

A Strategy for Returning Agriculture and Rural America to Long-Term Full Employment Using Biomass Refineries

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Production agriculture in Rural America has two major problems. The first is that *it has long-term excess productive capacity at acceptable prices*. The second, accentuated by the recent change in Federal farm program policy, is *widely fluctuating prices with their resulting "boom and bust" cycles*. These severely damage the economies of communities in which production agriculture provides the majority of the economic stimulus. These two problems are closely linked and the foci of this conceptual analysis.

HISTORICAL

Within the context of the two major long-term problems mentioned above, two major events during the last two years will have significant change for Rural America. The first was passage of the Federal Agriculture Improvement and Reform Act of 1996 (PL 104-127, FAIR legislation) that effectively shifted price risks for major grains from the Federal Government to individual farmers. No longer will land diversion be part of the annual absorption of the sector's excess capacity (recognizing that the longer-term Conservation Reserve Program (CRP) remains for up to 10 additional years under current law). Many believe that elimination of Federal farm price supports will increase price instability, thus resulting in wider price swings in the future than have existed previously.

The second major result was the development of a potential negating force for some of the price instability problem that resulted from recently completed research by this projects principal investigators (PI's). It was the discovery of a process to produce a set of important industrial products including ethanol that is *economically viable* without government subsidies as is now the case with fuel ethanol. By simulating the production of ethanol as a coproduct with a higher value chemical, furfural, documentation now exists that huge volumes of grain crop residues and other lignocellulosic (LCF) materials can be converted in biomass refineries to multiple industrial products. In addition to crop residues LCF resources also can include woody biomass, energy crops, wood construction debris, the paper and organics portions of municipal solid waste, and other residues. For purposes of this chapter LCF resources will be described as crop residues when, in fact, other types of residues might be used depending on availability and price. Since the conversion process is fermentation, biomass refineries can select the mix of feedstocks—including grain and LCF resources—that is most profitable. *This concept is extremely important since it would be market driven, not the result of year-to-year Federal agricultural policy*. Finally, not only can the biomass refinery of the future use multiple feedstocks but also it will be able to shift output from the production of one chemical to another in response to market demands. Given that the markets for these chemicals, especially ethanol, are very large, a national chain of biomass refineries can redefine the agricultural/industrial interface. Obviously, these recent findings, described by some as a breakthrough, have tremendous implications for helping to stabilize the price "roller coaster ride" that is beginning to characterize agricultural markets.

An excellent indicator of the long-term excess productive capacity at acceptable prices in production agriculture is the number of cropland acres that have been idled by various types of Federal farm programs. The number of cropland acres that have been idled annually for all Federal farm programs from their beginning in 1933 through 1996 is identified in Fig. 1. Of particular note is that during three multi-year periods large acreages of cropland have been idled. The first was during the 1930s and early 1940s just prior to World War II. The second was from the late 1950s through the early 1970s when more than 50 million acres were idled during nine of those years. Over 60 million cropland acres were idled during three years of this same period. The last multi-year period was from the mid-1980s to today when almost 80 million acres of cropland have been idled during three of the years. During these three multi-year periods there was sufficient excess productive capacity to justify major expenditures by the Federal government to take land out of production, thus helping to reduce production and the cost of storing excess crop supplies. However, when large acreages of cropland were not retired, full production was needed to produce adequate volumes of traditional food,

feed and fiber crops to supply both domestic and foreign demand.

Another indication of farm gate price instability is shown for corn (maize) in Fig. 2. The average annual farm gate price in the US is compared to carryover stocks from the previous year. Note the inverse relationship between the two series. For instance, at the end of the 1995 crop year corn stocks were estimated to have dropped to 426 million bushels and the corresponding average farm gate corn price was \$3.24 per bushel. This low carryover level resulted primarily because of devastating floods of 1993 and 1995, even though a record production of 10.1 billion bushels was achieved in 1994 (USDA 1998). This degree of instability occurred in spite of the fact that Federal farm programs had protected farmers against low prices in previous years. Now even that protection is gone unless some type of emergency aid is granted such as the \$5.9 billion disaster relief aid granted by Congress in 1998, an election year. A more likely scenario is that of the last three years during which Midwest corn prices gyrated from about \$5.25 per bushel at the farm gate (\$5.54 futures price, Rudel) to about \$1.50 per bushel at some Midwest elevators (\$1.87 futures price, Rudel). Clearly, such instability does not bode well for Rural America.

