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PROSPECTS FOR BIOTECHNOLOGY IN A RESOURCE-LIMITED WORLD

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It is certainly unnecessary, before this audience, to discuss the nature and extent or recount the history of the resource problems which now face the industrialized world. In little more than a century of intense - and frequently wasteful - industrial development, material resources accumulated in the earth over millenia have been consumed. Petroleum is only the most obvious example. Most of the minerals upon which modern technology depends are in short supply in Europe, Japan, and North America (1). For many of these materials, the industrialized world is almost totally dependent upon external sources, many of them in areas suffering from social and political instability.

Arguments abound regarding the causes of and responsibilities for our current resource dilemma. Everything from "acts of God" to "conspiracy" has been claimed but the primary cause is certainly the desire for material affluence which pervades the middle-class societies of Europe and, especially, the United States. Pogo, the American cartoon character, put it well when he said: "We have met the enemy and he is us!"

But, my business here is neither to analyze our difficulties or place blame. We are desperate for viable solutions to our resource problems; preferably solutions which will reduce our standard of living as little as possible - for it will be reduced! I therefore wish to offer some thoughts on possible approaches to our resource dilemmas and, more specifically, to argue that biotechnology enjoys a special opportunity to contribute to their resolution. This opportunity arises, I believe, from certain unique characteristics inherent in the nature of bioprocesses.

In order to better focus this discussion, I shall employ a specific application of biotechnology, the production of alcohol (ethanol) from cellulosic materials for fuel use. This is a matter of broad current interest and intense debate. It therefore brings a special relevance and immediacy to an otherwise general consideration of the prospects for biotechnology in a resource-limited world.

One final point is in order in these introductory remarks. With apologies to the audience for stating what may well be obvious, I would like to offer brief definitions of the two terms used above: "biotechnology" and "bioprocesses." Biotechnology can be said to embrace all aspects of the exploitation and control of living cells, or their products (e. g. enzymes), to achieve desirable ends. Bioprocesses have been defined (2) as "a collection of steps, at least one of which involves a biological entity, whereby materials are transformed by chemical or physical mechanisms."

APPROPRIATE TECHNOLOGY

If biotechnology is to contribute importantly to the resolution of material resource problems, technical elements - the bioprocesses themselves - must be closely integrated with raw material sources and product markets. We must be especially aware of competing claims on renewable resources, for what one man considers waste may be another's need. And finally, we must be careful to include specific and realistic social costs and benefits in our proposals.

In this context let us look for a moment at the concept of "appropriate" - or "intermediate"- technology. These terms are not easily defined because they mean different things to different people. Indeed, what is appropriate to one situation may be quite inappropriate to another.

Despite this fundamental ambiguity, there is no shortage of formal definitions. For example:

> Appropriate technology is a process of establishing social and environmental goals, evaluating the potential positive and negative social and environmental effects of a proposed technology before it is developed, and then attempting to incorporate beneficial elements into the various phases of development and utilization (3).

Putting aside formal definitions, we find considerable agreement on the essence of "appropriate technology." Most fundamentally, it suggests the matching of local resources to local needs and the employment of local talents and techniques to convert the first to meet the second. For many, "appropriate technology" is closely identified with E. F. Schumacher's Small is Beautiful (4); indeed, "small-scale" is an integral part of many definitions.

Some characteristics of appropriate technology are identified in the following statements from a recent study (5):

> Appropriate technology . . . means technology that is optimal for a particular situation in a particular . . . nation, given that nation's economic and social conditions and goals. . . . for many nations this would imply technologies which are capital-saving and/or labor-intensive . . . . It would also imply technologies that are relatively easily learned by workers with no prior industrial training or experience and technologies to produce goods which are less specialized, simpler to use, and more versatile. . . . The manufacturing processes implied by these appropriate technologies do not necessarily have to be small in scale; hence appropriate technology. . . should not be considered synonymous with cottage industries or . . . Schumacher's concept, "small is beautiful."
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> It is not at all clear that highly labor-intensive technologies are appropriate for all industrial sectors, even in developing countries. . . . Moreover . . . capital-intensive investments in some basic industries . . . may be the most effective way to promote small and medium-sized industry and establish. . . conditions for maximum overall employment in the economy.

The two references to E. F. Schumacher invite further comment. His views now exert enormous influence in the world; indeed he may well deserve a place in the pantheon of the "worldly philsophers"(6). Schumacher was not, as some have claimed, an "anti-technologist." He emphasized the potential virtues of decentralization, diversification, and scale-down in managing our increasingly scarce material resources. In doing so he urged the utilization of a wider spectrum of technologies, each better suited - or more "appropriate" - to a particular time and place than the monolithic, single resource-base approaches which now dominate the industrialized world.

