

CHEMISTRY, POPULATION, RESOURCES

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Plant photography by Genevieve Calvin

Abstract - Chemistry has played a central role in improving living conditions and therefore contributing to the increased population of the last century, with its concomitant drain on natural resources, particularly energy. It will be a chemical task to help provide the means of supporting that increased population and particularly the energy it needs in the future.

INTRODUCTION

Chemistry plays a dominant role in the development of modern human societies over the entire globe. It has done so by virtue of the central position it has occupied in improving the health and nutrition of people, as well as by improving their physical environment by providing the new and necessary amounts of materials for clothing, shelter, transportation, and other such amenities of the modern organized world. As you will see in a few moments, this double role has both its merits and its demerits. As a result, at least in part, of the contributions of chemistry to the improvement of the food and nutrition of the global population (Ref. 1), as well as a contribution to the improvement of the public health and the health of individuals, the population of the globe has been rising very rapidly, as shown in Fig. 1.

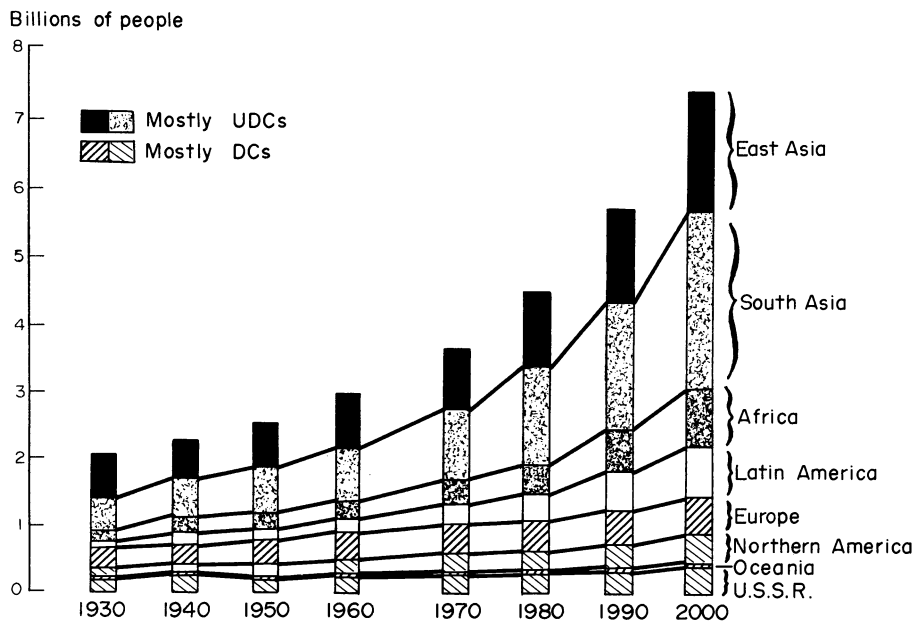


Fig. 1. World population projections.

POPULATION

The projection here is that the population will rise to about seven billion by the year 2000 from a present value of about 3.5 billion. Most of that rise in numbers will clearly take place in Asia, in Africa, and in Latin America. Part of the reason for this differential, of course, is the fact that the rest of the world has already reached some new equilibrium, with the better living conditions which chemistry has helped to produce, whereas the aforementioned countries are just now reaching it.

One of the ways in which one can evaluate that differential is to note what has happened to the life expectancy at birth in the Western countries, such as the United States and Western Europe, in the last hundred years. This enormous increase in life expectancy from forty to about seventy years in the one hundred years just past, shown in Fig. 2, appears now to have

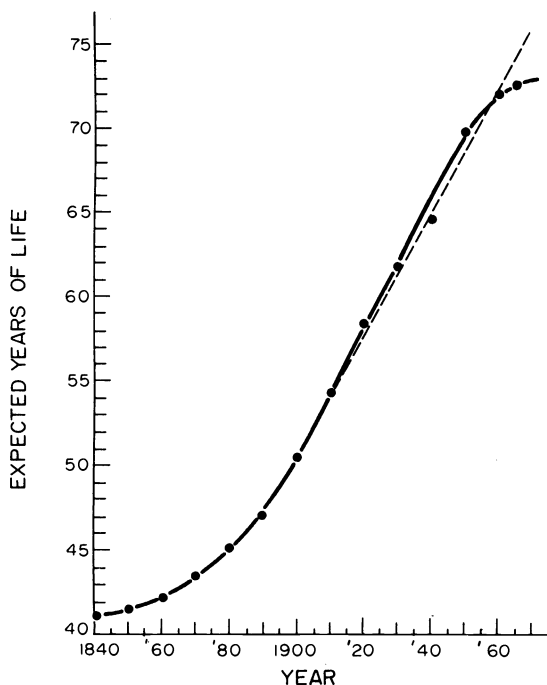


Fig. 2. Average expectation of life at birth: Europe and the U.S.

reached some kind of new level. The life expectancy in the less developed countries, in which the population growth is expected to take place, is at present some twenty to thirty years less than that shown for the Western world; as these less developed countries improve their public health, nutrition, and medical facilities, they too can expect an increased life expectancy, and therefore have a much higher impact on the population of the world.

One of the factors which has been of major influence on the growth rate of population has been the increased food supply and the better nutrition that has resulted therefrom. Chemistry has played an enormous role in this development by helping to produce the fertilizers that were necessary for the higher production, as well as in playing a role in the food processing and the preservation of food after it is grown. We can expect molecular biology, a specific branch of chemistry, to have an even greater impact on the quality of the crops that will be grown in the coming years; and therefore again we can expect that the productivity of the acreage that we have available will actually increase even more.

AGRICULTURE

The contributions of chemistry to worldwide agriculture and to the increased productivity in all parts of the world is made clear in Fig. 3. Here one can see that in all of the four groups of countries shown, the absolute rate of production of food is increasing at very nearly the same rate throughout the world. However, when we look at it in terms of the per capita availability of food, we see that only in the developed countries such as the United States and Western Europe is the actual amount of food per person increasing, whereas in most of the other countries the amount of food per person is barely remaining constant over

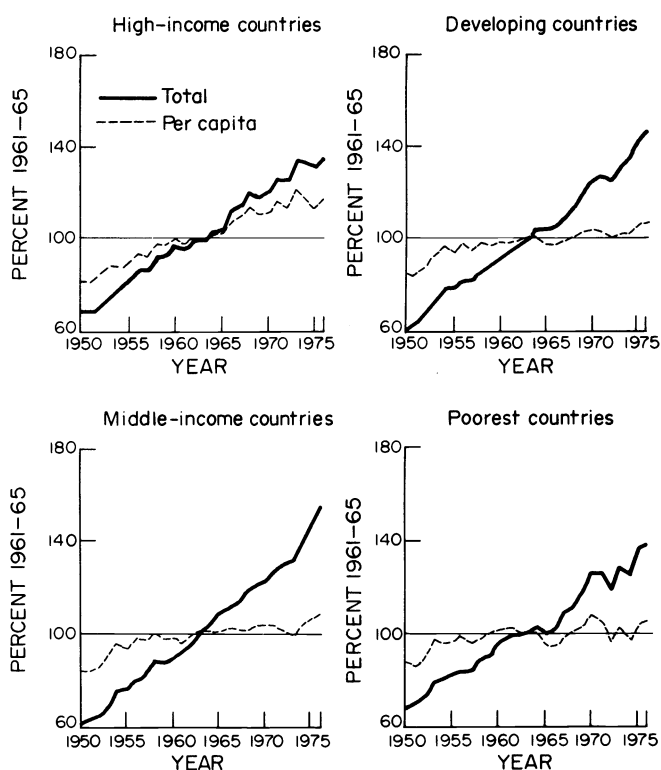


Fig. 3. Food production indices: total and per capita, 1950-1976.

the last twenty-five years. The reason for this is now clear. The food production capability is increasing in all parts of the world at about the same rate, due to the improved technologies. However, the population increase in the less developed countries is increasing even more rapidly, with a consequence that the per capita food available in these places has remained very nearly the same for the last twenty-five years. Thus it is clear that the problem is not so much in improving the rate of food production as it is in reducing the rate of population growth. This, also, is a problem to which chemistry will help and contribute. However, chemistry cannot solve the problem by itself. Nevertheless, one can expect that chemistry will play an important role in helping to provide a feasible and useful means by which various societies will not only be able, but willing, to help in the control of their own populations, thus allowing the increased food productivity which chemistry has also provided to increase the available food per person in those countries, thereby also contributing to the increased life expectancy and the health and well-being of the people in them.