DIAGNOSIS OF A RECENT CYCLE

A brief discussion of the events surrounding the period from the late 1970s to date will provide an indication of forces facing agriculture and rural communities on a perpetual and unpredictable basis. Using corn as an example, they are as follows:

- 1978–82 Farmers urged to plant “fence row-to-fence row” to produce for both domestic and very strong international grain demands.
- 1980–81 No cropland idled by Federal farm programs as the result of strong demand.
- 1983 Federal PIC (payment in kind) program where farmers idled cropland and accepted grain from government storage to: (1) reduce government storage costs, and (2) entice farmers to take land out of production.
- 1984 Reduction in idled acres via conventional programs to restore grain stocks to a “comfortable level.”
- 1985–86 Large crop production years with carryover corn stocks in the 1986–87 crop year of 4.882 billion bushels (USDA 1998, p. 60)
- 1987–88 Idled 76.2 million and 77.7 million acres, respectively in an attempt to reduce carry over grain stocks and maintain prices at acceptable levels.
- 1989–95 Idled acreage of 60.9, 61.6, 64.5, 54.9, 59.2, 49.2, 54.8 million acres, respectively. Again, large acreage reductions were used in an attempt to reduce excess supply and the high costs of carryover stocks.
- 1993, 95 Major flooding throughout much of the corn belt resulted in low levels of corn production on a

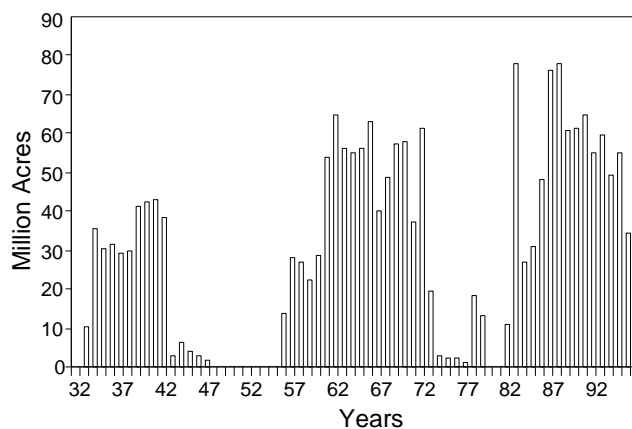


Fig. 1. Cropland idled by Federal farm programs in the US, 1932–1996. Note: Federal farm program legislation was implemented in 1933. Source: Anderson and Magleby (1997).

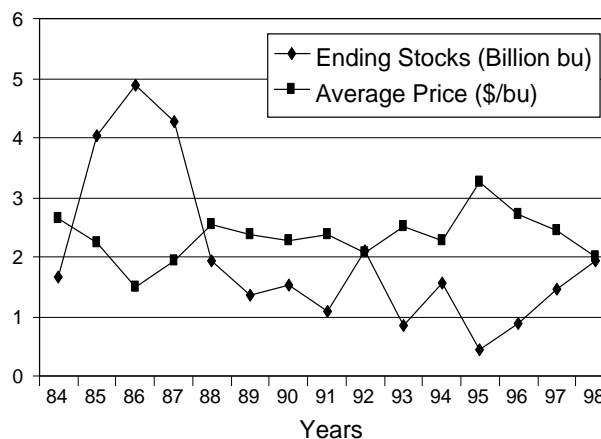


Fig. 2. Relationship between farm gate price of corn and carryover corn stalks from the previous year in the U.S., 1984–1998. Note: Data for 1998 are estimates. Source: R. Rudel, Univ. of Missouri (unpubl. data).

reduced number of harvested acres, with production of 6.3 and 7.4 billion bushels, respectively in the two years (USDA 1998).

- 1994 Historic record corn production of 10.1 billion bushel (USDA 1998).
- 1996 Elimination of most Federal crop price support programs, except the CRP program.
- 1998 Emergency farm “bailout program” for agriculture with Federal expenditure estimated at \$5.9 billion, with grain prices plummeting as illustrated by corn at \$1.50 per bushel in some local Midwest cash markets.