But, what has all this to do with biotechnology? Very much, I submit. Many of the qualities cited above as characteristic of "appropriate technologies" are inherent in bioprocesses. They can accept a variety of different raw materials to produce the same products. They are "relatively easily learned, less specialized, simpler to use, and more versatile." Indeed, Finn and Fiechter, in a recent paper (7), emphasized exactly these attributes of bioprocesses. They say that:

> "A major strength of the fermentation industry has always been the simplicity and versatility of its reactors. A standard stainless steel tank, baffled, aerated and with a set of turbine agitators can turn out a variety of . . . products. Such versatility is rare in the chemical industry."

Another inherent asset of the classical fermentation reactor is that increased plant capacity can readily be achieved by adding more of these basic units. This means that the capital costs of fermentation plants are less sensitive to scale-factors. As a consequence, the investment incentives for building one large plant rather than several smaller ones, as in the petrochemical industry, may be substantially less for bioprocesses. Biotechnology is therefore especially suited to the generation of "appropriate technologies."

BIOTECHNOLOGY AND ENERGY RESOURCES

Western Europe, Japan, and, especially, the United States, are now plagued with periodic shortages of fuels and with rapidly climbing energy costs. The causes of these conditions are complex in detail but simple in principle. Over the last four decades industrial societies have permitted themselves to become excessively dependent upon petroleum and natural gas as their basic energy resources. During this same period, increasing affluence and the desire for convenience in these societies have led to a rapid increase in demand for products derived from these commodities, especially internal combustion engine fuels.

We have but four options for alleviating our current, painful situation and the uncertainties which lie before us. Industrialized nations may:

(1) Increase supplies of petroleum liquids and natural gas, or their equivalents, within the areas where they exercise economic or political control.

(2) Make more effective use of existing resources.

(3) Curtail consumption of these materials.

(4) Replace petroleum and natural gas derived fuels with those obtained from other sources.

It should be noted that each of these options entails significant choices with regard to social values. The first will bring economic advantages to some segments of the population but environmental costs will surely be high. Furthermore, available evidence does not support the belief that large new oil or gas resources are likely to be found. The second option - a primary element of "energy conservation" efforts - is an obvious requirement which can have positive economic consequences. Only the third choice - curtailment of consumption - is likely to reduce our standard of living.

The final option - substitution - incorporates two additional choices. We may turn to other fossil resources, coal or oil shale, for example, or to renewable, i.e. solar-derived energy forms. Among the several manifestations of solar energy which we can employ, only biomass has a built-in storage mechanism to bridge the seasonal and diurnal variation in the sun's radiation. Furthermore, pending the development of efficient electric vehicles, the only practical approach open to us for the production of solar-derived, portable liquid fuels is the conversion of biomass to alcohols, methanol and ethanol. From this circumstance, an outstanding opportunity for biotechnology has arisen.

ALCOHOL FUELS

We may complain about the social and environmental burdens imposed by automobiles and trucks but we cannot, for the present, do without them. For more than half a century we have been building our "life-styles" and their physical expressions - homes, factories, businesses, etc. - around increasing individual mobility and we must now "pay the piper." A portable fuel, compatible with the existing technical and organizational infrastructure of mobile transportation, is therefore a <u>sine qua non</u> for the industrialized and, indeed, much of the developing world. We must surely use available petroleum resources more effectively but, for the next few decades, we cannot do without adequate supplies of gasoline and diesel fuel, or their equivalents.

The lower alcohols, methanol and ethanol, are the only reasonable candidates to replace petroleum-based liquid fuels. They can be used in existing engines either as blends with gasoline or "straight" (alcohol only). Automobiles can be operated, with varying degrees of satisfaction, on blends of alcohol and gasoline ranging up to about 20% alcohol. Blends containing less than 10% ethanol ("gasohol" in the U.S.) require little or no modification of the vehicle; methanol blends are less satisfactory, although they may be used (8).

Technically, either alcohol can also be used "straight." The disadvantages of a "pure" alcohol fuel are considerable:

(1) Fuel consumption increases significantly (as much as 60% for methanol; much less for ethanol) because of their oxygen contents and correspondingly lower heats of combustion.

(2) For the same reason, fuel tank and pump capacity and fuel line sizes must be greater for a given power output.

