POTENTIALS FOR EXTRACTING PROTEIN, Medicines, AND OTHER USEFUL CHEMICALS FROM PLANTS: SOME SOCIOLOGICAL OBSERVATIONS

(A Review of the OTA Workskop Papers)

Frederick N. Buttel
Department of Rural Sociology, Cornell University

Introduction

The extraction of useful chemicals from plants has a number of potential benefits from a sociological perspective. The major societal benefits would include substitution of domestically produced commodities for petroleum and other imports, thereby alleviating balance of payments problems; more productive use of resources, particularly in marginal farming areas; and diversification of the U.S. agricultural system, which would permit market expansion without farmer dependence on increasingly expensive and politically problematic Federal subsidies from traditional commodity programs. Some degree of government subsidy and other forms of intervention probably will be required to stimulate farm- and industrial-level plant extracts industries, Such government intervention may be greatly preferable to export subsidies for foodgrains, feedgrains, and other agricultural commodities in light of problems of aggravated balance of payments deficits and the farm recession.

This paper addresses sociological aspects of plant extraction in the United States and its agricultural industry. The paper is organized into six sections. The first provides some general comments on the socioeconomic context of efforts to develop plant extract industries. The second discusses constraints , on plant extract development relating to the land resource base, The third is devoted to research and development (R&D) activities necessary to undergird commercial scale plant extract industries. The fourth and fifth examine possible impacts of plant extract development in terms of the organization of agricultural production and the organization of nonfarm industry, respectively. The final section explores various policy and political issues that have or may emerge in stimulating an expanded plant extract industry in the United States.

The Current Socioeconom ic Environment **for Developing** Plant Extract Industries

All 10 papers presented at the OTA workshop support the expansion of plant extract industries. However, it is essential to recognize that the present economic era is not entirely propitious for the types of initiatives proposed in the papers. Thus, a realistic view of potentials for extracting proteins, pharmaceuticals, biocides, and other useful chemicals from plants must be tempered by a variety of conditions that constrain industrial development in general and that of plant extracts in particular,

The dominant feature of the contemporary United States and world economy is global recession. That the recession has been and continues to be global reminds us that all manner of magical cures for national economic ills must be taken with a grain of salt and that we must view the situation more broadly as a fundamental point of global economic reorganization. It is crucial for policymakers to recognize that the conditions of the post-World War II economic boom are unlikely to be replicated and that policies for the 1980's must reflect new socioeconomic realities. This is both promising and discouraging for plant extracts. Much of the thrust behind stimulating the plant extracts industries is "import substitution. " The character of trade relations in the new economic order that will emerge during the late 1980's* will make it attractive to substitute domestically produced substances for chemicals and raw materials that we have imported during the past several decades. At the same time, however, the very conditions that characterize a recession—capital scarcity, fiscal crisis, economic uncertainty, rigidities in public policy—make it more difficult to expand new industries rapidly.

Capital scarcity will certainly be a key constraint to widespread development of plant extract industries. "Real" interest rates (the nominal interest rate less the rate of inflation) remain at levels unprecedented during the post-World War II period, despite recent declines in the prime rate. High interest rates make it much more difficult for new industries to attract capital and greatly increase the riskiness of new ventures with uncertain markets and production technologies.

● These trends will likely involve: 1) further decline of *traditional* U.S. manufacturing industries (e.g., autos, steel) and increased competition with the firms of foreign countries (especially Japan, South Korea, Taiwan, Singapore, and Hong Kong), and 2) an eventual tightening of markets in petroleum and other raw materials. These two trends suggest continuing balance of payments problems, making import substitution industries such as plant extracts quite attractive.