One of the ways in which chemistry has been able to improve the productivity of the agricultural community has been to provide it with the necessary fertilizers and other energy-consuming assistants, to improve the yields. This has led to a high energy consumption in those countries in which there is a high food production, and consequently a high gross national product, however one measures it.

ENERGY AND MATERIALS - PRESENT USE

There are various ways to examine this relationship between energy consumption and social values. One way is shown in Fig. 4, in which the energy consumption per capita is indicated. Here one sees that the energy consumption per capita is highest in those countries in which the standard of living is highest, such as North America, Western Europe, and Japan, whereas in those countries in which the standard of living (however it may be measured) is low, the energy consumption is low.

Another, and perhaps even more realistic, way of looking at it is to examine Fig. 5, in which we show the relationship (at least in the United States) between the value of the gross national product produced by the country per million BTU's (a unit of energy) that it uses. It is clear that, in general, the increased value produced per unit of energy used means a more efficient organizational and structural entity, and this has been the case over the last twenty-five years, as is evident in this figure. In fact, part of the reason why the agricultural productivity in the United States has been so bounteous as to be able to be an important aid to the rest of the world has been because of the large input of energy into our agricultural activities. This energy has had its source primarily in the form of fossil

REGION	1950		1960		1970	
	POPULATION (MILLION)	Per capita CONSUMPTION (10 ⁶ BTU)	POPULATION (MILLION)	Per capita CONSUMPTION (10 ⁶ BTU)	POPULATION (MILLION)	Per capita CONSUMPTION (10 ⁶ BTU)
NORTH AMERICA	166.1	221.9	198.7	245.1	226.2	329.3
CANADA	13.7	197.6	17.9	217.0	21.4	328.9
UNITED STATES	152.3	224.3	180.7	248.0	204.8	329.3
WESTERN EUROPE	302.4	57.8	326.5	79.8	356.4	134.3
OCEANIA	12.2	73.0	15.4	90.8	19.2	127.7
LATIN AMERICA	161.9	14.8	212.4	23.3	282.0	32.4
ASIA (EXCL. COMM.)	805.4	4.7	970.6	8.5	1231.3	16.9
JAPAN	82.9	21.0	93.2	39.4	103.4	208.9
OTHER ASIA	722.5	2.9	877.4	5.2	1127.9	8.5
AFRICA	217.0	6.0	276.0	7.8	349.5	10.5
USSR & COMM. EAST. EUR.	269.8	47.6	312.9	83.0	348.4	128.5
U.S.S.R.	180.0	46.8	214.0	83.5	242.8	131.8
EASTERN EUROPE	89.7	49.2	98.5	82.0	105.6	120.9
COMMUNIST ASIA	569.8	2.2	677.5	9.7	795.6	14.2
WORLD	2504.5	30.7	2989.9	41.5	3608.6	59.4

FROM: ENERGY IN THE 1980's (ROYAL SOCIETY OF LONDON)

Fig. 4. World energy consumption and population.

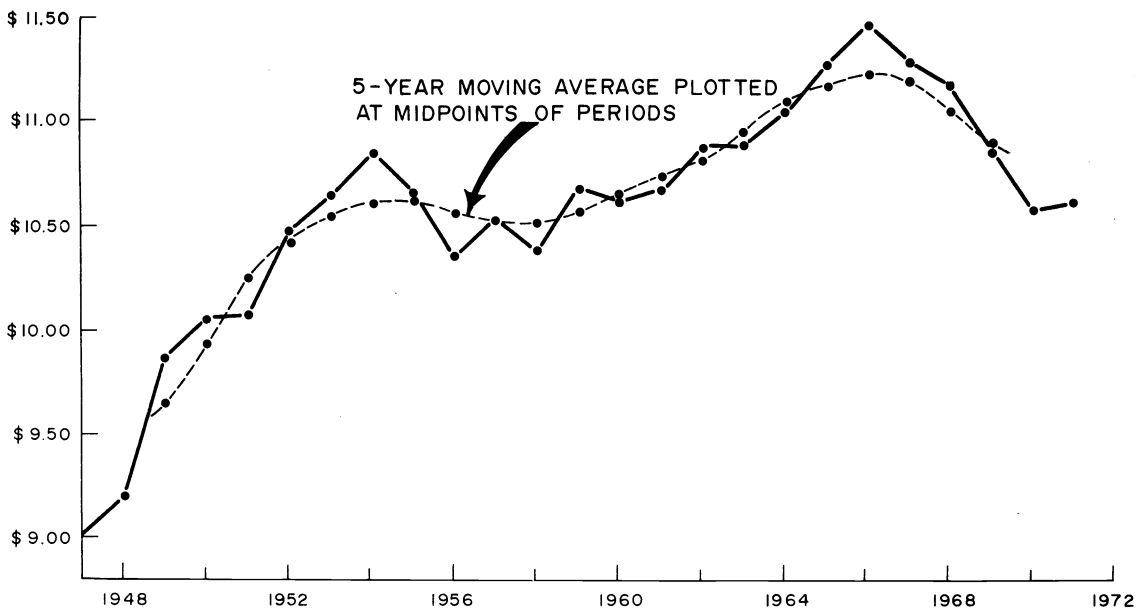


Fig. 5. Dollars of gross national product per million BTU, gross energy consumption.

energy - namely coal, oil and gas. In recent years, however, it has been dominated by oil and gas, which are more convenient, and more environmentally acceptable energy sources than coal. However, there is a limit to how much of this fossilized photosynthetic carbon is available, and the limits are already visible - especially in the oil and gas areas.

The next figure (Fig. 6) shows the rate of discovery of new oil in the United States as a function of the number of feet of well drilled. It is evident that there has been a sharp decrease in the rate of new discoveries, even though the drilling rate has increased. This

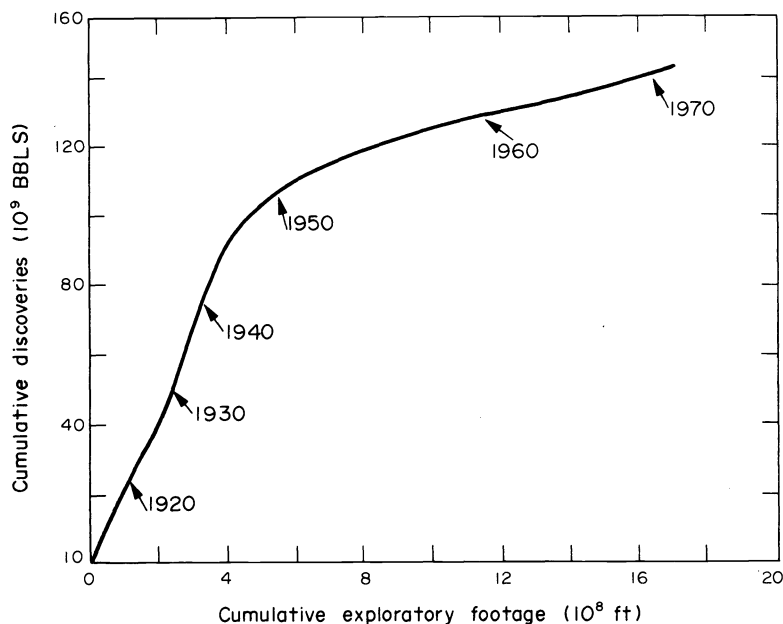


Fig. 6. Cumulative U.S. crude oil discoveries per foot

decrease began in about 1950, and it is now leading to a total decrease in the net available oil on the American mainland. It can only mean that the available oil to be found in this geographical area has now passed its peak, and that we can only look forward to a decrease in the total amount that we will have available from this source. In fact, we believe that the peak production capability in the continental United States was reached several years ago. It also appears to have been reached on a global scale as well, as shown in Fig. 7.

