with energy. Thus the emergence of conceptually advanced processes will probably set the future trends in industrial energy use.

References and Notes

1. These data are taken from the *U.S. Statistical Abstracts* (Government Printing Office, Washington, D.C.).
2. Conversion factors are: from British thermal units to joules, 1055; from acres to hectares, 0.4047. One board foot is 1 inch thick and 12 inches square.
3. The peak year for lumber production in the United States was 1901. These high volumes of production were the result of overcutting. Conservation policies instituted under the Roosevelt administration introduced systems of forest management under which lumber production was to be limited to annual growth. During the very period that the interfuel competition between wood and coal was under way, the forests were being exploited at a rate which exceeded their natural capacity to replenish themselves. One might suppose that clever or greedy exploiters of forest lands could have gathered fuel wood (slash, limbs, nonmarketable species, for example) to sell to industry, while taking other more valuable trees for lumber. The marginal cost of gathering otherwise useless wood for fuel, once one had established a basic system for gathering logs of high value, would probably have been rather low; the fuel wood might have been a by-product of the rapidly growing logging industry.
4. B. E. Fernow, *History of Forestry in Europe, the United States and Other Countries* (Univ. of Toronto Press, Toronto, 1913).
5. According to a number of U.S. Department of Agriculture studies [for example, *U.S. Dep. Agri. Bull. 753* (10 March 1919)] a harvest of 10 cords per acre is reasonable, even in the northeastern United States with its short growing season.
6. Approximately 3 acres of trees were required to produce sufficient charcoal to make a ton of iron.
7. The first coal-fueled glass plant in the United States was, in fact, built in Pittsburgh in 1808, by Blakewell. Details of the design of the furnaces and other equipment are not available; it was a batch process plant and the glass produced there was noted for its exceptional quality.
8. The influence of the rapidly developing field of coal chemistry on intellectual life in the second half of the 19th century was far-reaching. This subject is discussed even in the works of radical political writers of the day, including the works of Lenin.
9. According to this school, talent follows money. An alternative view is that money is created by talent.
10. A visit to Nottingham today will illustrate this. The forest that shielded the legendary Robin Hood from his pursuers has been reduced to a few specimen trees.
11. See, for example, D. B. L. Young, "A wood famine? A question of deforestation in the old regime of France," *Forestry* (1976).
12. The notion of the Environmental Impact Statement evidently goes back a way in history. The attempt by the French crown to curtail industrial fuel also might be compared with U.S. Federal Power Commission Order 467 of 1973.
13. Young (*11*), among others, suggests that France's economic and social reorganization to exploit its ready availability of traditional fuels (wood and charcoal) retarded French economic development.
14. J. G. Percival is credited with the introduction of covered crucibles to protect the glass from the products of combustion of the coal.
15. During the English Protectorate patent rights lapsed and certain glass products were once more imported from the continent. In 1663 the Duke of Buckingham obtained a ban on glass imports but he failed to obtain the monopoly over glassmaking which he had sought. Buckingham did operate a glass works which was noted for production of very high quality glass.
16. F. H. Norton, *Elements of Ceramics* (Addison-Wesley, Cambridge, Mass., 1952).
17. S. Lorant, *Pittsburgh—The Story of an American City* (Doubleday, New York, 1964), p. 147.
18. Carnegie was blessed with good luck also. He happened to have available ores that circumvented certain metallurgical problems with Bessemer steel that were not fully understood until the work of Thomas in 1875.
19. P. Sporn, *Technology, Engineering, and Economics* (MIT Press, Cambridge, Mass., 1969).
20. W. Trinks and M. H. Mawhinney, *Industrial Furnaces* (Wiley, New York, 1927), vol. 1.

Industrial Energy in Transition: A Petrochemical Perspective

Ronald S. Wishart

Although the growth of the petrochemical industry in the United States is attributable to several factors over the years, one of its basic strengths has always been the abundance of relatively cheap raw materials. Even though the industry has never used more than 8 percent of the petroleum and natural gas consumed in the United States, it produces 80 billion pounds of chemicals annually. Out of this has come a cornucopia of products that has affected our daily living and, indeed, has influenced the form of our civilization. A world without plastics, synthetic rubber, manmade fibers, and pesticides would be a different world from the one we have enjoyed at relatively low cost during the past three decades.