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In addition to capital scarcity, economic recession involves several other conditions adverse to expansion of new plant extract industries. First, the recession's downward pressure on inflation rates, especially when combined with restrictive monetary policy in the United States, tends to make imports cheaper relative to domestically produced commodities. Thus, to the degree that plant extract industries involve import substitution, they will be attempting to produce commodities domestically that have been imported at a time in which a strong U.S. dollar lowers the relative price of these imports. This has been the case particularly for fossil fuels and other raw materials, against many of which domestically produced plant extracts would compete. Raw material prices are heavily influenced by the level of demand, which in turn is heavily influenced by general economic conditions. For example, declining energy demand has led to dramatic declines in the real price of energy, which now is only slightly higher than before the Arab Oil Embargo of 1973-74. Global economic recovery, which is likely to proceed slowly over perhaps a 5-year period, will lead to a tightening of oil and other raw materials markets and will than cause rapid increases in relative prices of these raw materials some years later. However, the fact remains that plant extracts that compete against imported raw materials or industrial feedstocks must temporarily buck an otherwise strong logic of increased import dependence on raw materials. Wise policy makers will recognize, however, that raw materials markets will tighten over the next decade and that the most desirable time for front-end R&D and other subsidies for the development of plant extract industries is now. For most plant extract commodities, a decade will be required to conduct further research and establish a stable position in domestic markets. Thus, advance planning will be necessary to bring import substituting industries up to scale before U.S. industry falls victim to the next round of hyperinflation of raw materials prices.

Another feature of global recession is the political-economic volatility of trade. Recession on a global scale tends to increase nationalist sentiment, especially in regimes that blame their economic problems on "unfair" foreign competition (see, for example, *Business Week (4)).* Economic nationalism tends to involve protectionism vis-a-vis imports and export subsidies to increase international sales of domestic commodities. Economic nationalism thus makes trade-related investments especially risky; import substitution investments can be undermined by other countries' export subsidies, and where investments such as those in plant extracts industries are premised on exports, export sales can be undermined by protectionist policies.

Another feature of the current socioeconomic conjuncture is the increasing export dependency of the United States with regard to its basic foodgrains, feedgrains, and oilseeds. Roughly 35 to 40 percent of the value of U.S. agricultural production is exported, making farmers' incomes highly dependent upon maintenance or expansion of export markets. Moreover, virtually all forecasts of agricultural markets over the next several decades indicate that a growing proportion of farmers' gross receipts will be from exports (8,12,17). However, the current global recession, combined with the 5-year legacy of the executive branch suspending certain international grain sales as a foreign policy lever, has undermined agricultural export earnings and exacerbated the farm crisis (16). Thus, counterbalancing an otherwise gloomy situation for plant extracts industries deriving from international economic stagnation, the disproportionate burden of economic stagnation borne by farmers will no doubt make agricultural diversification look increasingly attractive for both producers and Federal officials. Diversification of markets can benefit producers in obvious ways, while the Federal Government should welcome strategies that can shrink costly Federal commodity programs.

Most plant extract commodities discussed in the 10 workshop papers will require considerable additional R&D investment for commercial scale-up, However, current conditions for expansion of R&D in the public sector are unfavorable. Over the past several years there has been stagnant or declining support by the Federal Government for nonmilitary R&D, including agricultural research. * Moreover, Federal fiscal austerity and accompanying cutbacks in Federal support of applied research have a questionable justification-that the private sector should shoulder a greater burden for applied research, while publicly funded research should be confined largely to basic research. To be sure, science policy should not encourage duplication of effort by underwriting public research that focuses on problems more efficiently explored by the private-sector, But such duplication of effort is not frequent or un-

● The Reagan administration recently appears to have reversed itself with regard to the priority placed on basic science research funding. The National Science Foundation apparently will receive a substantial funding increase in real terms (5). However, it would appear that Federal funding for applied research will experience stagnation in real terms over the next several years.