COSTS AND AVAILABILITY

Another different way of making an estimate of the availability of resources is to look at the history of the costs that have been attributed or laid down to a particular resource. In this case, we are considering now the fossilized photosynthetic materials: coal, oil, and gas. In Fig. 8, I have shown a price history of these three materials in the United States over the last fifteen years, with a projection of what that price might be in the next four or five years. As you can see, it was fairly constant for a period of about ten years, and then began to rise very sharply - partly for political reasons, and partly for technical reasons of shortage.

The separation of these two factors is not possible for me. In any case, as the price rises the result of that price rise will be a more limited use of the materials, so that we must find other ways of fulfilling our needs. We can hardly expect that the price of oil or gas will ever fall again to anything approaching the values shown in the first ten years of this illustrated period. There is not much question that at least part of the reason for this is the real and total depletion of the stores of such materials that are presently in the Earth. If we accept for the moment the basic premise that most of this oil and gas (if not all of it) was once the product of a living organism, using the sunshine as a source of energy, we can be sure that the amount of it available to us stored in the ground is a limited amount by the standards that we are now using for the rate of its use. In fact, there have been a number of historical analyses of other resources going through a similar use and depletion cycle, and it has been suggested that we are already on the decaying side of the oil depletion curve. Therefore, we can expect it to be truly used up within a relatively short period of history.



Fig. 7. World oil discoveries (5yr running mean) excluding U.S.S.R., Eastern Europe and China.

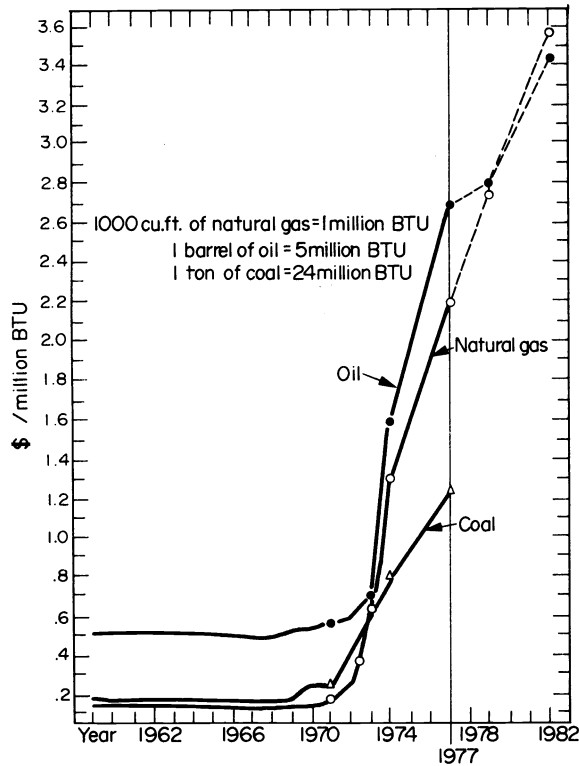
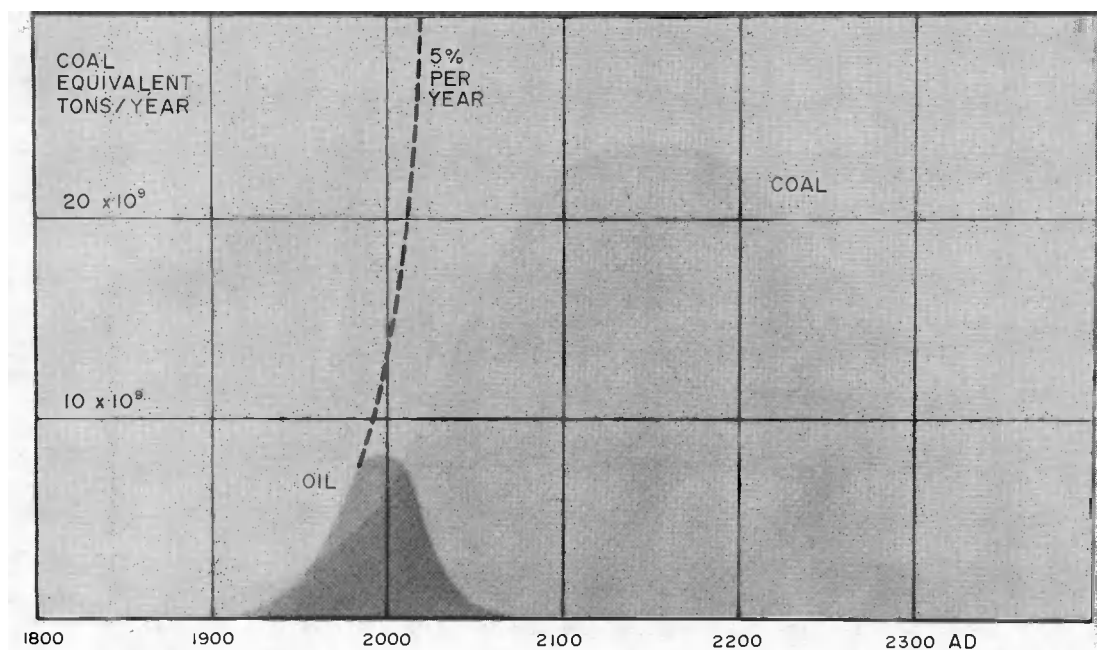


Fig. 8. Average fossil fuel prices in the U.S. at point of production.

The amounts of available coal, however, are globally believed to be much higher. In Fig. 9, the two resource use curves are superimposed on each other, and it is clear that the coal resource use curve extends far beyond any limits of technology which we can now perceive. It is for this reason that many of our political leaders, both domestically and internationally, have supposed that we could go forward with a much larger expectation for coal use



from Quest, 1977

Fig. 9. Oil and coal use cycles.

than we have in the past, this this would carry us into the next century, by which time our solar and nuclear technologies would have developed to the point where they would fulfill our energy needs.

COAL CONSTRAINTS

There are, however, a number of constraints on the vastly increased use of coal as a source of all our fuels. These constraints must be considered and alleviated, if we are going to do what has just been proposed. One of these constraints is the mere fact that we are extracting stored carbon from underground; and by burning it in a fuel cycle of some sort, it is consequently being injected into the atmosphere as carbon dioxide. That this injection of fossil carbon into the atmosphere has been taking place at a rate greater than it is being removed is evidenced in Fig. 10. Here is shown the history of the carbon dioxide level over the last fifteen years, taken at a mountaintop in the middle of the Pacific Ocean. As you can see, roughly one-half of the carbon injected into the atmosphere each winter is removed during the following summer, resulting in a consequent net rise of carbon dioxide in the atmosphere each year. Furthermore, a closer examination of this data indicates that the rate at which it is rising is actually accelerating somewhat over the last fifteen years. This is indeed a global measurement, since the same kind of result has been obtained from stations at the North and South Poles. The question of what the consequences of this increased carbon dioxide blanket might be for the Earth is another matter. There is, however, one aspect which is very hard to deny - and that is that whatever the mechanisms of carbon dioxide production might add up to and whatever the mechanisms of carbon dioxide removal might turn out to be, they are not matched. The rate of production outstrips the rate of removal. As a consequence, the blanket of carbon dioxide around the globe will increase in thickness. While the meteorologists cannot as yet make any predictions in detail of what the consequences of this increased carbon dioxide blanket are likely to be in terms of changes in the weather, there is one general conclusion which hardly seems avoidable. This is that the average global temperature must rise, due to the transparency of carbon dioxide to visible radiation and its opaqueness to the resulting infrared, which is generated at the Earth's surface upon conversion of the visible sunlight. The details are yet to be worked out about the weather modifications which this increased blanket is likely to produce. It is a problem of some serious magnitude, and efforts must be made to control it. Here again, chemistry will undoubtedly play an important role.