While idled farm acreage provides a measure of excess agricultural productive capacity it also suggests the excess capacity that occurs in supporting rural businesses. For example, for each acre of cropland idled, there are corresponding reductions in the purchases of fertilizer, seed, chemicals and other inputs; reductions in the volumes of grain to be stored and marketed; plus reductions in all other supporting rural businesses such as banking services, health care, restaurants, automotive purchases and repairs, etc. Thus, idling of farm crop acreage actually result in a “spiraling down” of virtually all economic activity in rural communities—especially in those areas where agriculture is the primary industry.

From the beginning of Federal farm programs in 1933 until today there have been only 10 years when no cropland was idled. Thus, US agriculture has tremendous excess productive capabilities at acceptable prices in most—but not all—years. *This excess capacity calls for efforts to diversify agriculture beyond traditional food, feed, and fiber to include the production of industrial products.* Markets for traditional commodities are mature. However, markets for industrial products are large. For instance, approximately 115 billion gallons of gasoline and 50 billion gallons of number 2 distillate fuel (about one-half for transportation) are used in the US annually. Large volumes of a multitude of chemicals also exist, as evidenced in Fig. 5. Although intuitively appealing, there are two problems. First, profitable methods must be found for producing large volumes of industrial products from agricultural feedstocks. Potential progress in this area, to be reported in the next section, has been made recently that suggests a breakthrough in this area. Second, what would processing plants producing industrial products from agricultural feedstocks do in those years when all cropland is needed (bid away) to produce traditional food, feed, and fiber? Building upon the recent findings concerning profitable uses of agricultural feedstocks for industrial production, this problem will be addressed with a non-conventional design for the production of ethanol and higher value chemicals.

PREVIOUS AND UNDERLYING RESEARCH

The study that was alluded to above is highly relevant. This analysis, completed by the PI’s, evaluated the technical and economic feasibility of converting lignocellulosic feedstocks (LCF) resources into ethanol and higher value chemicals. It was based on technology that could be commercialized today. Part of this technology is being implemented by BC International (BCI) in a plant under construction in Jennings, Louisiana (SERBEP). The most important results include the following. First, the production of ethanol as a *sole* product from LCF resources is technically feasible, but not economically viable when priced at \$1.25 per gallon with no subsidies. Second, *co-production of ethanol and higher value chemicals (using furfural as an example) can be highly profitable.* Finally, the optimum size processing plant—with a given volume and location of LCF resources—was estimated for an area in West Central Missouri (See Fig. 3). This chart shows the discounted present value earnings over a 15-year lifetime versus processing plant size represented by the tons of LCF resources that would be processed

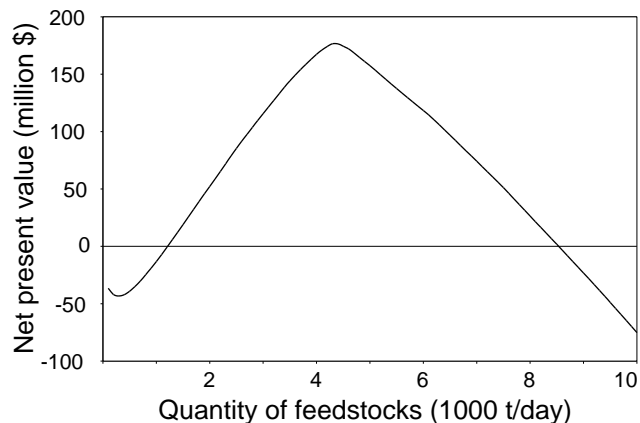


Fig. 3. Estimated net present value of a ligno-cellulose-to-ethanol and furfural plant with varying levels of feedstock use, Carroll County, MO, 1998. Source: Van Dyne et al. (1998)

daily. An important finding of the research was that economies-of-scale for processing plant size is extremely important. A plant of less than about 1,300 tons of feedstock used daily is not profitable when producing both ethanol and furfural. Optimum profitability would be reached with a plant that uses about 4,360 tons of feedstocks daily. However, the most likely plant size probably would range from about 2,000 to 2,500 tons of feedstock used daily. Summary results for a plant that would process 4,360 tons of feedstocks daily include:

1. dilute acid processing technology was assumed to be used;
2. potential feedstocks included crop residues, woody biomass and the paper portion of municipal solid waste (MSW);
3. prices assumed for ethanol and furfural were \$1.25 per gallon and \$0.32 per pound, respectively;
4. plant produces 47.5 million gallons of ethanol and 323 thousand tons of furfural annually;
5. processing plant would cost an estimated \$455 million to construct;
6. annual income, costs and net profit would be \$281 million, \$173 million, and \$108 million, respectively;
7. increases employment by an estimated 6,095 jobs (additional temporary jobs would be created during plant construction);
8. increases personal income by \$155 million and total economic activity by an estimated \$624 million annually;
9. increases local tax base, increases revenues for state and federal income taxes, real and personal property taxes, sales taxes, plus state and federal excise taxes on fuel sales; and
10. reduces imports of petroleum and chemicals.

SUMMARY OF RECENT RESEARCH FINDINGS

This research is monumental because it demonstrates that ethanol can be produced profitably without subsidy if it is coproduced with other higher value chemicals! Further, it begins to suggest how the boom-and-bust cycles can be moderated. In periods of surplus capacity this BioRefinery approach can use both grain and LCF materials to produce ethanol and other higher value chemicals. During periods of high grain prices this approach can utilize LCF materials alone, such as corn stalks or wheat straw or forages (that can be safely produced on highly erodible land like that in the Conservation Reserve Program).

Based on the above, the specific purpose of this conceptual analysis is to provide a method that could help agriculture produce and operate at full capacity on a long-term sustainable basis by including the production of industrial products in addition to traditional food, feed and fiber yet continue the production of industrial products when all the land resources are needed to produce traditional products.

CONCEPTUAL ANALYSIS

This concept proposes to help improve the long-term sustainability of agriculture and rural communities by: (1) more fully utilizing the long-term excess capacity in rural communities, and (2) help stabilize agricultural prices, thus reducing the wide fluctuations in agricultural prices that create “boom and bust” cycles throughout rural America. This will be accomplished by diversifying agriculture beyond traditional food, feed, and fiber products to also include profitable production of industrial products. *It includes the need to further evaluate the technical and economic feasibility of using BioRefineries to convert agricultural feedstocks—both grain and LCF materials—into industrial products.*

Attention now will be turned to the description of various types of BioRefineries. Subsequently, a more thorough description will describe the characteristics of the one studied in this conceptual analysis.

Phase I BioRefinery

An example of this type of processing plant is a dry mill ethanol plant. It uses grain as a feedstock, has a fixed processing capability, and produces fixed outputs of ethanol, feed coproducts, and carbon dioxide. It has almost no flexibility in processing. This type will be used for comparison purposes only.

Phase II BioRefinery

An example of this is the current wet milling technology. This technology uses grain feedstocks, yet has the capability of producing various end products depending on product demand, prices, and contract obligations. Such products include starch, high fructose corn syrup, ethanol, corn oil, plus corn gluten feed and meal. This type begins to suggest the chain of industrial plants needed to moderate the boom-and-bust economy in agriculture today.

Phase III BioRefinery

A Phase III BioRefinery is the type evaluated in this conceptual analysis. A Phase III BioRefinery can not only *produce a variety of chemicals, fuels and intermediate or end products*, but also can *use various types of feedstocks and processing methods* to produce the products for the industrial marketplace (see Fig. 4). The *flexibility of feedstock use* is the factor of primary importance for accommodating the changes in the demand for and the supply of feed, food, fiber, and industrial commodities. In brief, this plant of the future will: (1) accommodate a mix of agricultural feedstocks; (2) have the ability to use various types of processing methods, and (3) have the capability to produce a mix of higher value chemicals while coproducing ethanol.