warranted, and the withdrawal of public support from applied research relating to industries, such as plant extracts, could be quite crippling. For example, front-end research required to stimulate plant extracts industries is extremely varied and requires discrete sets of trained researchers and suitable research facilities. A large share of these research tasks could be accomplished efficiently through grants to established research teams in universities or private research organizations. Wise science policy must recognize that the now-popular image of creating division of labor between university-based "basic" and private-sector-based "applied" research is suitable primarily for "high-tech" sectors within large multinational firms with well-funded, established research organizations. It would be unrealistic to expect small- to medium-sized businesses to shoulder the burden of R&D in numerous diverse areas ranging from agronomy, plant breeding, physiology, microbiology, plant pathology, entomology, engineering, bioassay, synthetic organic chemistry, market research, etc. The current climate of retrenchment in public support of applied research thus will be a substantial barrier to the development of the plant extracts industries. Congress should be urged to consider more carefully the general long-term implications of short-term savings in R&D spending and the specific problems such policies will cause for the expansion of the plant extracts sector.

A final aspect of the current socioeconomic milieu that will have crucial implications for industries seeking to extract useful chemicals from plants is the emergence of genetic and cellular manipulative technologies such as protoplasm fusion, cloning, tissue culture, recombinant DNA, and immobilized enzymes. While these technologies will have positive long-term implications for substituting natural substances for petrochemicals and other nonrenewable resources (18), these technologies may at some prior point discourage investment and innovation because of the threat of rendering conventional plant extracts technologies obsolete. For example, recombinant DNA and industrial microbiology techniques may displace field production of plants and chemical methods for extracting fractions of plant tissue. To help avoid this conflict, it might be prudent for the Congress to encourage biotechnology research firms to take the lead in selected areas of plant extracts technologies. There are several biotechnology research firms (e.g., the International Plant Research Institute, Cetus, and Agrigenetics) that are oriented heavily to research on agricultural crops and other higher plants. Their agricultural capability and growing expertise in industrial microbiological aspects of industrial scale-up may make these firms highly suited to the development of plant extracts technologies requiring agronomic and plant breeding research. At the same time, it should be recognized that venture capital biotechnology firms will have proprietary interests. Where it is undesirable for research results to be proprietary property, R&D subsidies should be directed to public research institutions such as State agricultural experiment stations or USDA's Agricultural Research Service.

The Land Resource Base

Most potential plant extracts discussed in the 10 workshop reports involve cultivation and harvesting of higher plant species. In some cases (e.g., endod, neem), the species are perennials native to the production region, and expanded use of these plants would require little or no increased spatial or ecological "demand" on the land resource base. However, several plants—especially guayule, crambe, jojoba, lesquerella, vernonia, kenaf, tobacco, milkweed, and conventional oilseed crops—if used for plant extracts industries, would have substantial implications for the quantity and quality of U.S. land resources. This section thus will provide some observations on the degree to which the U.S. land resource base would be adequate to support the cultivation of 60 or more million additional acres of crops devoted to plant extracts.

The adequacy of the U.S. land resource base is a very complex issue and has received increased attention over the past decade (1,7,11,13,20). Land resources will be more than sufficient to feed the U.S. population and provide industrial raw materials (e.g., cotton, sugar, wool, wood) for the short term. However, the adequacy of the land resource base over the long term depends on certain unpredictable phenomena about which surprisingly little is known.

Probably the most unpredictable aspect of demand for land is the future level of export sales. Over the past decade, roughly 35 to 40 percent of U.S. agricultural production has been exported and, as noted above, the consensus among econometric predictions of future trends is that it will increase perhaps to the point where over half of U.S. agricultural production will be exported by 2010. However, these predictions have been based on relatively favorable assumptions about global economic growth, and if the next few decades are characterized by continued economic stagnation, the level

of export sales and hence demand on land resources may be considerably less than most analysts have anticipated. Further, levels of export sales are not derived entirely from "natural" economic forces. Certainly, much of the rapid increase in farm exports over the past 15 years has been accounted for by political considerations. Exports have long been sought as a means to dispose of farm surpluses and to increase farm income without Federal subsidies. The 1970's and 1980's reflect a continuation of this expectation which rarely has been fully realized. In addition, farm exports have acquired added political importance due to their role in reducing balance of payments deficits. The fact that the next several decades promise little alteration in political conditions favoring the stimulation of export sales suggests prudent caution: export sales may not increase as rapidly and steadily as was predicted a few years ago, but the most likely prospect is to devote increasing numbers of acres of farmland to producing feedgrains, woodgrains, and oilseeds for export.