However, there is still another and more immediate consequence of the increased use of coal, which has been proposed worldwide. As you all know, coal is very poor in hydrogen compared to petroleum or natural gas, and therefore much richer in aromatic components. As an example,

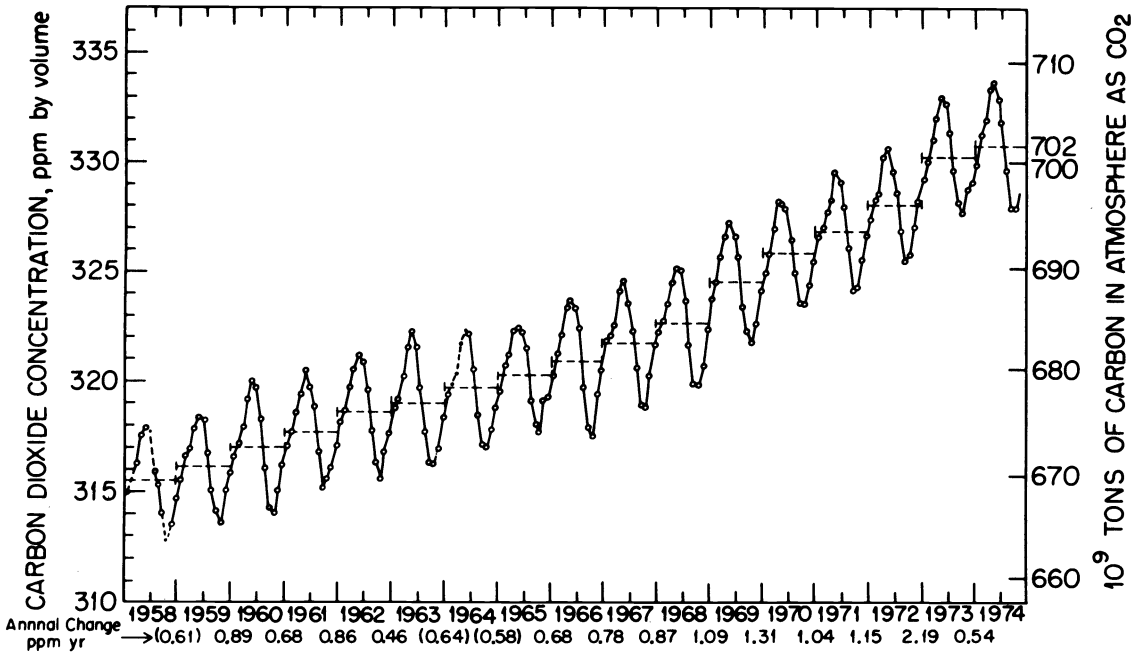


Fig. 10. Atmospheric CO_2 concentration at Mauna Loa Observatory (2500m).

we know that when coal is burned in a boiler (or any kind of combustion process, for that matter), a much larger amount of aromatic emissions results from such a combustion process.

A somewhat easier way of expressing the hazards involved in the use of coal is to be found in an examination of the oil which is produced by coal liquifaction (a process which was first used as early as World War I, used again in World War II, and which is now being proposed for renewal). Figure 11 shows an example of one such oil produced from coal, in an experimental plant in the United States. These plants have been designed at a level of about 25,000 tons/day of coal, and it is made clear in this figure that the amount of aromatics that will be in such an oil is very high indeed. In particular, such a plant would produce about ten pounds of benzopyrene per day. When we remember that benzopyrene is one of the most potent carcinogens produced in any combustion process, and that it is effective at the milligram level in producing lung cancer, we can easily visualize the enormous problems which such an enhanced production of benzopyrene spread into the atmosphere might entail. As a comparison, I have given the analysis of ordinary petroleum, which is not so rich in aromatics compared with this particular coal oil. You can see that there is ten to twenty times as much benzopyrene in the coal oil as there is in petroleum. Of course, the benzopyrene can be removed from this coal oil, and I daresay it will be; but the costs of doing this will affect the uses to which that oil may be expected to be put.

These are only two of the constraints that the environmental problems of coal use will place upon us. The particulate matter that issues from a coal combustion process, and the various kinds of other toxic materials which would issue in the water effluent from a coal liquifaction or gasification plant, are also problems which will have to be considered.

SOLAR RESOURCES

Thus, we are left with the only other alternative which would neither increase the carbon dioxide level nor enhance the carcinogen level (nor produce any other environmental hazard that we are aware of at the moment). This alternative is the use of sunshine, directly as it comes to us, rather than using up the fossilized sunshine which constitutes the petroleum, natural gas, and coal, and which took several hundred million years to produce. We are thus, in a sense, living on our capital account of fossilized sunshine; and the time has now come when we must learn how to live on the annual income of energy from the sun, which is represented by the photosynthetic process.

As an introduction to this, I would like to have you look at a map of the world (Fig. 12) showing where the natural photosynthetic carbon fixation actually occurs. In this figure you will see that most of it occurs in the humid tropic regions around the equator: in the Amazon valley, the Congo Valley, and Southeast Asia. Here the fixation rate is of the order of one

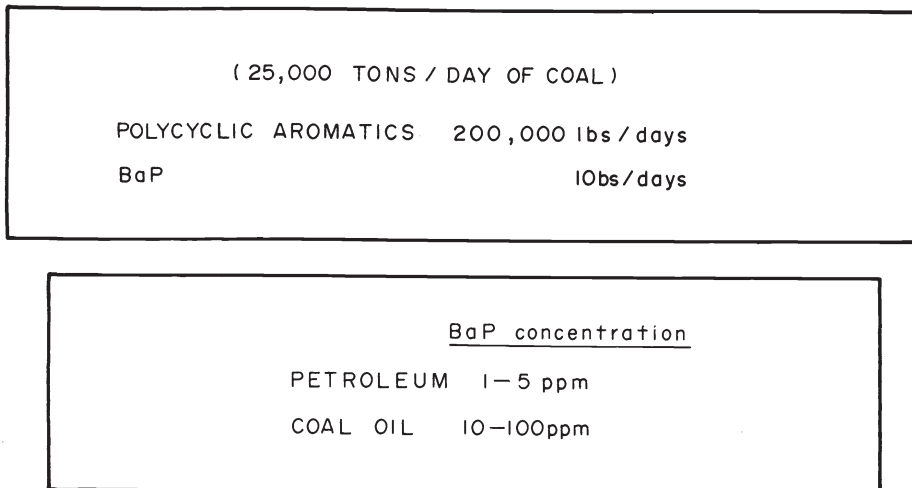


Fig. 11. Potential carcinogen production in coal oil plant.