Although the domestic demand for such products continues to grow (6 to 8 percent per year according to recent estimates), the petrochemical industry can no longer look forward to satisfying this growth by relying solely on traditional raw materials that are approaching economic depletion. True, "economic depletion" is a relative term; today, we routinely recover hydrocarbons that were considered "uneconomic" just a few years ago. But the concept of finiteness is now significant in the energy dialogue because the costs of recovering oil and gas have escalated and are approaching, for the first time in history, the costs of utilizing substitutes. The impact of this fact on the petrochemical industry will be sizable, but we in Union Carbide are convinced that both the resourcefulness and the required technology exist to meet this challenge.

Over the years, industry has demonstrated its sensitivity to the dynamics of economics and technology in making decisions about energy. At Union Carbide our own hydrogeneration projects powered some of our earliest operations, and we used coal in some other locations. For many years we found oil and gas attractive as fuels as well as feedstocks, but we have been switching oil- and gas-fired boilers to coal for some time now, in recognition of the scarcity of oil and gas, their increasing price, and their greatly enhanced value as feedstocks.

Boiler conversion alone, however, is not enough. Even if we conserve all the scarce hydrocarbons that we can through conversion, improved efficiencies, and other conservation measures, the economics of feedstocks will continue to signal the need for more radical actions. We see the costs for oil and gas converging with and eventually exceeding the costs for some substitutes by the year 2000. These signals have been clear for years, and we have oriented our research and development to prepare ourselves to make the adjustments. Our goal is to minimize the cost of our feedstocks and thus retain the competitive value of our petrochemical products. We are convinced that we have in hand or under development the technologies necessary to achieve this goal.

To understand the role we see for technological innovation in the petrochemical industry of the future, we must first understand the role of oil and gas in the industry today, the economic and technological forces that will be affecting

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this role in the years ahead, and the paths along which we expect innovation to develop.

Oil and gas hydrocarbons today account for 98 percent of the feedstocks used by U.S. petrochemical producers. The industry is built on oil and natural gas because of their specific hydrocarbon composition, their relative lack of impurities, and their historically attractive price and abundance. Only 2 percent of U.S. feedstocks are now derived from coal.

Recently, however, economic and political forces have combined to make hydrocarbons less attractive as a long run feedstock for the industry. Specifically, the price of oil and gas has gone up and domestic production has dropped. The U.S. dependence on imports has increased, bringing with it greater vulnerability to supply interruptions. In addition, we now recognize that there are absolute limits to economical recovery of remaining hydrocarbon resources.

Because of this, alarmists have envisioned petrochemical production declining over time, with adverse impacts on employment and growth of national income. But these threats are mitigated by the relatively small proportion of oil and gas devoted to feedstock use and the fact that public policy has to date recognized that feedstocks are a preferred use. And—despite the energy intensity of petrochemical and plastics manufacture—we are less impacted by energy induced cost escalation than by metals or natural fibers. The understanding is also spreading that few, if any, nations can afford to displace acreage for food production with natural fiber production.

The alternatives to conventional feedstocks now being explored range from the familiar—synthesis gas from coal—to the exotic—biological synthesis to turn biomass and solid waste into chemicals. Some technologies are nearing the demonstration stage, others are still in more preliminary stages of development. And, although it is difficult to forecast with too much precision, it is possible that the alternatives we are now studying could provide 10 to 15 percent of the feedstocks that will be needed by the year 2000. Under realistic assumptions, however, such alternatives will not constitute more than 25 percent of the feedstock mix by the turn of the century.

The transition will be evolutionary and is more likely to be measured in decades than in years. This is because the petrochemical industry still does not have the proven processes to significantly reduce its short term use of oil and gas without facing severe output reductions. In addition, oil and natural gas are still relative bargains; they are available in the United States at prices below the cost of the next most expensive substitute. Finally, the transition to alternative feedstocks will be evolutionary because most of our recent additions to capacity have used relatively efficient petroleum-based processes rather than processes based on increasingly scarce and expensive natural gas. Thus the feedstock alternatives of the future are more likely to replace obsolete gas-fed plants than newer, more efficient oil-fed facilities.