A second unpredictable factor is the nature and pace of technological change in the direction of in creased land productivity. It has been generally acknowledged that the 1970's was a decade of relatively stagnant land productivity, and many observers felt that agricultural researchers had encountered limits to productivity growth through conventional plant and animal breeding (15). However, at the same time that dire predictions were being made about meager land productivity increases in the U. S., biotechnological techniques (e.g., genetic: engineering for increased photosynthetic efficiency) were emerging that promised continued advances in per acre yields. Unfortunately, these new technologies remain at such an early stage of development that it is difficult to speculate on the timing or consequences of their commercial deployment, and hence on their impacts on the land resource base.

Complicating international trade and technological uncertainties about demand for land resources are disagreements over recent historical trends that have affected the quantity and quality of land resources available for production of agricultural and industrial raw materials. The first is the extent and significance of the loss of agricultural land to urban development, water impoundments, highways, airports, etc. While it has been assumed that irreversible conversion of farm land to other uses has been significant (approximately 3 to 5 million acres per year), recent evidence questions the accuracy of these data and argues that this loss of agricultural land will be relatively trivial in the next several decades (20). The second area of disagreement has focused around soil erosion and related forms of land degradation. While it is generally recognized that soil erosion in many areas of the country remains unacceptably high, there is considerable disagreement over the degree to which land degradation will limit agricultural productivity in the future (7,8,17,19,23,24,26).*

One final complicating factor in anticipating the availability of land for plant extracts production is the extent to which land will be used to produce biomass energy. Late-1970's enthusiasm about using agricultural biomass for energy has, of course, subsided now that the real price of energy has been reduced to levels approaching pre-Arab oil embargo figures. Yet, petroleum markets may tighten again and resultant increases in the real price of energy may cause a significant allocation of agricultural land to energy production.

Of the 10 reports, that by Tankersley and Wheaton pays the greatest attention to land resource questions, primarily because the plant extracts potentials discussed in this paper have the greatest implications for pressing against the limits of the U.S. land resource base. Tankersley and Wheaton point out that "production of one-third to one-half of the industrial materials (presently) purchased abroad would demand about 60 million acres of cropland." While this increased demand on the land resource base would entail roughly a 20 percent expansion of land in crop production over the 1979 figure of 348 million acres, the authors are relatively unconcerned about plant extracts industries creating undue pressure on land resources. Two rationales undergird this argument. First, Tankersley and Wheaton cite data that there are "36 million acres of pasture and other land in farms that can be easily converted to the production of crops with little costs" and that the U.S. "has about 96 million acres of land that can be converted to crop production with more difficulty and cost than the 36 million acres cited above. " Given that "the Nation's total cropland base . . . is 540 million acres" and "projections made by the Department of Agriculture . [that] about 462 million acres of cropland will be needed in the year 2030 to meet domestic and foreign trade demands for food and fiber," 78 million acres of cropland would remain to devote to plant extracts industries and other land uses. Be-

● *See* also *Impacts of Technology on U.S. Cropland and Rangeland Productivity* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-F-166, August 1982).

cause these *78* million "slack" areas are in excess of the 60 million acre estimate of the land required to substitute for one-third to one-half of industrial materials purchased abroad, the authors see little problem with regard to the adequacy of the land resource base. Second, the authors see clear public benefits associated with pressing up to the limits of the agricultural land base; "at that rate of utilization, there should be no need for farm commodity support or subsidization programs for food and fiber."