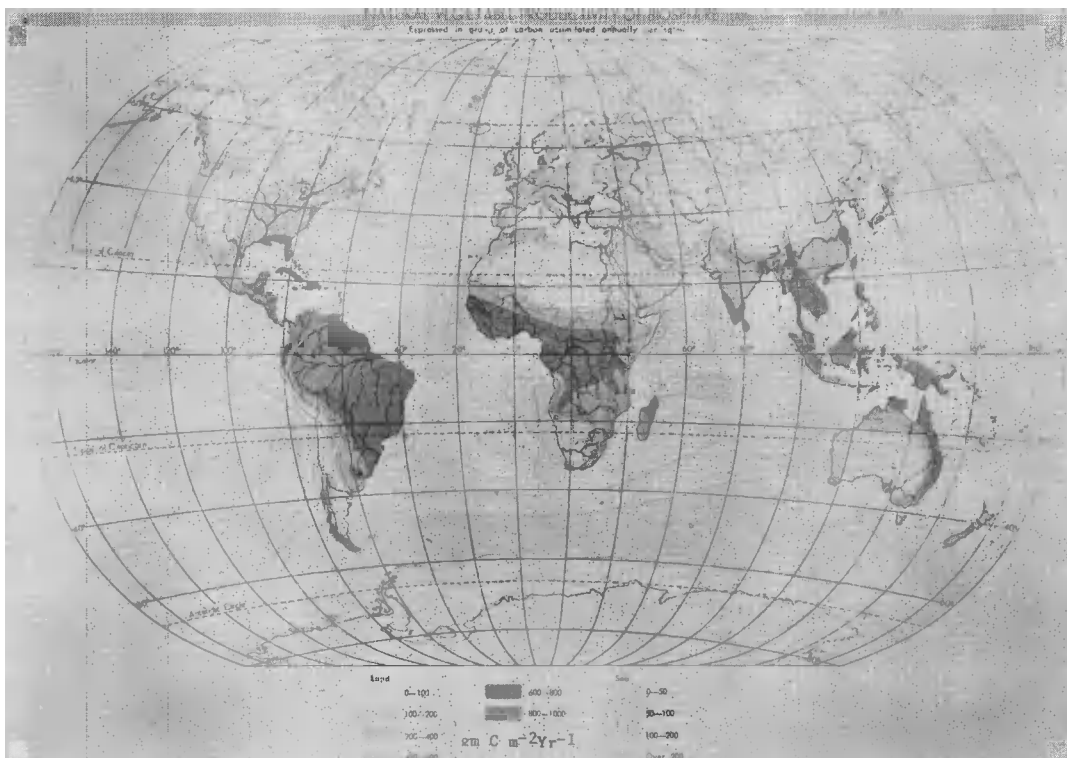


Fig. 12. Natural vegetable productivity of the biosphere expressed in grams of carbon assimilated annually per m².

kilogram of carbon per square meter per year. However, these regions are relatively fragile, and must be used for more highly important purposes, such as food production. The production of materials, however, ranks a very close second to that of food. What I have contrasted here is the production of materials such as those used in the chemical industry with those needs which are simply the production of energy.

There are other ways in which the energy of the sun might be captured directly, but there is none yet that can use this energy to reduce carbon directly and thus make it useful as a materials resource, which we need for so many other applications. Roughly about ten percent of the fossil hydrocarbon used today is used in the petrochemical industry as a materials source rather than an energy source, and it is that ten percent materials source toward which we can hopefully look as a possible substitute in direct photosynthetic carbon reduction.

PHOTOSYNTHESIS

We do know a good bit about how the green plant captures the quanta and uses that energy to reduce carbon. The details of that carbon reduction cycle are shown in Fig. 13. Here it is clearly seen that the first major product of all green plant photosynthesis is essentially carbohydrate, and most plants store most of the energy so captured in this form (shown in the

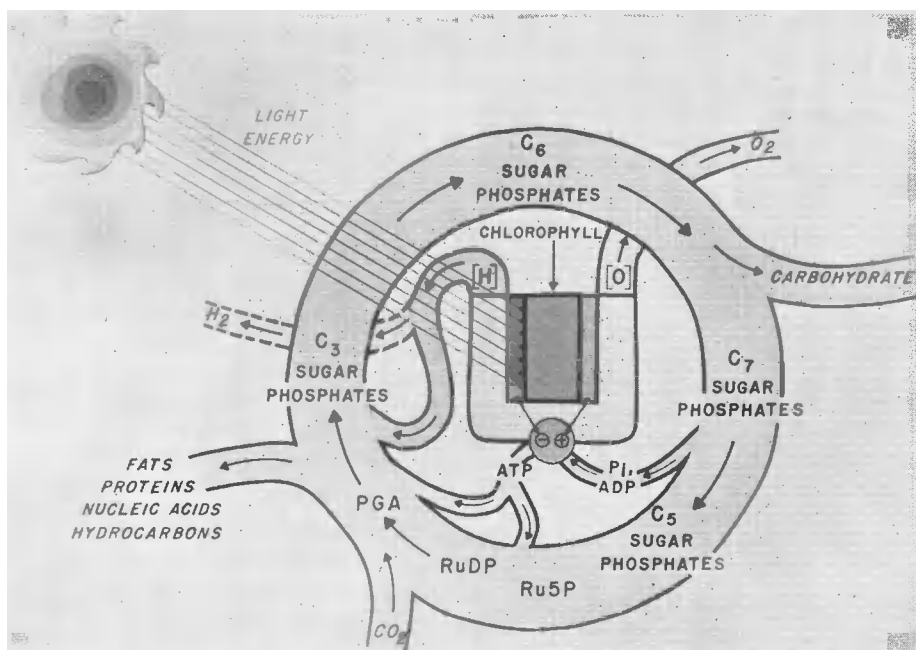


Fig. 13. Photosynthetic carbon reduction cycle.

upper righthand corner of the circle). In fact, there is a great deal of effort going on throughout the world at this time to find ways to convert that carbohydrate, which is the primary storage product of all green plants, into some form more useful than wood. It is true that one hundred years ago most of the world subsisted on that wood as an energy source. Today, however, our systems are built on more convenient fuel sources (as well as more convenient materials sources), such as liquid hydrocarbons and their relatives. It is this kind of conversion that we are now seeking to make.

Efforts to use carbohydrates stored by plants are perhaps farthest along in the case of the directly fermentable sugars (such as those produced by sugar cane), in which case the sugars can immediately be converted into a liquid fuel by a fermentation step. An example of the growing of sugar cane is shown in Fig. 14, which illustrates a cane field being prepared for harvest by a preliminary burn of the dried leaves, which will allow for the entry of the harvesters (either people or machines). This step seems to be universal in the large scale harvesting of sugar cane, and it seems to represent a substantial loss of material. Nevertheless, considerable progress has been made in the development of sugar cane as a source of both fuel alcohol and alcohol that might be used as a starting point for chemical processing.

The essential transformation is shown in Fig. 15, in which it is apparent that the conversion of the solid sugar to a liquid form involves a loss or reduction of weight by one-half, without the concomitant loss of any substantial amount of energy. Thus, 180 grams of sugar will produce about 90 grams of alcohol, and it will retain over 90% of the energy content of the sugar in the process. This alcohol can now be used directly, as a fuel, in an internal combustion engine such as the automobile. All that is required to make the mixture of 95%



Fig. 14. Sugar burn, Puerto Rico.

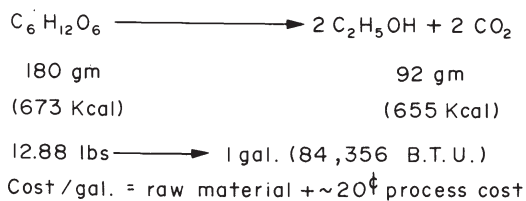


Fig. 15. Fermentation reactions.

alcohol and 5% water by useful as a fuel is the insertion of a small heat exchanger between the carburetor (which micronizes the alcohol) and the intake manifold, using the heat of the cooling water from the engine block to vaporize the alcohol. Such engines have actually been built (particularly in Brazil), and are used both for motor cars and for harvesting machinery. In my own experience, such a motor car seems to run just as well, or perhaps even better, than one running on gasoline. The only difference seems to be that the one running on alcohol smells better.

ALCOHOL

A more important use for alcohol, perhaps, is as a raw material or a beginning feedstock for the petrochemical industry. This intercalation is shown in Fig. 16, in which the present route to ethylene from naphtha is illustrated, as well as the corresponding route from sugar to ethylene, as the crossing point or point of entry, into the petrochemical industry. The availability of a substantial pool of alcohol in the large sugar growing countries of the world (such as Brazil, and perhaps the Philippines) may very well induce a number of chemical companies to build alcohol crackers to make ethylene, in place of their naphtha crackers from petroleum, which is becoming increasingly unavailable.