Summary. The future growth of the petrochemical industry depends in part on the industry's ability to improve efficiency in the use of oil and gas feedstocks and to develop promising alternatives. Technological innovation is proving to be the key to the long-term viability of the industry. The next 6 to 7 years will be characterized by the commercialization of new technologies designed to improve the efficiency of petroleum as a feedstock. Union Carbide's advanced cracking reactor, now nearing the demonstration stage, exemplifies this type of effort. The increasing price of oil and gas will make coal-based synthesis gas more attractive as a feedstock, particularly for oxygenated petrochemical products. A further development involves the conversion of biomass, through fermentation, to useful chemical products and the gasification of municipal wastes to raise steam for electricity generation and as a possible, supplemental feedstock. By the year 2000, it is predicted that feedstocks from all sources other than oil and gas may constitute 10 to 14 percent of the total new material requirement for the petrochemical industry.

On the basis of our experience in developing and commercializing new technologies, we foresee three phases of change in the industry and its resources that we believe will bridge from the present to the year 2000.

The first phase, starting now and lasting at least into the 1990's, is essentially a continuation of today's technology with the introduction of new techniques to more efficiently utilize crude oil, so as to produce higher yields of high-quality chemicals from each barrel.

The second phase, which will mature in the late 1980's, will be characterized by increasing production of synthesis gas (carbon monoxide and hydrogen) made from heavy petroleum fractions and coal for producing bulk chemicals now made from ethylene and other olefins—for example, ethylene glycol.

Paralleling these two phases and effectively extending the duration of phase 1, supplemental crude oil derived from shale, tar sands, and coal will begin to appear in the 1980's and become significant in the 1990's. Wide substitution of coal for fuel uses of oil and gas has already begun, and this is even more important in extending phase 1, well into the 21st century.

In the third phase, the production of chemicals by treatment of various forms of biomass will become significant. In a small way, this trend is beginning now, but it is unlikely to be commercially significant until some time in the 2000's.

These phases are not edged with discrete boundaries, but will overlap and blend into one another as the transition period proceeds. Accordingly, Union Carbide is working in all areas at the same time. For instance, we have a substantial ongoing effort in fermentation and other biochemical processes to understand how industrial chemicals can be produced economically from regenerable raw materials.

Let us now consider each stage of development in detail, and Union Carbide's role in it.

Phase 1: More Efficient Use of Petroleum as Feedstocks

During the next 6 or 7 years the petrochemical industry will have to look more and more closely at devices designed to help reduce costs by increasing the efficiency of using crude oil-based feedstocks. Products of crude oil currently provide 35 percent of the industry's feedstock, and are likely to provide a higher share as new gas liquids (which now furnish 39 percent) soar in cost and become harder and harder to find.

Union Carbide's contribution to efficiency of utilization is our advanced cracking reactor (ACR), which has been under development in cooperation with the Kureha Chemical Industries and Chiyoda Chemical Engineering and Construction Company. This reactor can free a chemical company from dependence on specific naphtha, gas oil, or gaseous paraffin feedstocks and permits savings in net processing costs. A $15-

million demonstration plant which is expected to go on stream at the company's Seadrift, Texas, plant in the middle of 1979, will produce 5 million pounds of ethylene a year, enough to allow testing of scale-up parameters in preparation for the construction of a full-scale plant.

The success of the ACR depends on the production of 2000°C superheated steam in a combustion section. Rapid vaporization and cracking of oil droplets occur as the droplets are injected into the high-temperature stream. The cracking time is a few milliseconds, and the steam and reaction products are quenched in a specially designed cooler that prevents further decomposition of the product. The cooling system is based on Japanese patent 90302/1976 issued to partner Chiyoda, and is known as the Ozaki quench cooler heat recovery system. It involves special circulatory features, notably injection of quench oil upstream of the heat exchanger, which prevent fouling of the walls by coke and tar deposition. These features permit efficient waste heat recovery—for example, steam at 600 to 1500 pounds per square inch—from the hot product stream, which is too "dirty" for conventional transfer line heat exchangers.