Several points can be raised about the inferences the authors have drawn from these data. First, I would urge a more cautious point of view with regard to the ease of conversion of land now used for pasture and other purposes into cropland. Most of this land is withheld from cropping for the simple reason that it is too steeply sloped, too poorly drained, etc. to justify cultivation in an intensive cropping regime. The authors quite correctly imply that noncropland "in farms" is easier to convert to cropping than land with no connection to operating farms, Nevertheless, there is by no means a consensus among researchers about the ease or cost of converting such land to crops. *

Second, Tankersley and Wheaton's arguments about the "96 million acres of land . . . " neglect a crucial problem in reallocating this land to cropping. Because much of this land is owned by nonfarmers and is being "used" (e.g., as recreational property), efforts to add this land to the effective cropland base of the United States will encounter two key problems. One will be transfer of control or ownership, since it is likely that this land will need to be leased or sold to farmers to be converted to cropping. Second, given that the land is not idle in the strict sense—i.e., the land is being enjoyed or otherwise used for some purpose that contributes to human satisfaction—returns from cropping the land must be fairly substantial to induce a shift from its current pattern of use.

Third, I have reservations about Tankersley and Wheaton's ideas on "utilization rate." The authors operationalize this rate as the number of acres of land in crops divided by the number of acres in the potential cropland base (times 100). The implication is that the higher the utilization rate, the more efficiently cropland resources are being used. A utilization rate approaching 100 percent should not be regarded as unambiguously desirable. As noted earlier, the extent of demands on the U.S. cropland base are difficult to predict three or four decades into the future. Therefore, a moderate "utilization rate" would seem to be more prudent than a rate approaching 100 percent. Intensive cultivation of marginal lands, even under the best circumstances, threatens to degrade the quality of this land and other resources (e.g., soil erosion and fertilizer runoff leading to sedimentation and eutrophication of lakes and streams). Moreover, a moderate utilization rate enables the society to have a land reserve which can be drawn upon in the event of unforeseeable circumstances. I suggest that policy makers be cautious in pressing the use of fragile lands to their limits and thus reducing land use options in the future.

In a certain sense, posing the issue as we have—asking whether the sum total of demands for agricultural land will exceed the supply of land—is unrealistic. The use of land will be determined in great part by market forces. Given this reality, it will be important, however, for policymakers to ask: which uses of land are essential or socially desirable and should be encouraged, and which are less essential and do not deserve public subsidies? My own view is that the use of land for both plant extracts feedstocks and low-intensity reserves of low- to moderate-productivity land serve the societal good, albeit in very different ways. Most importantly, as demands on the U.S. land resource base increase over the next decades, policy makers, essentially for the first time in history, will have to grapple with the costs and benefits of particular land uses and make explicit decisions to encourage or discourage particular uses of land.

Research and Development Aspects of the Plant Extracts Industries

The potential commercial crops discussed in the workshop vary greatly according to "front-end" R&D requirements, Even the plant sectors requiring only modest amounts of R&D before widespread commercialization becomes possible need a suitable R&D system that can produce continued refinements in on-farm production and nonfarm industrial techniques. Thus, much of the future of the plant extracts sectors will depend upon establishment of appropriate R&D systems that can facilitate breakthroughs and continued fine-tuning.

It is important to emphasize the particularly complex nature of plant extract research and development requirements. Most plant extract commodi-

*Tankersley and Wheaton's optimistic assessments of the amount of land that can be converted into plant extracts production (and of the speed of this conversion) can be contrasted with the much more pessimistic results reported by Doering (9,10) with regard to converting noncropland for biomass energy production.

ties require a long chain of research tasks. This is, of course, most true for pharmaceutical commodities and somewhat less so for biocidal materials, given the necessarily long and careful procedures required for licensing of substances that might have deleterious impacts on humans or other life forms. Also, most of the plant extract commodities that involve agricultural production face R&D requirements spanning a variety of scientific disciplines. Perhaps the most difficult problem is that these agriculturally related commodities require agronomic and related research—the bulk of expertise for which lies in public, land-grant institutions—and industrial biochemistry and engineering research—the bulk of which is now privately funded and entered into on a proprietary basis. Moreover, the situation becomes even more complex if by-product use is required to begin commercial scale-up, Coordination and control will be potentially crippling problems in linking research advances made in what previously have been relatively distinct segments of the U.S. R&D system.