(3) Cold starting can be a problem, again especially with methanol.

(4) Methanol is corrosive and toxic; ethanol could be illicitly diverted to beverage purposes.

(5) Excessive vaporization losses and vapor lock may be encountered.

On the positive side, alcohol fuels offer:

(1) High octane ratings; RON's (Research Octane Numbers) of 106 to 115 for methanol and 106 to 107.5 for ethanol have been reported (9). Reported MON's (Motor Octane Numbers) for methanol range from 82 to 92; for ethanol from 89 to 100.

(2) Reduced emissions: Alcohols contain no sulfur and can release no unburned hydrocarbons. The lower engine temperatures associated with their combustion should reduce NOX formation. (With blends, however, experimental tests have indicated increased NOX emissions.)

So far alcohol fuels have been used almost exclusively in engines designed for gasoline. The development of engines specifically for alcohol fuels, featuring higher compression ratios (13-14 rather than the 8-8.5 typical of current models), and probably lighter in weight, appears to offer advantages. Such a unit is reportedly being studied in Brazil but performance information is not yet available.

ALCOHOL FUELS: PAST AND PRESENT

Alcohol fuels for internal combustion engines have had a checkered history. They were often used in experimental automobiles of the late 19th century and have been utilized in times of gasoline shortages, for example, in Germany and Eastern Europe during and after the 1914-1918 and 1939-1945 wars. During the 20's and 30's many European countries either made the supplementation of gasoline with alcohol mandatory or provided tax incentives to encourage it. These programs reflected both the general agricultural depression affecting much of the world during this period and the availability of surplus alcohols - from excess wine production, for example - in some countries.

Although these alcohol-supplemented fuels were satisfactory in a technical sense, the overall programs were less so. It has been claimed (10) that the essential difficulty was the instability of alcohol supplies. Since surpluses were the basis, the supply of alcohol for incorporation in fuel varied greatly and government regulations were changed frequently. This necessitated equally frequent engine adjustments followed by increasingly negative consumer reaction.

Willkie and Kolachov (10) in the United States, offered a provocative argument for an extensive, carefully planned alcohol program. They urged the use of pure (190-proof or 95%) alcohol, rather than blends. They argued that "captive" markets existed, farm tractors for example, which could support such a program and that the use of pure alcohol rather than blends would eliminate the greatest short-coming of the earlier program. Willkie and Kolachov's proposal was published on the very eve of America's entry into the second World War. It represented the culmination of one of the strongest arguments in the "chemurgy" program of the 1930's, conversion of grain surpluses to "power" alcohol. The exigencies of a war economy, however, overwhelmed it. Grain surpluses disappeared as the U.S. was called upon to feed its allies during the war and much of western Europe after it. There was considerable production of alcohol from grain during the war but this was needed to supply increased industrial requirements and to replace the imported molasses previously used.

Since 1945 the United States has helped to supply the food needs of nations which had previously been cereal grain exporters but whose population growth had outstripped their own productive resources. The grain surpluses of earlier decades steadily dwindled away until, in the 1970's, shortages, for export at least, and rapidly increasing prices were encountered.

Despite this unfavorable climate, the dream of alcohol fuels lingered on until two factors, the oil embargo of 1973-74 and rising cereal grain surpluses since 1975, breathed new life into the concept. In the United States, "gasohol" (normally 10% alcohol and 90% gasoline) is now marketed widely in the grain producing Midwest and its availability elsewhere is growing rapidly. Brazil has committed itself to widespread use of "gasohol" fuels and, increasingly, "straight" alcohol. It is said that Brazil's plan calls for all motor cars to be fueled with alcohol by 1990.

Brazil's fuel alcohol will be produced from sugar cane and the starches of cassava root, babassu nuts, and sweet potatoes (11). Sorghum is another potential source. In contrast to the cereal grains now being converted in the United States, the Brazilian crops do not require intensive fertilization with petroleum-based plant nutrients.

This last point is the basis for considerable skepticism regarding the potential for "gasohol" in the United States. It is argued that if one accounts fully for all energy inputs, including the petroleum or natural gas consumed in producing fertilizers, fuel used on the farm and in the distillation of alcohol, etc., the use of "gasohol" will result in a national energy loss rather than gain. This debate remains unresolved, however, especially in the light of potential improvements in alcohol production technology (12). It is nevertheless clear that nations lacking crops like sugar cane, which give high yields without heavy fertilizer use and intensive machine cultivation, cannot expect to significantly improve their national energy balances through the use of alcohols from agricultural sources.