The ACR has numerous advantages over conventional cracking systems. From the viewpoint of the chemical manufacturer, it is efficient in producing a high yield of valuable chemical intermediates from a unit of crude oil. In fact, 60 to 70 percent of the crude oil barrel is converted to chemicals, as compared to 40 percent in conventional systems. The company can buy crude (a world commodity), or crude oil fractions that may be in surplus because of imbalance in energy end use, and thereby gain a measure of flexibility from oil company supplies. There is also a predicted price advantage in the ACR product estimated to be 3 to 4 cents per pound of ethylene, and a lower sensitivity compared to conventional cracking to variations of price and cost in the marketplace.

The ACR provides flexibility in choice of raw materials for cracking and in product distribution. With respect to raw material, possible feedstocks for cracking extend from naphtha to vacuum gas oil or deasphalted residue, as well as any blend of these, including petroleum distillates and some undistilled crudes. Since such feedstocks produce much the same product spectrum, it is possible to choose the advantageously priced material for utilization in the ACR and not have to accept what is offered. This freedom gives the ACR a substantial edge over conventional technology. Depending on the demand and supply of crude and crude fractions for fuel, the ACR can be fed oil company discards at less than premium prices.

The present concept of the ACR process also includes the recycle of certain reactor products through the system for further cracking. Ethane, propane, and raffinate C_4's can all be utilized to generate more ethylene under favorable economic conditions. Other feedstocks, such as hydrotreated (desulfurized) whole crudes, also would yield more and richer C_4 gas than that obtainable through conventional processes. Sulfur, moreover, is not a restrictive factor in the ACR process; and, indeed, the process train has been designed to remove substantial quantities of hydrogen sulfide (H_2S) and other sulfur compounds.

With respect to the products, for a given raw material the ACR can produce a wide range of products, depending on the "severity" of cracking. This is conveniently measured by the ratio of ethylene product to acetylene (E/A), ranging from 8 or less (high severity) to 25 or more (low severity). At low severities, propylene coproduct approaches in magnitude the amount from conventional olefin plants. At higher severities, propylene falls, but acetylene and aromatics become more important. At E/A = 10, for example, production of acetylene from a billion-pounds-per-year ethylene plant would be 100 million pounds, enough for a sizable vinyl acetate or chloride plant. The upgrading of the liquid products of ACR cracking to higher chemical values is an ongoing challenge.

The ability to shift the ratio of propylene to ethylene over a wide range is of special interest. Conventional technology can make only small shifts in yield patterns and excess by-products must be recycled, fueled, or marketed under distress conditions. The ACR gives us a better chance of balancing product slate with demand in the reactor itself, as well as flexibility in the choice of feedstock.

Phase 2: Coal as Feedstock

In the 1980's or 1990's, as the price of oil continues to rise, we expect to see the beginnings of a shift from oil to coal, which is by far the most generally available substitute for petroleum and natural gas. Known recoverable U.S. reserves of coal run to some 250 billion tons, and ultimate reserves may be twice this. Coal is estimated to constitute about 90 percent of the nation's remaining fossil fuel reserves. Coal as mined is neither chemical nor hydrocarbon but a rather intractable rock, anywhere from 10 to 50 percent of which is mineral matter and water. Conversion to chemical intermediates, whether by gasification, carbonization, or hydrogenation, involves heavy capital expenditure and difficult, potentially polluting processes. Today only South Africa is practicing coal conversion to high-grade fuels and chemicals in any large way, although there are smaller installations around the world.