Of extreme importance in the success of long-term production of industrial products from agricultural resources is markets for those products. Fig. 5 provides a schematic description of some of the more important industrial products that can be developed from fossil resources (natural gas, petroleum, and coal). Note that information in Fig. 5 includes not only the path of derivation of various industrial products but also included in parenthesis under each chemical is the volume that is consumed in the US annually (Morris and Ahmed 1992). Most of the consumer end-products identified in the right hand column—as well as many others—can also be derived from biobased resources. In fact, most were derived from biomass prior to the petroleum era which began after the turn of the century. *This conceptual analysis establishes the methodology for evaluating the technological feasibility and the profitability of a multi-input, multi-output plant, i.e., a Phase III BioRefinery.*

Of primary importance in stabilizing agricultural production—and thus commodity prices—over time can be seen by evaluating the significance of Fig. 1, 2, and 5. First, the industrial products such as chemicals and fuels compete mostly with fossil resources for market share, not other agricultural commodities and products. Second, the mix of feedstocks used by the BioRefinery depends on their relative prices. For instance, when large cropland acreages need to be retired and large volumes of grain are in storage, grain prices are typically depressed. In this situation the BioRefinery will use considerable volumes of grain to produce industrial products. However, when little or no cropland is retired, carryover stocks will be low and grain prices will be relatively high. Under this scenario the BioRefinery will use most/all lignocellulosic feedstocks and no grain. *This substitution is possible with the front end equipment complement in the BioRefinery because both types of feedstocks yield sugars as intermediate products in a BioRefinery. Once the glucose is available as a fermentable sugar, essentially the same process equipment can be used to produce ethanol, acetic acid, acetone, butanol, succinic acid, or other products of fermentation.* Thus, the flexibility of different feedstock use in the production of industrial products by the BioRefinery is important for the successful development of the conceptual analysis. The flexible feedstock use is essential in developing the most profitable mix of higher

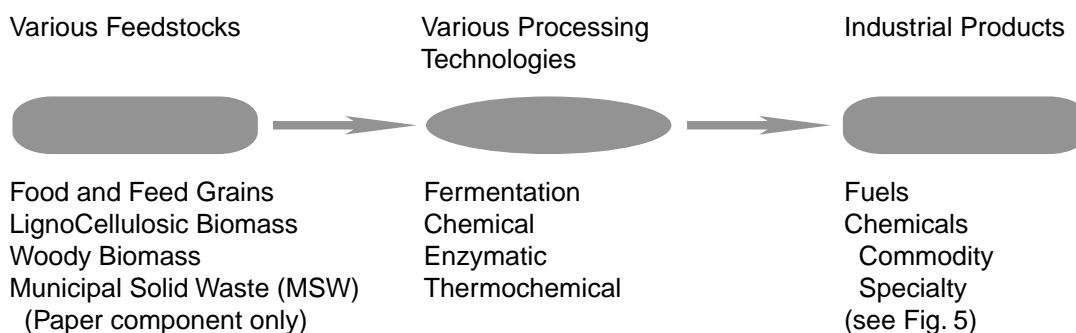


Fig. 4. Conceptual design of a Phase III BioRefinery.