Despite the fact that virtually every plant extract commodity discussed would require a combination of public and private research, none of the papers, with the partial exception of Farnsworth and Loub, make explicit recommendations about how public and private funds and institutions should be combined to advance the plant extract industries. Also, I am struck by the large amount of basic "agronomic" (including parallel disciplinary work in plant breeding, plant pathology, entomology, and soil science) research that will be required to realize the full potential of the agriculturally related plant extracts such as milkweed, guayule, jojoba, crambe, etc. Related data on potential ecological impacts of commercial scale production of these commodities are also generally lacking in the papers (and in the scientific literature).

The crucial problem for the plant extract industries will be how to leverage public and private funds for R&D in ways that private companies will not be inappropriately subsidized or discouraged from entering the industry. It was noted above that the public nonmilitary R&D sector (especially for publicly funded applied research) faces stagnating or declining budgets (in real terms). Thus, adding significant research responsibilities for a number of nonconventional crops would severely strain the resources of the publicly funded State agricultural experiment station (SAES) and ARS systems. Moreover, the SAES and ARS systems are implicated in what may prove to be severe crises of public confidence; many agricultural research administrators and agricultural experts outside of the system are questioning whether this system is yielding high quality, "cutting-edge" research (21). It is likely that traditional formula funding appropriations for the SAES will stagnate in real terms over the next several decades and that any real increases in agricultural research funds will come in the form of "competitive grants" (which in theory would be available to nonland-grant as well as land-grant researchers). Thus, Congress should strongly consider making plant extracts research a high priority item and make funding available through a competitive grants program administered through USDA. This is not to argue that individual land-grant SAES should not pursue plant extracts-related research from their formula funds. Indeed, such an allocation of funds would be highly desirable. However, it should be recognized that the pressure on the use of these funds from traditional commodity and other clientele groups of the SAES will be increasingly intense as formula funding levels stagnate, and plant extracts "interests," being relatively new and not so entrenched as traditional commodity groups, cannot hope to fare well in this intensified competition for scarce research resources.

Private research funding problems are of a quite different nature. The bulk of privately funded research is conducted in two major sectors: "venture capital" (or other small) firms and large multiproduct translational companies. The venture capital sector has several advantages and disadvantages as a locus for plant extract research. On one hand, venture capital firms tend to be more risk-taking in their approach and typically are able to attract high-quality scientific talent because their working conditions by comparison with large corporations are more similar to those of a university. At the same time, venture capital firm research tends to be volatile, as it depends on the continued faith of venture capitalist investors; redundant, as several venture capital firms pursue similar research topics; and short term, since venture capital firms must "strike it rich" with immediate discoveries in order to survive beyond the initial period of venture capital funding. Moreover, most venture capital firms tend to have a "high-tech" bias—i.e., they are typically oriented toward highly advanced technologies which lead to valuable patents. Finally, most venture capital firms are too small to be effective in industrial scale-up.

The R&D systems of large transnationals generally tend to be more stable than those of venture capital firms because long-term funding is secure.

However, large firms' R&D tend to be relatively conservative and focused on differentiation of current product lines. Innovative research in areas such as plant extracts frequently promises to threaten existing product lines. For example, a large agrochemical firm maybe reluctant to explore plant-derived biocides, since these biocides might cut into the sales of existing product lines and create research information that could lead competitors to provide substitutes for their products.

Evidence presented in several of the workshop papers and other literature suggests that private sector plant extracts research would be more likely to occur in the small or venture capital firm sector than in the translational sector. The following comments, therefore, will focus on ways in which research results generated in public SAES/ARS and private venture capital institutions can be coordinated to develop plant extracts industries. One of the limitations in examining this issue is that the workshop papers contain little information on which types of research will be privately profitable (and hence attractive for the private Sector) and which will not (and hence needed to be conducted by the public sector or be publicly funded and contracted out to private firms). Thus, were Congress to be asked to enact legislation encouraging plant extracts industries, the aspects of plant extracts R&D that will be profitable to private firms to conduct and those that will require public subsidies should be determined.