Although coal is plentiful and United States' experience with its utilization has a long history, coal conversion technology is not as simple as the conversion technology of oil and gas. As one of my colleagues puts it, "Anything you can do with oil you can do with coal—only worse." Handling solids is difficult, especially a solid that may become sticky under reaction conditions. There is the ash which has to be removed, and overriding all the other disadvantages is the problem of air and water pollution. Nonetheless the huge amounts of synthesis gas used today could be made from coal. And many chemical products, especially oxygenated products, could be made from the synthesis gas. Some aliphatic derivatives, notably polyethylene, are more difficult to picture coming from syngas; hence, even as coal's importance as a fuel or a feedstock increases, the ability to bid for a share of the remaining oil and gas supplies will be important to petrochemical manufacturers.

Synthesis gas is already produced in the United States in huge quantities (one estimate puts it at 70 billion pounds per year, calculated as a 1 : 1 mixture of H_2 and CO). And purchase of its precursors, mainly methane and naphtha, is becoming more difficult and definitely more expensive. What, then, is the probability of the raw material base moving to coal? The answer appears to us to be "pretty good," although an interim period is probable in which the base shifts to heavier petroleum liquids, that is, residual fuel oils. A probable scenario making synthesis gas available is the following:

1) The need for medium Btu gas (more or less synonymous with synthesis gas) for upgrading and replacement of methane in existing plant furnaces or for synthetic natural gas to fill the pipelines continues to grow.

2) Coal gasification plants (or heavy oil gasification plants convertible to coal) are built in or near chemical plants.

3) Chemical plants based on synthesis gas from these large units become competitive with plants based on an ever more costly ethylene.

Thus chemicals from coal-based synthesis gas may begin as early as the mid- to late 1980's and become important in the 1990's and beyond.

Processes to make almost any important aliphatic product from synthesis gas can be imagined, although finding an appropriate catalyst is generally the key. Ethylene, for example, can in theory be made from synthesis gas, thus permitting production of the whole spectrum of ethylene products. But, no practicable catalyst directing the synthesis efficiently toward ethylene is available.

The class of organics which has seemed to us to be a most logical candidate for synthesis is the oxygenated aliphatics, especially the polyhydric alcohols. We began to study the feasibility of such processes in the 1960's, after successful development of our low-pressure Oxo process, which makes alcohols and aldehydes. The direct synthesis of ethylene glycol, based on a unique rhodium cluster compound catalyst, has arisen from this work. At present, Union Carbide holds some 15 patents and is involved in extensive development work on the process.

Some time in the 1980's, as ethylene demand catches up to the now overabundant supply, and as oil and gas raw materials continue to rise in price, glycol from synthesis gas should be more attractive than glycol from ethylene. And glycol can join the ranks—with ammonia, methanol, and acetic acid—of bulk commodity chemicals based on synthesis gas.

Synthetic Crudes:

Oil Shale, Tar Sands, and Coal

In our judgment, it is unlikely that synthetic crudes will ever be the dominant feedstock for petrochemicals. Rather, we see such materials contributing to the overall supply of liquid fuels and feedstocks, thereby extending the duration of phase 1, the era of oil and gas.

The estimates of recoverable oil from oil shale run to very large numbers—50 billion, 100 billion, or more barrels depending on economic assumptions used in the analysis. Optimistic estimates of the maximum likely rate of production, however, are about 2 million barrels per day, about 10 percent of present oil demand. Some very optimistic estimates take the figure as high as 4 million barrels a day. Such production cannot possibly be reached before late in this century, at the earliest.

The limitation on shale oil production is not the size of the resource, but rather environmental and logistical constraints. Questions arise as to what can be done with spent shale, where will the necessary process water come from, and how can we avoid contamination of water supplies.

There is no special merit in shale oil as a chemical feedstock. Because of its lower hydrogen content, severe hydrogenation is necessary to upgrade it to feedstock or fuel-use quality. Similar problems exist in the recovery of feedstocks from tar sands. There are, however, two sizable refineries based on the Canadian Athabaska sands, apparently now capable of operating at a profit.

Tars and heavy oils are reported to exist in huge quantities in various parts of the world, often—like the Venezuela heavy oils—at great depths, or in difficult locations. But the logistics, economics, and energy costs of recovering these supplies are unknown. Nor is there any certainty that any net energy could ever be obtained from them. So in the near future, we cannot count on these supplemental sources to augment the world supply of oil.