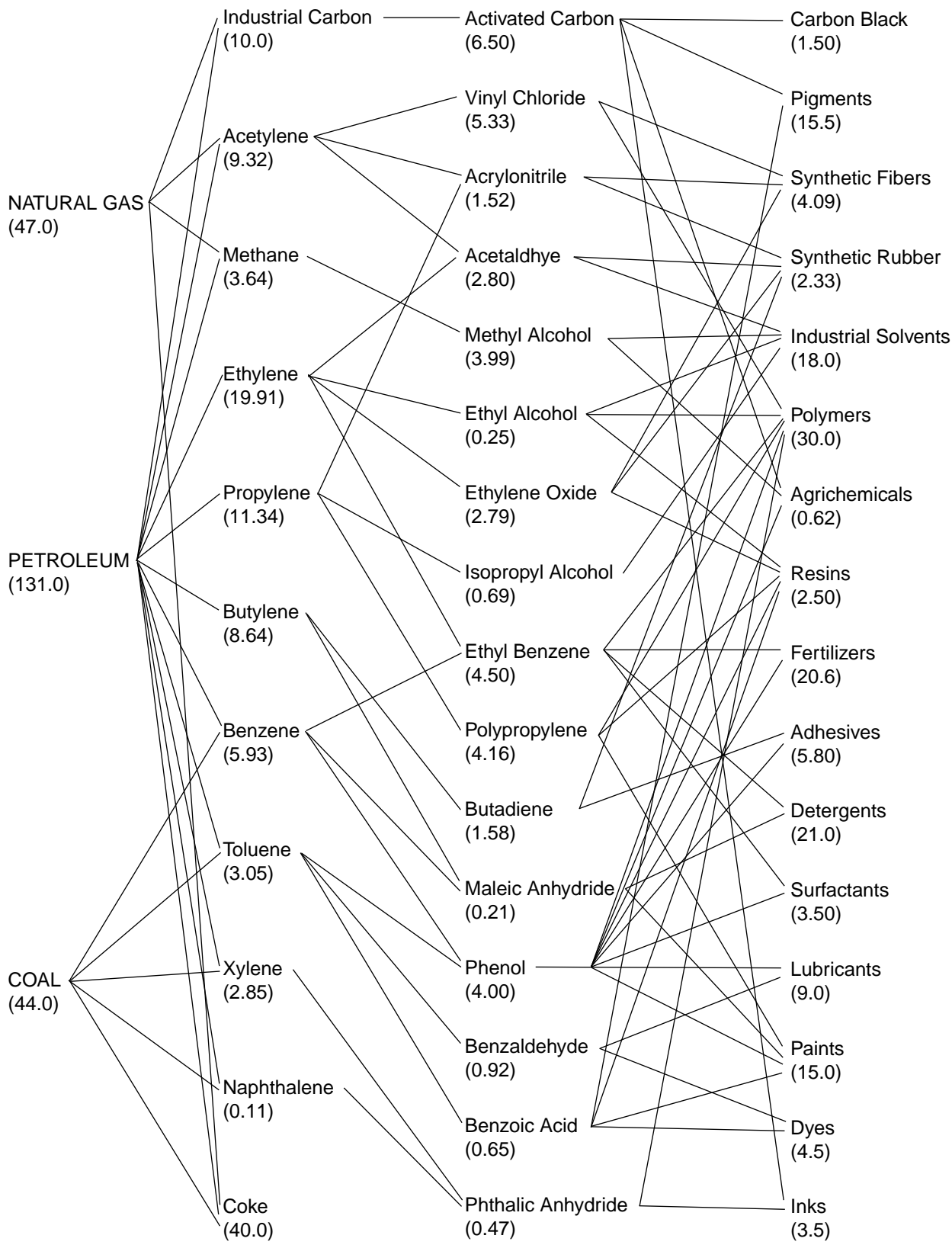


Fig. 5. Interrelationship of major precursor chemicals derived from fossil fuels for the manufacture of consumer end-products in the US (millions of tons). Source: Morris and Ahmed (1992)

value chemical outputs. Moreover, “smoothing” the year-to-year changes also helps stabilize prices in the long-term and increases the economic sustainability of Rural America.

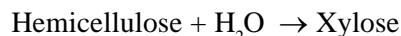
Three important factors should be reemphasized. *First*, the stabilizing of production, use and prices will be possible as the result of relative prices in the marketplace—without government intervention. *Second*, it also assures that the production of industrial products will not be at the expense of having inadequate supplies of food, feed, and fiber commodities because the supply-demand conditions are based on market demand, not inflexible Federal farm policies. *Finally*, the BioRefinery will help to fulfill the large void anticipated as the result of the Federal government transferring risks to farmers created in the “Freedom-to-Farm” legislation.

Example of a BioRefinery Approach

Lignocellulosic materials are made up of three primary chemical fractions, hemicellulose (a polymer of five-carbon sugars), cellulose (a polymer of glucose, a six-carbon sugar), and lignin (a polymer of phenol). The sugar polymers, hemicellulose and cellulose, can be converted to their component sugars through the chemical addition of water. This process, called hydrolysis, is relatively easy in the case of the hemicellulose and rather more difficult for the cellulose fraction.