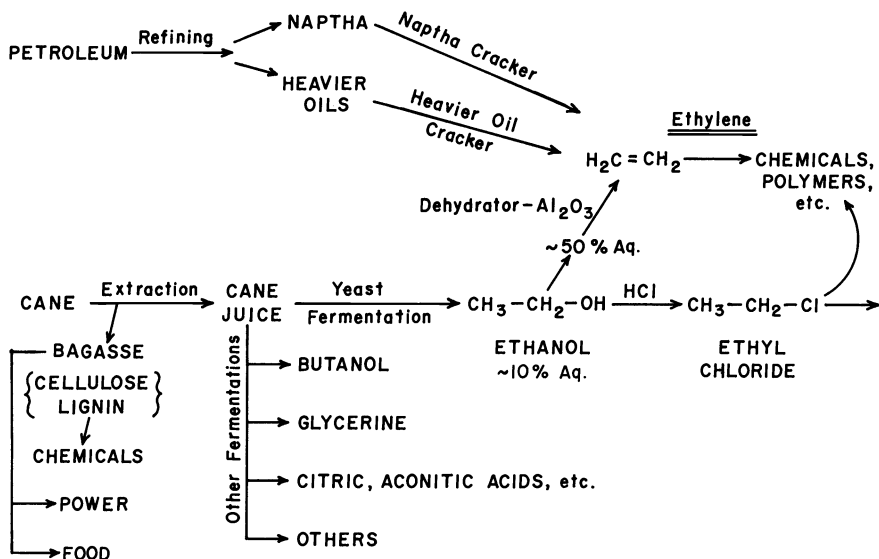


Fig. 16. Renewable resource for chemicals

Thus, we have a route from the carbohydrate (the primary storage product of most plants) to the hydrocarbon material, which is the raw material of the petrochemical industry. However, this route is limited to those places in which fermentable sugars can be readily and cheaply produced. In many parts of the world this cannot be done. Instead, the storage product is in the form of cellulose. This would require a preliminary hydrolysis of cellulose to fermentable glucose before the alcohol fermentation could occur. There is a great deal of work going on in the United States and Western Europe (and probably in Northern Europe, as well) toward this end. It is very likely that this work will meet with considerable success, and thus present a new resource for the temperate regions of the world in the form of the ability of these regions to produce cellulosic materials, as a starting point for the kind of petrochemical industry to which we have become accustomed. However, those plants, as a general rule, which are very competent carbohydrate producers also require the kind of land that can also be used for food production; therefore, the competition between food production and materials production by these routes might begin. This seems to me to be an undesirable competition, in view of the food requirements of the world. Therefore, we have set about to find other ways than this one to fill the need for hydrocarbon.

HYDROCARBONS

Let me remind you of the photosynthetic carbon cycle, which I showed you in Fig. 13. While it is true, as shown in that figure, that most of the plants with which we are normally familiar store their solar energy in the form of reduced carbon (carbohydrate), there do exist a number of plants which can store this energy, in substantial amounts, in the form of

a more fully reduced carbon (such as hydrocarbon). The ones that are most commonly known to you as a commercial crop are the rubber plants of the world. There is one major rubber plant, and one minor one, which is rapidly rising in importance. The major one, of course, is Hevea brasiliensis, for which all the plantations exist on a large scale in Southeast Asia, primarily in Malaysia and Indonesia. Figure 17 is a picture of a tapped rubber tree in Brazil, but they look very much the same all over the world. The latex that you see running out of the



Fig. 17. Rubber tap, Brazil.

tap, and along the bark into the cup, is an emulsion of hydrocarbon in water consisting of about one-third hydrocarbon. The molecular weight of that hydrocarbon is very large (approximately two million), so when the emulsion is coagulated and the hydrocarbon settles out as a coagulum, the hydrocarbon separated from the water is an elastomer. That is, it is rubber.

There are many other plants belonging to the same family (the Euphorbiaceae family) that Hevea belongs to, which also produce latex. In many cases this latex consists of an emulsion of a hydrocarbon in water in which the molecular weight of the hydrocarbon is much smaller - of the order of ten to twenty thousand. In this case, when the oil and water are separated from the emulsion, the resultant hydrocarbon that remains is not big enough to be a solid rubbery material, but rather is a liquid oily material consisting of a very complex mixture, mainly of reduced carbon atoms. These plants, however, tend to grow for the most part in the humid tropics, and we saw many of them as we moved down the Amazon in our search for oil producing plants.

However, there a number of such plants, both in this family and in other families, which grow in the arid regions of the Earth. An example of such a plant that produces a large hydrocarbon, rubbery in character, is the well-known guayule plant. Guayule is a member of the Compositae family, and grows in the deserts of Northern Mexico and the Southwestern United States, as is shown in Fig. 18. If plants with this behavior (that is, plants which could be grown in the arid and the semi-arid parts of the world) could be found which produce lighter or lower molecular weight hydrocarbons, then we might have a direct source of photosynthetically produced hydrocarbons which would not be in competition with the land that may ultimately be required for food production.

Figure 19 shows a map of the land areas of the Earth in which the semi-arid regions and savannas are illustrated and distributed, covering both the Northern and Southern Hemispheres, and including the Southwestern part of the United States, Southern Africa, Australia, and South America. These lands are presently relatively unproductive, either for food or for any other use. We hope to be able to find plants that can be adapted to that kind of a growth environment, which will produce hydrocarbon directly.



Fig. 18. Guayule, Saltillo, Mexico.

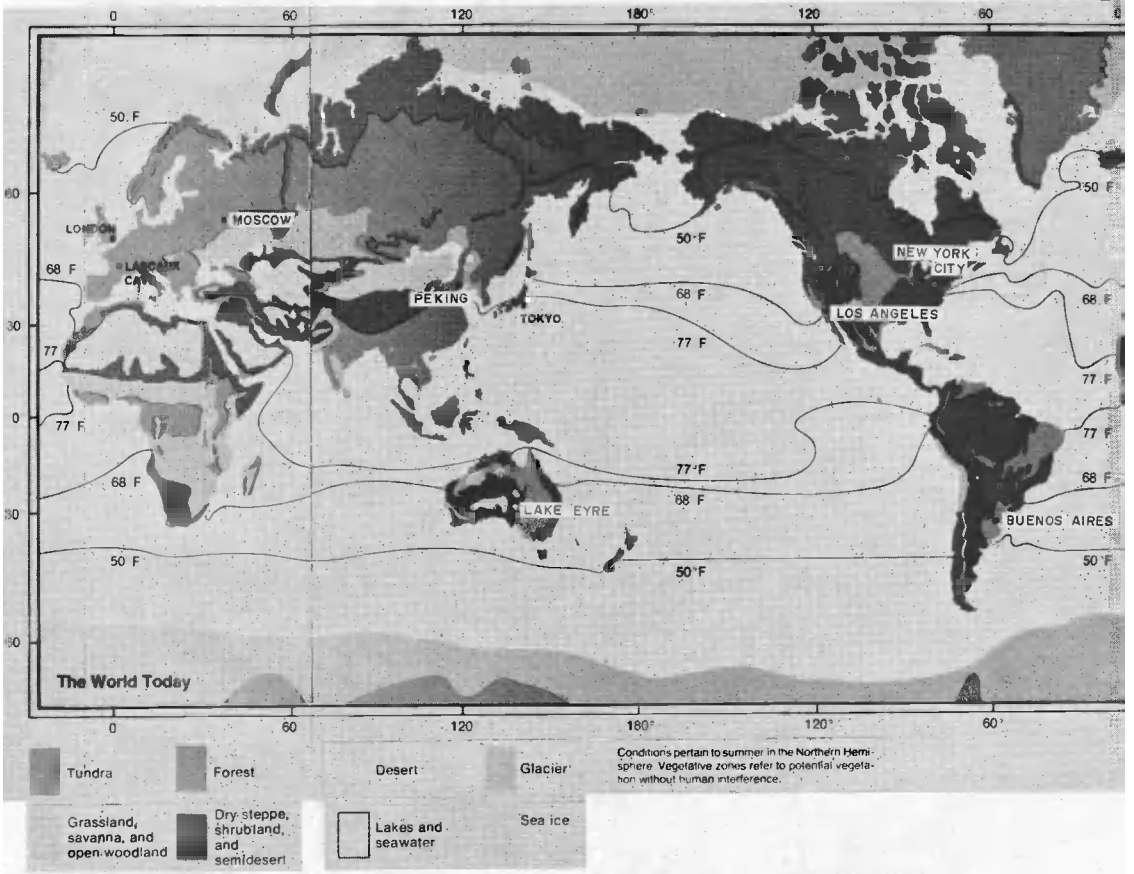


Fig. 19. Global map showing semi-arid and savanna regions.

