by the radius. It can be shown that the expenditure for this distance is the product of the price and the circumference of the circle:

\[ C'(r) = \text{mg/l cost of expanding radius} = P(r) (2\pi r) (dy) \Delta r \]
Then the total expense is

$$c(r) = \int_0^r P(r) \left(2\pi r\right) (dy) \, dr$$

Assume that our price gradient function is linear:

$$P(r) = P_o + tr$$

Then

$$C(r) = (dy) \int_0^r (P_o + tr) r \, dr = (dy2\pi) \left[P_o \int r \, dr + t \int r^2 \, dr\right]$$

$$C(r) = (dy2\pi) \left[P_o \left(\frac{r^2}{2}\right) + t \left(\frac{r^3}{3}\right)\right]$$

$$C(r) = (\pi r^2) \left(dy\right) \left[P_o + \frac{2tr}{3}r\right]$$

Average input cost = \[\frac{C(r)}{Q(r)}\] = \[P_o + \frac{2tr}{3}\]

\(P_o = \$16.5\)
\(t = \$0.1/\text{ton/mile}\)
\(r = 49.63\)
\(\text{AIC} = \$19.8/\text{ton}\)
Appendix B: Potential ethanol yield for corn stalk conversion.

First, consider the conversion of cornstalks to usable sugars. The approximate corn stalk composition is:

- cellulose .34
- xylan .36
- lignin .11
- sucrose .12
- other .07

In turn, the components convert to several sugars. Cellulose is a polymer of anhydroglucose, C_6 anhydrosugars, and converts upon hydrolysis to glucose, adding a mole of water (MW 18) to anhydroglucose (MW 162), thus has a molecular weight gain of 10%. Hemicellulose is a polymer of arabinose and xylans C_5 anhydrosugars, and convert upon hydrolysis to arabinose and xylose, both MW 150, adding a mole of water, and a gain of 14%.

Per 100# dry basis corn stover:

- 34# cell • (1.1#gluc/cell) • 0.95 (eff fac) = 35.5# glucose.
- 36# hemi • (1.14#xlose/hemi) • 0.95 (eff fac) = 39.0# xlose.
- 12# sucr. • 1... = 12.0# sucrose

Total fermentable sugars = 86.5#

Second, the theoretical yield of ethanol is \( \frac{0.51 \text{ lb ethanol}}{1 \text{ lb sugar}} \) -- this yield is based on the theoretical chemical reaction that converts fermentable sugars to ethanol; nearly one-half of the material is converted to \( \text{H}_2\text{O} \), which has little value. Also, it is customary to assume that only 95% of the theoretical yield can be achieved, so the maximum practical yield is:

- 0.48 lb ethyl alcohol

Third, the composite yield of ethanol from cornstalks is the product of the sugar yield and the alcohol yield as follows:

\[
\frac{0.865 \text{ lb sugar}}{1 \text{ lb corn stalk}} \times \frac{0.48 \text{ ethyl alcohol}}{1 \text{ lb sugar}} = \frac{0.415 \text{ lb ethyl alcohol}}{1 \text{ lb stover}}
\]

Finally, the equivalent yield can be expressed in tons and gallons using the following conversion:

\[
\frac{2000 \text{ lb stover}}{1 \text{ ton stover}} \times \frac{0.415 \text{ lb ethyl alcohol}}{1 \text{ lb stover}} \times \frac{1 \text{ gal ethyl alcohol}}{6.6 \text{ lb ethyl alcohol}} = 126 \text{ gallon}
\]
The reciprocal conversion is .00795 t stover > gallon ethyl alcohol. This number is lower than the input requirement used in .0083 t stover > gallon ethyl alcohol cost calculations. Hence, a slightly conservative estimate of the technology's potential is used in cost calculations and economic impact assessments.
Appendix C: Calculation of energy-product value for corn stover

(1) Energy-based price for corn stover:

- Wholesale gasoline price: $0.592/gallon
- Stover processing costs: $0.300/gallon
- Residual value for stover: $0.292/gallon

(2) Conversion factor to raw material units. Convert product yield from lb/lb to ton/ gallon.

\[
\frac{0.3975 \text{ lb ethanol}}{1 \text{ lb stover}} \times \frac{2000 \text{ lb}}{6.6 \text{ lb ethanol}} = 120 \text{ gallon/ton}
\]

or 

\[
0.0083 \text{ tons/gallon}
\]

(3) Convert residual value to $/ton stover:

\[
\text{value} = \frac{0.292}{1 \text{ gallon}} \times \frac{1 \text{ gallon}}{0.0083 \text{ tons}} = \frac{\$35.18}{\text{ton}}
\]

(4) Net income to stover processing:

\[
(\frac{\$35.18}{\text{ton}} - \frac{\$16.5}{\text{ton}}) (125.9 \text{ bil lb} \times \frac{\text{ton}}{2000 \text{ lb}}) + (\frac{\$35}{\text{ton}} - \frac{\$35}{\text{ton}}) (202.9 - 125.9) \text{ bil lb/ton}
\]

\[
\text{energy net harvest supply to energy feed industry} \times \text{value of stover 2000 lb}
\]

\[
\frac{\$18.68}{\text{ton}} \times 0.06295 \text{ bil ton} + \frac{\$0.18}{\text{ton}} \times 0.0385 \text{ bil ton}
\]

\[
\$1.18 \text{ bil} + \$0.01 \text{ bil} = \$1.19 \text{ bil}
\]
(5) Number of plants required

\[ \frac{350.5 \text{ mil gal}}{\text{plant}} \]

\[ \frac{2.9027 \text{ mil ton stover}}{\text{plant}} \times \frac{2000 \text{ lb}}{\text{ton}} = 5,805 \text{ mil lb} \]

\[ 125,900 \text{ mil lb stover supply in Midwest} = 21.69 \text{ plants} \]

\[ 5,805 \text{ mil lb per plant} \]

\[ 21.69 \text{ plants} \times \frac{\$562.4 \text{ mil}}{\text{plant}} = \$12,198 \text{ mil} = \$12.2 \text{ bil} \]