The glucose fraction from cellulose can be fermented to produce materials as described above. The xylose fraction from hemicellulose can be fermented by some organisms, but these fermentations are notably low in yield. The remaining material, the lignin, is a natural adhesive which has some commercial value, but because it has a heating value approaching that of sub-bituminous coal, but with no sulfur content, it is a premium quality solid fuel. An attractive option for the use of the xylose fraction, however, is its conversion into furfural, and as described below, into furfural derivatives, including nylon.

The biomass-to-nylon process takes advantage of the fact that the hemicellulose fraction is readily hydrolyzed to xyloses. The reaction conditions most commonly used are reactions with dilute sulfuric acid at a temperature of about 160°C. The same reaction conditions that hydrolyze the hemicellulose also can further convert the xyloses to furfural, an industrial chemical used in refining of motor oils, for making certain plastics, and use in new “clean” liquid fuels.



Furfural in fact has many uses, but important to this discussion is that furfural can be converted into both of the precursors of nylon 6,6 or into the raw material for nylon 6. The original process for making nylon 6,6 was based on furfural. The last of these plants closed in 1961 because of the artificially low price of petroleum. Nevertheless, the size of the market for nylon 6 is huge.

The production of the nylon precursors requires hydrogen which is a product of the gasification reactions used to destroy waste materials in the waste management/power production part of the plant. Similarly, the nylon plant produces carbon monoxide, carbon dioxide, and methane which are products in the fuel gas made in the gasifier section of the waste management plant.

In the case of the biomass conversion, there are additional opportunities. The hydrolysis of the hemicellulose takes about one-third of the total biomass fraction. The remaining two-thirds, cellulose and lignin, can be used for power production, but this discards an additional valuable resource, the cellulose.

The hydrolysis of cellulose to glucose can be carried out through chemical processing or by enzymatic processing. The rotting of wood in the forest is the natural version of enzymatic hydrolysis that can be used for the preparation of glucose. The cost of commercial enzymes is high, and the process is rather slow. Chemical methods, particularly the use of mineral acids and higher temperatures than those required for hemicellulose

hydrolysis, lead to commercially viable production of glucose from cellulose. The original acid hydrolysis process for cellulose, called the Schöller process, was used extensively before and during World War II to produce ethanol for fuel.

An attractive addition to the biomass-to-nylon process is the hydrolysis of cellulose to glucose. Once the glucose is available as a fermentable sugar, essentially the same process equipment can be used to produce ethanol, acetic acid, acetone, butanol, succinic acid, or other fermentation products.

In sum, the process strategy is to create a highly integrated waste management, power production, and chemicals and fiber production complex. The three aspects of the complex complement each other in terms of exchange of inputs and products, making the sum much more profitable than the parts. *In essence, the effluents from one segment of the operation are the inputs for another segment. The result is an extremely efficient, near-zero discharge facility. The several technologies involved are all proven—the competitive advantage lies in the integration of the parts.*

Implications for Economic Analyses

Economic analyses—based on the assumption that the processing capabilities are technically feasible—are absolutely essential for the BioRefinery concept to work. That is, industrial products made from agriculture—relative to those made from other feedstocks including petroleum, coal, and natural gas must be price competitive. Also, they must be at least as high quality, have similar or better performance characteristics, and have as dependable supply over time as those derived from traditional resources.

A tool that is useful in estimating the economic feasibility of a BioRefinery is a non-linear optimization model, General Algebraic Modeling System (GAMS). Initially, GAMS can be useful in estimating the optimum size BioRefinery by evaluating the tradeoffs between economies-of-size of the processing plant versus increasing feedstock costs that result from delivery of biomass resources from more distant locations for ever larger plant sizes. The optimum size BioRefinery plant will vary among locations because of differing feedstock densities, as well as feedstock characteristics (relative composition of cellulose, hemicellulose, and lignin) that are used in making industrial products. The GAMS model of a Phase III BioRefinery allows a variety of feedstocks—both grains and crop residues—in a variety of locations to be used as inputs, while also allowing a variety of industrial products, depending on: (1) the feedstock composition (cellulose, hemicellulose, lignin, starch, etc.), and (2) economic parameters such as feedstock price, transportation costs, product prices, processing plant costs, and other relevant factors. Hence, the model will show not only the minimum cost feedstock mix, but also the location from which it will be drawn and, of course, the location of the BioRefinery. Moreover, the optimum size plant also will identify the mix of industrial products to be produced, given the product prices. The sensitivity of the optimum profitability of the plant can be evaluated by varying the most important and relevant prices, costs, and conversion efficiencies.