In fact, such an exploration of such parts of the world has already begun. In Southern California we have found a number of members of the genus Euphorbia which grow wild and which

are prolific producers of latex. Similarly, along the Southern Coast of Puerto Rico, we have seen another group of plants growing, also of the Euphorbia genus. Figure 20-A shows one of them, Euphorbia lactea; and when we pierced it with a knife, the flow of latex was evident.



Fig. 20-A. Euphorbia lactea showing flow of latex.

The South Coast of Puerto Rico is a relatively arid region, as shown in Fig. 20-B, and might be considered fairly representative of the larger semi-arid regions of the world shown in the previous map.



Fig. 20-B. Euphorbia lactea, South Coast of Puerto Rico.

Many other plants of the same genus grow in similar circumstances. Euphorbia tirucalli, the well-known African milkbush, grows very well in Southern California, and could very likely be developed as a latex-producing tree as well. However, being a Northern Californian, I was seeking plants which might be grown in the somewhat harsher climate farther North. In fact, we found a member of the genus Euphorbia that grows very well in Northern California, and a picture of it is shown in Fig. 21. It is known as Euphorbia lathyris. We have indeed begun

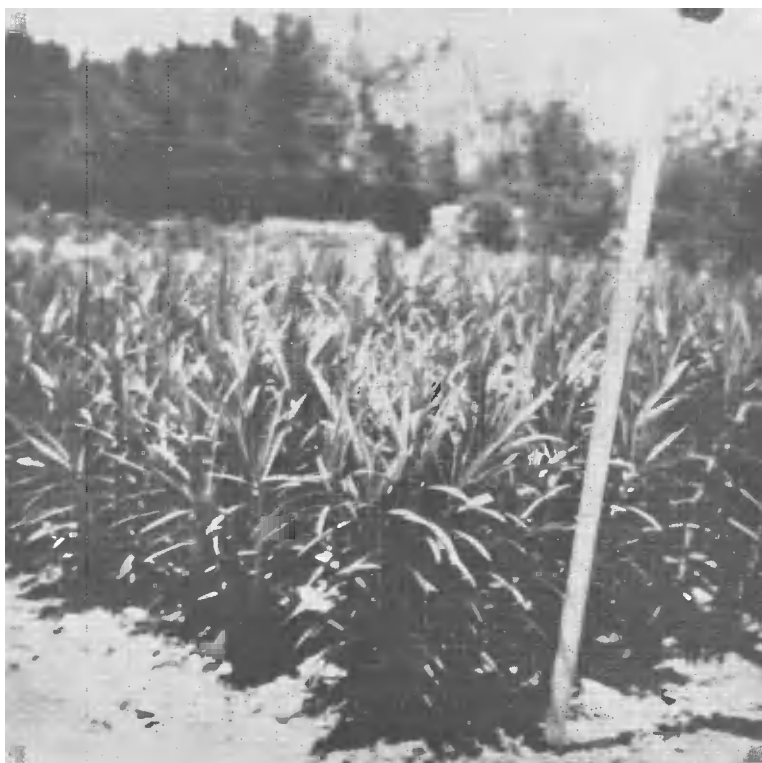


Fig. 21. Euphorbia lathyris, South Coast Field Station, 6/77.

to determine the growth rate of this plant. The Euphorbia lathyris can be grown annually from seed and harvested in much the same way that sugar cane is harvested, as opposed to the trees (Euphorbia lactea and tirucalli) discussed earlier, in which the oil would have to be harvested by a tapping (or at the very least, a mowing) operation.

The growth data on the Euphorbia lathyris is shown in Fig. 22, and it indicates that we can expect to obtain with confidence not less than six barrels of oil/acre/year. This would be about fifteen barrels/hectare/year. This is, of course, without any agronomic care or selection of the plant at all. It comes from a wild seed, and this is the first planting of it.

Bearing in mind that we are seeking, in the first instance, a replacement for the petrochemical feedstocks rather than solely a fuel use, we must now learn much more about the chemical composition of the hydrocarbon mixtures of these Euphorbias that I have just described. We have begun to do this, and Fig. 23 shows an analysis of the sterol contents of a variety of Euphorbias. In Table 1, the relative amounts of open-chain polyisoprene, here designated as rubber, are compared with the sterol content. The relative amounts of sterols are also shown in a wider selection, which also includes an analysis of guayule and Hevea. Most of these latexes also contain a number of terpenes as well, but we have not analyzed for them.

Finally, in Fig. 24, I want to show a comparison of the molecular weights of the rubber component of a genuine rubber plant such as Hevea. In Hevea, the molecular weight distribution is shown to be bimodal, with a peak at half a million and another one at two million, as compared to a similar gel permeation chromatogram on the low molecular weight of hydrocarbons obtained from another Euphorbia. Here you see that the peak is somewhere in the vicinity of twenty thousand, and its significance beyond that is moot. The only thing we can say with confidence about this curve is that the molecular weight distribution in most of the other Euphorbias (of the open-chain polyisoprenes) is considerably smaller, and they peak somewhere around the ten thousand molecular weight range.

Now, the question is almost certain to be in your minds as to how much, or at what costs (both in money and in land), can we obtain this material. Unfortunately, the experiments of

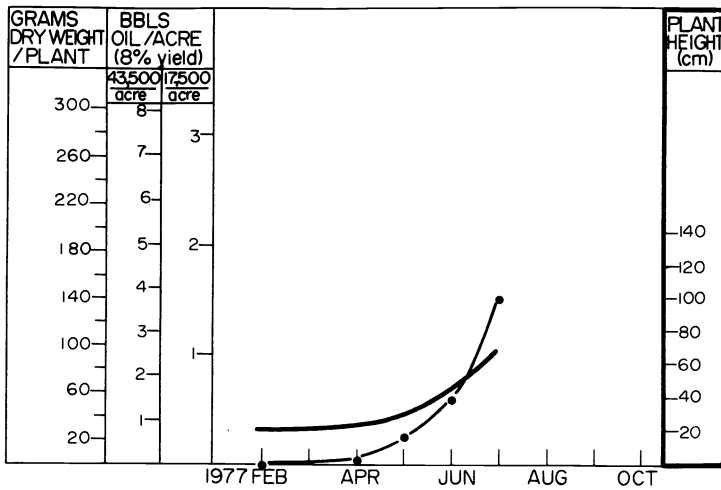


Fig. 22. Growth rate, *Euphorbia lathyris*, 1977.

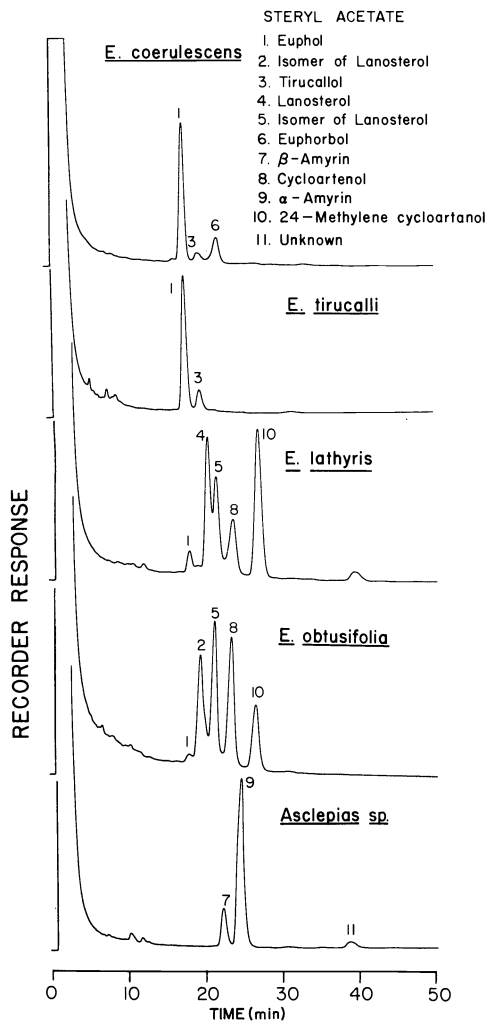


Fig. 23. GLC of *Euphorbiaceae* steroids.