It is, of course, most sensible to convert damaged cereal grains, or those rendered unfit for food use in any way, to fuel alcohol. In the United States today, however, a major argument for "gasohol" is that it will consume surplus grains. Given the energy balance considerations noted above, this argument loses force. Clearly a national policy which encourages the production of unneeded grains, and thereby consumes vital petroleum or natural gas, must be questioned.

Even if the overall energy balance for ethanol production from alcohol were found to be favorable, the maximum amount of alcohol available from cereal grains in the United States would replace only a small fraction of current gasoline consumption. Many different calculations to support this view have been offered. While their conclusions differ in degree, they all arrive at similar orders of magnitude. For example, Keller (8) estimates that conversion of the entire U.S. production of corn (maize), wheat, barley, oats, and grain sorghum plus the indigenous sugar crop would yield ethanol equivalent to about 15% of 1977 U.S. gasoline consumption.

The various naturally occurring cellulosic materials constitute another potential source of fuel alcohols. Furthermore, they offer, in principle at least, many advantages over the intensively farmed cereal grains. Technologies for the conversion of cellulose to sugar are, however, still not sufficiently developed for them to be economically competitive with alcohol production from sugar and starch - at least at current prices for these commodities.

The specter of availability also hovers over the cellulosics, although the information at hand is very poor and subject to widely different interpretations. This is especially true for so-called "wastes" and "by-products." Even so, available supplies of conventional cellulose, e.g. from the forests, would not replace significant amounts of gasoline. Again, Keller (8) estimates that conversion of the entire U.S. wood harvest - not just the waste - to methanol by pyrolysis would provide the equivalent of 14% of 1977 U.S. gasoline consumption.

Sometime ago I estimated (13) the gasoline equivalent which could be generated by converting to ethanol the cellulosic portion of the 200-million tons (an admittedly imprecise figure) of "mixed municipal refuse" (solid wastes) then said to be produced annually in the U.S. Assuming demonstrated yields for glucose from cellulose and ethanol from glucose, one could produce fuel alcohol equivalent to about 5% of 1974 U.S. gasoline consumption from this waste source. Others have reached similar conclusions.

If these estimates are at all fair, the potential for fuel alcohol production from renewable resources appears to be extremely limited. If this is the case, are not the prospects for biotechnology in this area rather bleak? And how is it possible for me to claim - as I did earlier - that biotechnology enjoys a special opportunity to contribute to the resolution of our resource dilemmas? The answer to these questions lies, I submit, in employing bioprocesses in the "appropriate technology" mode rather than in direct competition with conventional - or new (e.g. coal) - sources of portable fuels.

I cannot conceive of any large-scale use of biomass-based alcohol fuel in the near future or, for that matter, ever. I do, however, believe that ethanol produced from locally available, renewable resources to meet local needs could be a key to the avoidance of serious economic and social disruption in specific regions, both of the industrialized and the developing worlds. I will now attempt to support this contention with a specific illustration drawn from my experiences over the last four years.

APPROPRIATE BIOTECHNOLOGY

Among the fifty states, Vermont ranks relatively low in all things except physical beauty. The state has less than 500,000 inhabitants, mostly dispersed in small towns and villages. On the national scene, this small population affords little political influence. There are few urban areas, and no large ones. Heavy industry is completely absent and only one area enjoys a significant concentration of modern, "high technology" industry. Per capita income is low, especially if one eliminates from the average the more affluent area just noted.

Physically, Vermont is much like the southern Scandinavian peninsula. It is mountainous with many rivers and lakes. Winters are severe and the growing season is short. Almost 80% of the land is now forested, although this resource had been reduced through intensive logging and sheep raising, to about 25% at the end of the end of the 19th century. The forests are a mixture of northern hardwoods (American beech, sugar, maple, and yellow birch predominating) with boreal zones ("Taiga") comprising spruce and firs. These forests are the state's primary natural resource, for nature has provided no mineral wealth except for decorative stone. Long, cold, winters, a small, dispersed and predominantly rural population, a lack of fossil fuel resources, and a growing economic dependence on tourism have made Vermont uniquely vulnerable to aberrations in the supply of petroleum-based fuels. Moreover, the Northeastern U.S. is almost completely dependent on liquid fuels produced from imported crudes so prices are high and the dangers of embargoes extreme.