The methodology to evaluate the economic feasibility of a BioRefinery described above is similar to that used in the petroleum refinery industry. While their feedstock is crude oil, the mix of products to be produced for the day or week varies depending on relative prices, product demand, and contract obligations. The determination of the volume of each type of product, i.e., gasoline, distillate, residual, etc., to be produced is determined by some type of mathematical program such as linear programming (LP) or nonlinear program such as the GAMS model described previously. The frequency of using LP or GAMS in determining product output depends on various factors such as volatility of relative product prices and changing contract status for various products.

Implications for Policy Analyses

Development of a series of Phase III BioRefineries throughout the US could address the two major problems in Rural America identified in the opening paragraph of this paper: (1) long-term excess productive capacity at acceptable prices, and (2) widely fluctuating prices with their resulting “boom-and-bust” cycles. Producing industrial products in addition to traditional food, feed, and fiber feedstocks would help to more fully utilize all rural resources on a long-term sustainable basis. Also, the feedstock flexibility of Phase III BioRefineries would result in firms responding to relative market prices to choose between using grains and

LCF resources, thus helping reduce wide price swings. This would provide much more efficient and reasonable use of agricultural resources, than relying on prices influenced by Federal government programs as we have since their beginning in 1933.

An extremely important issue is how to go from a Federal farm program mentality to an agriculture that would include the production of industrial products as an important long-term mission for rural America. While considerable detail is necessary to move toward biobased production of fuels and chemicals, the single most important factor is *the reduction of risk to the investors and producers*. Fortunately, the risk reduction issue is not new to agriculture and rural communities. Risk sharing is commonly done through loans and loan guarantees from various Federal agencies. For example, USDA provides various types of loans and loan guarantees. The Farm Service Agency offers, “direct and guaranteed farm ownership and operating loan programs to farmers who are temporarily unable to obtain private, commercial credit.” Also, loan guarantees can be made for housing in rural areas. Additionally, various types of support are available through the Rural Business and Cooperatives Service, the Rural Community Development Service, the Rural Housing Service and the Rural Utilities Service. Services provided by these USDA agencies range from loans and loan guarantees to helping to assess business opportunities. Other Federal agencies also provide various types of loans and loan guarantees to help share risk.

CONCLUSIONS

The potential for enhancing rural development and economic viability as well as improve environmental benefits throughout rural America represents an overwhelming opportunity for seriously studying and developing a strategy for moving forth with the BioRefinery concept. This nation-wide effort would effectively help to more fully utilize rural resources while also reducing the year-to-year fluctuations in commodity prices and thus helping to provide stability in rural economies.

The primary reasons that the BioRefinery can be a valuable component in helping to stabilize and enhance rural economies include the capabilities of: (1) using a variety of grain and lignocellulosic feedstocks; (2) using a variety of processing capabilities; and (3) producing a wide variety of intermediate and end consumer industrial products, including fuels plus commodity and specialty chemicals. The flexibility in feedstock use provides the opportunity to vary input use based on relative feedstock prices that are market driven, not the result of Federal farm policy. Secondly, a Phase III BioRefinery would have various types of processing capabilities which should result in more fully utilizing feedstocks, thus reducing the volume of low value or “waste” products from the processing stream. Finally, the flexibility of being able to produce various types of products and coproducts based on relative prices helps to assure maximum returns to the BioRefinery.

Diversifying beyond traditional feed, food, and fiber crops to also include production of feedstocks for industry has immense potential. A major question at this time is with the potential positive opportunities that such an effort would result, why didn't this effort occur long ago? Basically, while the effort has been attempted numerous times previously—usually in periods of surplus commodities—the technological feasibility of a Phase III BioRefinery now makes the potential for success much more promising in the future of rural American economies. Moreover, with the potential for much larger swings in product prices resulting from elimination of Federal farm programs, it becomes much more important now than ever before. The time to act is now!

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