planting and measuring are still underway. We have planted an annual, which I have mentioned earlier (*Euphorbia lathyris*), and this plant is giving us at least a clue as to the amount of oil we can expect from this particular *Euphorbia*. We have also put in a planting of *Euphorbia tirucalli*, which will grow to be a tree, and of *Euphorbia lactea*, which will also be a tree, or bush-like plant. The harvesting time for these two is considerably longer,

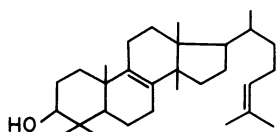
TABLE 1. Sterols and polyisoprenes from Euphorbiaceae latex

SPECIES	% of Dry Latex (w/w) ¹		Ratio (R/S)	RELATIVE AMOUNTS OF STEROLS											
	Rubber	Sterol		A	B	C	D	E	F	G	H	I	J		
<i>Euphorbia aphylla</i>					.37		.10	.82	1.0	.46					
<i>Euphorbia arbuscula</i>				1.0	.19										
<i>Euphorbia balsamifera</i>	4	93	0.04												1.0
<i>Euphorbia bupleurifolia</i>								.13	1.0	.68	.27				
<i>Euphorbia characias</i>															
<i>Euphorbia coerulescens</i>	1	75	0.01	1.0	.10	.20									
<i>Euphorbia cylindrifolia</i>				1.0	.25		.50								
<i>Euphorbia globosa</i>											.30				1.0
<i>Euphorbia ingens</i>	8	78	0.10												
<i>Euphorbia lathyris</i>	3	50	0.06	.12			.80	.50	.30	1.0					
<i>Euphorbia marlothii</i>									.41				.32	1.0	
<i>Euphorbia misera</i>				.69	.32		.66	1.0							
<i>Euphorbia obtusifolia</i>				.05				1.0	1.0	.50					
<i>Euphorbia sp. (American)</i>				1.0	.34										
<i>Euphorbia stenoclada</i>				1.0	.16						.29	.17			
<i>Euphorbia tirucalli</i>	1	50	0.02	1.0	.10										
<i>Euphorbia lactea</i>	1.5	76	0.02	1.0						.61					
<i>Elaeophorbia drupifera</i>				1.0	.16	.20									
<i>Achras sapote</i>	14	66	0.21									1.0	.20		
<i>Asclepias sp. (USA)</i>	(12)	(72)	0.17									1.0	.20		
<i>Asclepias sp. (Brazil)</i>	3.5	31	0.11									1.0	.20		
Guayule				1.0	.20		.35								
<i>Hevea brasiliensis</i> ²	87	1	87.0												
<i>Synadenium grantii</i>															1.0

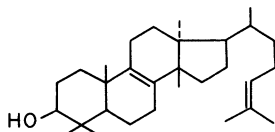
KEY: A Euphol B Tirucallol C Euphorbol D Lanosterol E Lanosterol isomer F Cycloartenol
G 24-Methylene cycloartanol H α -Amyrin I β -Amyrin J Other pentacyclics

1 These numbers were estimated on the basis of NMR spectra (60 m Hz, CDCl₃) of the benzene and acetone extracts.

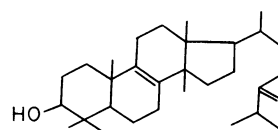
2 Identified sterols are β -sitosterol, fucosterol and stigmasterol (1.0, .50 and .25 respectively)



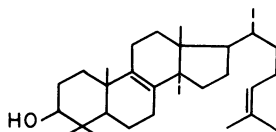
A Euphol



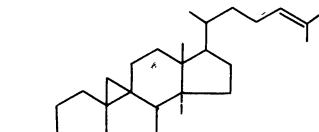
B Tirucallol



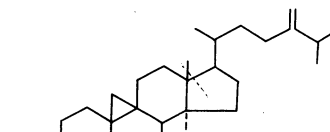
C Euphorbol



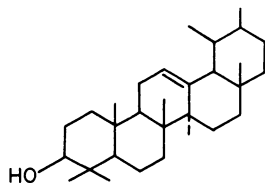
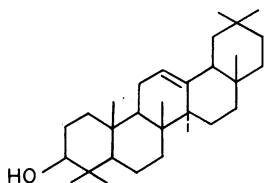
D Lanosterol



F Cycloartenol

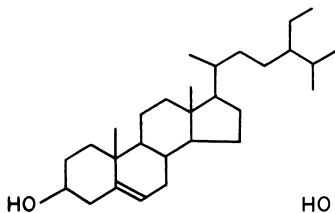
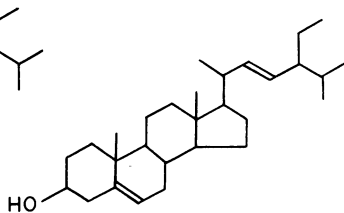


G 24-Methylene cycloartanol

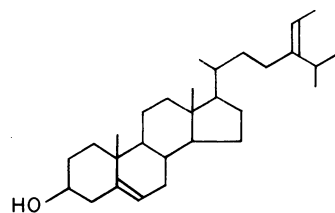
H α -AMYRINI β -AMYRIN

E Lanosterol isomer

J Other Pentacyclics

 β -Sitosterol

Stigmasterol



Fucosterol

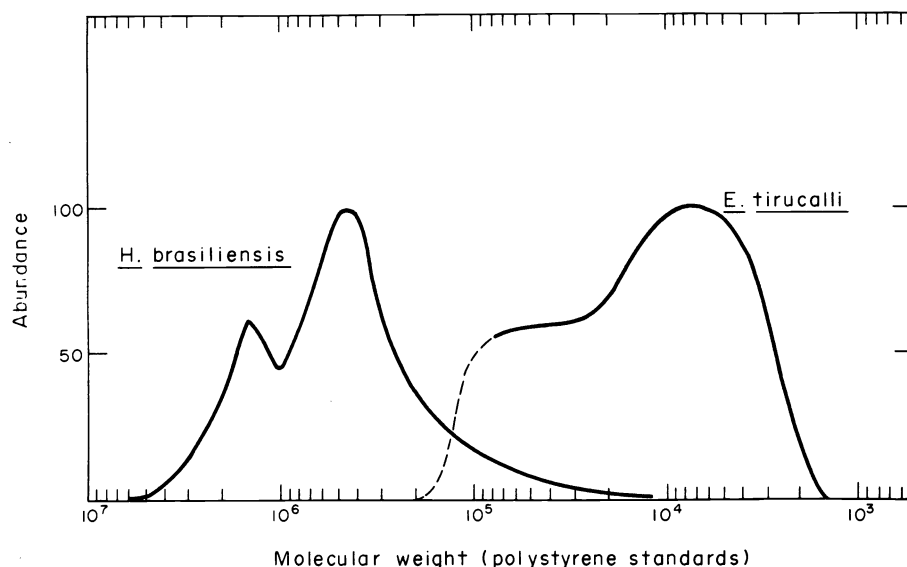


Fig. 24. Molecular weight distributions of polyisoprenes isolated from *H. brasiliensis* and *E. tirucalli*.

and therefore I cannot really give you any substantial information yet about the yields we may expect from these tree-like plants.

However, using what data we have on the *Euphorbia lathyris*, the annual plant, we do come out with some yield numbers which I have already given you, and also with some cost numbers, which are very rough, to be sure. But it looks as though we could make this complex mixture of hydrocarbons (as obtained from *Euphorbia lathyris* or the other *Euphorbias*) at a price of about \$10.00 to \$15.00 per barrel of oil in the field; and another \$10.00 per barrel would be required to take the oil from the plant and put it in the barrel. So we are talking about a price of crude oil, a mixture of hydrocarbons, of the order of \$20.00 per barrel. This price is not far from our present one of \$13.00 or \$14.00, and we know that this present price, for crude oil from the ground, will rise. Thus, it seems to me to be entirely possible that we may indeed be able to return to a current income account for our hydrocarbons needed for materials, as a resource. It may even be possible in some cases to use them as a fuel, as well. And this, in turn, will help solve the problems we indicated earlier which are limiting our productivity, both in agriculture (2) and in materials for the welfare of mankind.

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