Vermont has responded to these challenges with a rapid increase in the exploitation of its one local energy resource - wood. During the 1977-78 winter nearly two-thirds of the space-heating needs of individual homeowners in the State were met by firewood and the first commercial unit in the U. S. to generate electricity from wood is in operation and being expanded. These developments and others - e.g. hydroelectric expansion - have greatly improved the energy supply situation but the need for a reliable source of portable liquid fuel remains critical. It is here that opportunities for "appropriate biotechnology" can be found.

In order to realize the potential for meeting local energy needs through biotechnology, certain basic requirements must be met:

(1) specific, "captive" markets for the projected product - fuel ethanol - must be identified.

(2) reliable sources of local raw materials suitable for producing the product must be established.

(3) specific technology for converting these resources to the product must be selected.

(4) simple, small-scale plants for converting the local raw material to ethanol, compatible with locally available capital resources and management capabilities must be designed and built.

(5) local people must be trained to operate and maintain these plants.

Some additional comments on these several criteria will illustrate certain key considerations.

First, "captive" markets are essential; we cannot expect to transfer fuel ethanol to those who can use it via the normal gasoline distribution system. Typical "captive" markets which have been identified in Vermont are:

(1) local city bus systems

(2) farm equipment (trucks, light tractors, etc.)

(3) state police and highway service vehicles.

In the longer term, one can envision an alcohol-fueled minibus fleet bringing tourists - and their revenues - from urban areas north to the State's resorts!

Second, reliability of raw material supplies must be carefully assessed. This has proven to be the "Achilles heel" of many such schemes in the past. It is essential that the planner identify competing uses - existing or prospective - for supposed resources, especially those classed as "wastes", as well as more obvious factors such as seasonal variation, etc. Potential raw materials for fuel ethanol production in Vermont are:

(1) whey from cheese plants, currently a serious environmental problem.

(2) waste paper from the urban areas. (Recycling activities are already in existence and separated waste paper is a superior raw material for conversion to glucose because the pulping process has already destroyed the recalcitrant wood structure. This use of waste paper illustrates, incidentally, the "highest use" concept for forest products. The overall value realized by first converting wood fibers to paper and then using the paper for fuel is greater than that realized by burning the wood directly.)

(3) wood and wood wastes.

Technology for converting cellulose to glucose, either chemically or biologically, is available. Biological conversion offers many attractions but is less well developed (14). Recent advances and the prospect of greater support for process research and development in this area are encouraging, however. Other advantages of the "appropriate technology" mode in Vermont are:

(1) the potential for using firewood for alcohol distillation (it is already widely used to fuel evaporators in the local maple syrup industry).

(2) the existence of a local dairy industry market for by-product feed materials.

The last requirement - design of small-scale plants compatible with local capital resources - is technically simple but poses, in practice, the most difficult problem. Small-scale enterprise has certainly lost ground throughout the industrialized world in recent decades. Indeed, this is the essence of Schumacher's appeal. Conventional private sources of capital are suspicious of and reluctant to support them. Government programs, on the other hand, frequently impose bureaucratic strictures that stifle local initiatives.

At the same time, however, the advantages, noted earlier, which bioprocesses offer for small-scale plant design constitute an important asset. Furthermore, the social benefits which will accrue to the inhabitants of the poorer regions of Vermont - and places like it - must be fairly counted. Such plants will generate local income from local resources and end the flow of money out of the region and the nation for the purchase of petroleum-based fuels.

It should not be surprising if the foregoing considerations have a familiar ring. The same points may be found repeatedly in discussions of the prospects for technology in developing countries. What is new is the setting. The economic and social pressures arising from growing dependence on foreign energy sources have created conditions in some regions of the "highly developed" countries which approximate those encountered typically in the so-called "less developed" nations. Just as increased exploitation of indigenous, renewable resources through innovative, small-scale technologies has improved their quality of life, so it may for us. As we share ever more common problems, we may also be able to share similar solutions.

SUMMARY

The industrialized world faces, at best, major alterations in its economic fabric as the limitations of its physical resource base become more acute. As these strictures press harder on us, fuller utilization of renewable resources to meet material and energy needs becomes ever more attractive. Biotechnology enjoys a unique opportunity to contribute to the fuller employment of renewable resources. The production of portable liquid fuels from biomass is an example. But such a development will not occur automatically. We must recognize and exploit those characteristics of bioprocesses which offer unique advantages. These include relative simplicity, versatility, and a lesser penalty for small-scale operation. It is therefore essential that conversion technologies - the processes themselves - be closely integrated with prospective markets and raw material sources. All these considerations suggest expanded emphasis on "appropriate biotechnology."

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