Synthetic crude oil from coal, however, is a better possibility. Union Carbide hydrogenated bituminous coal in a small plant as long ago as 1955, marketing liquid products made in this process. Currently Exxon, Gulf, Ashland-HRI, and others, supported in part by the Energy Research and Development Administration, are pursuing coal-liquefaction techniques. Liquid products of these processes are even lower in hydrogen content than crude shale oils—totally unsuitable as feedstocks for aliphatic chemicals. However, they would contribute to the overall liquid fuel supply and could also be a potential source of aromatic chemicals such as benzene and phenol. By-product paraffin gases (ethane, propane, and butane) could—if the industry becomes sufficiently large—augment the feedstock supply for olefin plants based on natural gas liquids.

The operation of the first large commercial coal-liquefaction plant seems unlikely before 1990; so too is the development of a sizable industry much before the turn of the century. Therefore, if this happens at all, the impact will be felt mainly in the early 2000's. The same caveat probably applies to various proposals for processes that would make synthetic natural gas liquids (along with methane) from coal—for example, hydrocarbonization and some forms of catalytic reforming of coal with steam. These too would start late in this century and help extend our phase 1 into the 21st century.

Phase 3: Biomass

The ultimate alternative to oil and natural gas is biomass, the world cover of plant life, from weeds to trees. This is already a more significant source of fuel and chemical feedstocks in the United States than most people realize—on a Btu basis, perhaps 2 or 3 percent of the total supply. Like coal, biomass, in the form of starches and sugars, was once an even more important source of chemicals than it is today. The once-sizable fermentation industry, at least as far as bulk products are concerned, has been reduced largely to the production of ethanol and citric acid. While the ethanol is primarily beverage alcohol, a portion reaches the market as a chemical intermediate or solvent. In specific cases, fermentation alcohol already competes with synthetic alcohol from ethylene. A number of other important chemicals, such as glycerol, furfural, sorbitol, and mannitol, are also, entirely or in part, derived from biomass or animal sources.

The attraction of biomass, of course, is that it is the only feedstock which is regenerable. Planners who calculate how much land it would take to supply all the fuel uses of the United States would gag on the total. Assuming 5 tons per acre per year of material that yields 6000 Btu per pound, I calculate the requirement to be 1.27 billion acres or 1.98 million square miles (1 mile = 1.6 kilometers).

But we don't have to gag at biomass as a chemical feedstock. We already produce about half a trillion pounds a year of corn alone, a mass roughly 20 times that of the total ethylene production of the United States. From about 20 percent of the corn crop, we could conceivably make, by fermentation, chemical products equivalent in bulk to the total petrochemical product from ethylene and higher olefins.

Of course, this amount still requires a huge acreage. And corn is a high energy input crop and probably not the best feedstock. Sorghum, hydrolyzed wood, sugarcane, or something new might be better, but I leave this to the agronomists to work out.

As to how much biomass is available to be converted, the Department of Agriculture's Forest Products Laboratory in Madison, Wisconsin, estimates that "the net photosynthetic productivity of the earth," that is, the amount of new green plant life products, is 155×10^9 tons per year, with a total heating value of about seven times that of current world fossil fuel usage. Forests account for 42 percent of this total and croplands account for another 6 percent. Worldwide, the net productivity of forest exceeds, in heating value, the annual consumption of fossil fuels. While this is not true within the boundaries of the United States (after all, we use about a third of the total world's fossil fuel production), our forest's productivity is still very large compared to chemical usage.

Union Carbide has studied the potential of a number of U.S. crops (also of waste materials like newspaper) in terms of their availability for feedstock and the relative costs. Assuming it became necessary to use one of these crops to match the products of a billion pound ethylene plant based on oil or gas, we have noted that, of 18 tonnage crops or agricultural product groups examined, four can yield enough of the chemicals we need without significantly affecting the other uses of the product or its price structure. These include:

1) *Fermentable sugars*. While the costs are still marginal to high, they improve with time and improved technology. In developing countries like Brazil, the route to ethylene from sugarcane via ethanol can be competitive now.