As indicated earlier, publicly funded "front-end" research to stimulate private interest in the potentials of plant extract production probably will be needed, Some of this research may be expected to come from existing allocations within the SAES/ARS systems, but Congress may also need to consider a competitive grants program in the plant extracts area to allocate adequate research resources to these problems.

The private research organizations should not be solely responsible for research which is perceived to be privately profitable; the plant extracts industry as a whole may suffer if crucial patents become dominated by single firms. Public institutions should not avoid sponsoring research in areas that are attractive to private firms, since retaining certain crucial discoveries in the public domain may be essential to allow more than one firm to enter an industry. Nevertheless, it should be recognized that the bulk of the "industrial-level" research in plant extracts (e.g., fractionation processes, byproduct utilization) can and should be confined primarily to the private sector.

Plant extracts R&D will by necessity confront two issues that have assumed general importance in U.S. nonmilitary R&D. The first is the relationship between public and private research. During the past several years the U.S. R&D system has been in flux over the "proper" roles for public and private research. The mix of public and private research is now a major issue on many campuses (6) and in State and Federal Governments. It is recognized that public research should be coordinated more closely with the technical needs of industry, especially given the intense international technological competition that emerged during the late 1970's and early 1980's, However, there remains a great deal of uneasiness about how corporate influence on academic research priorities and procedures (especially control over the content of research and over patenting and licensing) will reduce academic freedom, stifle scholarly communication, and deflect research attention from projects that are of little interest to private firms but might be important to long-term public interest. The second current issue within which plant extracts will be implicated is the desirability of patenting life forms (and the corollary provisions of varietal protection offered by the Plant Variety Protection Act of 1970). On one hand, protection of proprietary interests in developing new varieties and life forms will encourage private sector research in these areas and reduce the level of public funding required to stimulate the agricultural and chemical-pharmaceutical industries. On the other hand, protection of new varieties and novel life forms raises certain ethical questions and may serve to deter public R&D in this area and keep useful plant varieties out of the public sector, It is useful to keep these issues in mind when formulating policy to encourage the plant extracts industries and to anticipate possible problems before they develop,

The Organization of Primary Production

This section will comment in general fashion on the papers, especially those by Telek, Wildman, and Tankersley and Wheaton, which discuss plant extracts processes requiring significant field crop production. The main concern will be how the primary production (or "farming") segment of these industries will be organized and the effects of these organizational structures.

The papers under review give virtually no information on how the primary production segment of

the plant extracts industries will be organized. In most cases this neglect is understandable; adequate information is unavailable and/or outside the author's area of expertise. Nevertheless, in exploring the potential of developing particular plant extracts, greater attention should be given to anticipating the socioeconomic structures and consequences that would result in the primary production area.

One crucial aspect of the organizational structure of the plant extract industries will be land availability. Land assembly arrangements will differ according to whether the land involved is owned by or leased to farmers and is cultivated. For lands owned or otherwise operated by farmers and currently under production, the crucial issue is: How will operators of these lands be induced to shift their uses of land? For land not under production, especially land not owned or controlled by farmers, the most important question concerns how these lands can enter agricultural production and, if necessary, undergo a transfer of ownership and control into the hands of farmers.

Inducing shifts of land from one agricultural use to another is basically a straightforward economic question. Commodity prices will have to be competitive with those of other crops, and mechanisms will be required to reduce the producer's risk. Newly developed crops can be competitive in the short run with traditional crops if an extract or product from the new crop is introduced as a "specialty" item. This high-value extract becomes a vector for greater long-term development of the crop for that and other products. By capitalizing on a novel or specialty item, the crop can be grown in restricted quantities for favorable prices, ensuring adequate and predictable returns for farmers and providing them with experience in growing the commodity and the opportunity to iron out production problems (e.g., tillage practices, pest control, variety selection). Initiating production of a new agricultural commodity in this way will provide the time necessary to complete further agronomic research and research in industrial engineering or byproduct use that will be critical to the long-term development of the industry. Nevertheless, incentives may be required to encourage farmers to shift their agricultural land from one crop to another, and contracting for guaranteed commodity prices or guaranteed returns may be an essential incentive necessary to effect this crop shift.