2) *Cellulose-rich products and wastes*. The technology of separation from lignins and of hydrolysis must be improved to make a fermentation route competitive. Possibilities of gasification of wood, forestry wastes, municipal trash, and the like are discussed below.

3) *Corn*. Corn as cornstarch is probably a current prime prospect, although its energy-intensive cultivation may make it less attractive in the future. Corn residuals are also a potential raw material, although many believe these are best returned to the ground as soil conditioners.

4) *Other crops grown on "energy farms."* Of the many crops suggested (including alfalfa, algae, kelp, water hyacinths, and many others), sorghum is already a major crop and is considered a practicable source of fermentable material.

Like coal, biomass, in any of its various forms, can be converted into synthesis gas. The chief disadvantages of the natural materials are their low heating value, high water content, and high harvesting costs. Still, this also is a potential route to all the chemical synthesis gas products.

One version of biomass gasification which Union Carbide has explored in depth is the gasification of municipal waste. The result is our PUROX process, based on a unique, oxygen-fed slagging gasifier that has been extensively shown in a pilot plant (yielding 200 tons per day) in South Charleston, West Virginia. The primary product is a medium Btu gas, much the same as the product of coal gasification. This product can be burned to raise steam and produce electric power or it can be converted into any of the chemical products referred to earlier.

Economic feasibility of PUROX, or of any of the competitive pyrolysis or gasification processes now in various stages of development, depends upon the existence of a sizable trash base—meaning a large population center. It would be perfectly feasible to feed to a PUROX furnace other organic materials, such as waste wood, industrial or agricultural wastes, or even the intentionally grown products of a future "energy farm."

The PUROX interest is primarily to supply a clean, economic method for disposing of municipal America's mounting mountain of solid waste. If the economics could be improved by the use of the gaseous product for chemical production, thus contributing to the overall feedstock supply, this improvement would of course be highly desirable. And extension of gasification to forest products—perhaps in timber-rich, fossil fuel–poor areas of developing countries, or even of the United States—is a definite possibility.

We have no doubt that biomass feedstocks will gradually expand in importance as the cost of petrochemical feedstocks grows. Ethanol fermentation will become more important, perhaps by way of such projects as Nebraska's "Gasohol." We in Union Carbide are sufficiently impressed by the potential importance of biomass to dedicate a sizable research and development group to various fermentations and other biochemical conversions. By the year 2000, the amount of biomass conversion should be significant.

These are the paths along which we see alternative feedstock technologies developing. Since oil and gas will dominate the feedstock picture for many years, the first step is to improve the efficiency of their use. But since these are finite resources, the industry is moving aggressively to develop economically attractive alternatives as the supply of oil and gas dwindles and the price continues to go up. Coal-based synthesis gas leads the list because of the abundance of coal and because of long industrial experience in synthesis gas processes. Crude oil from shale, tar sands, and coal will become more attractive as the price of crude from conventional sources goes up. Finally, increasing oil and gas prices and improving biomass and solid waste utilization technologies will make these sources attractive as feedstocks by the 1990's. By 2000, we predict that feedstocks from all sources other than oil and gas will constitute 10 to 15 percent of the total, but certainly less than 25 percent.

This leads to a larger lesson, namely, the roles and uses of technology in meeting the broader energy crisis. Whatever form the National Energy Act takes, we are certain that scientific and technological innovation will be the true driving force of the plan for both conservation and the development of new energy sources. And this must be done within a framework of high but workable standards for environmental quality and public health and safety. This is an imposing challenge, but one that can be met if we use our resources and resourcefulness wisely.

Those of us who take our signals from the marketplace have known for many years that oil and gas would be in a "price crisis" in the 1970's. Accordingly we have utilized research and development to find alternatives to oil and gas in their use as feedstocks. We are confident that our industry can and will use technology to make the transition to alternative resources so that we can continue to provide the products our civilization has come to need and demand. And given the willingness to use technology responsibly, we are confident that all sectors of the nation can do the same for other uses of oil and gas as well.