One question that may warrant attention in future technology assessments of plant extracts is the possible impacts of growing new agricultural crops on the production of other commodities such as wheat or sorghum and on the communities in which these new crops are grown. Generally, I suspect that the impacts on production levels of conventional crops would not be substantial or undesirable. Most field crop production in the United States has a large geographical range so that regionally confined shifts in cropping patterns would not greatly reduce the supply of other commodities. Perhaps more crucial might be "boomtown" effects of rapid growth and possible subsequent decline of the on-farm and off-farm segments of a plant extract process. Sociological attention recently has been focused on dislocating community-level impacts of boomtowns, both on the "upcycle" and on the "downcycle." In the upcycle, rapid increases in employment and population stretch public services to their breaking point, result in influxes of "outsiders," place pressure on and result in inflation in the value of housing stock, economically marginalize segments of long-term residents (especially the elderly), etc. (25). The dislocating effects of the ("ghost town") downcycle are obvious—deflation of asset values, loss of tax base, high unemployment, and so on. Thus, attention should be given to situations in which the development of plant extracts industries, particularly in what are now sparsely populated rural areas, might lead to a boomtown syndrome.

Earlier I alluded to several problems resulting from shifts of land into plant extracts agriculture. Unfortunately, our research and data base on land ownership in the United States are so inadequate that we lack sufficient profiles on the persons who own farmland that is not in farms and on the motivations for these ownership patterns. The scanty literature on this topic indicates that most of these lands are owned for esthetic and land speculation reasons and would not be shifted into agricultural production easily. One mechanism for shifting public lands, especially in the semiarid West, would be leasing these public lands for an indefinite period or perhaps selling them to farmers after a period of time. In sum, existing knowledge on the possible mechanisms for assembling land not currently in farms is highly inadequate for policy purposes. Identifying underused publicly owned lands in certain parts of the country for plant extracts purposes may be the most satisfactory short-term solution to the land assembly problem.

In addition to the neglect of land assembly issues, the workshop papers ignored the question of whether expanded agricultural production of plant extracts feedstocks will reinforce or undermine

family forms of agricultural production, Several key types of data will be required to address this issue, First, and most important, we need information on expected economies of scale in production, since one may assume that commodities for which there are substantial economies of scale will tend to be produced under large-scale "corporate" or "industrial" conditions. Second, information is needed on the amounts and types of labor required for production; for example, commodities that require large amounts of unskilled, cheap labor can be expected to be produced under nonfamily arrangements. Third, data are required on the capital-intensity of production (since highly capital-intensive production techniques tend to be biased against family farming units).

It can be argued that there will be social (especially community-level) benefits to the degree to which agricultural production can be undertaken by family (as opposed to industrial scale) producers (2,22). This is the case where the agricultural production process can be conducted without using a low-wage labor force, since a poorly remunerated labor force tends to have low purchasing power vis-a-vis local businesses. Where possible, the establishment of plant extract-related agricultural production should encourage family forms of production, and R&D should be oriented toward minimizing the barriers (such as high capital-intensity) to family farming units entering this area of production.

Organization of Nonfarm Plant Extracts Industries

For plant extracts industries to reach their full potential, R&D and pilot operations will have to be scaled up into commercial sized facilities. Scale-up involves both technical engineering and socioeconomic aspects. Chief among the socioeconomic aspects are the organizational routes to increased scale and the corollary processes of capital assembly. The scale-up process typically involves one of three major routes. The first route is for a small firm to pioneer in a pilot project, nurture the new technology, prosper, and acquire the capital necessary to become a large firm. The second route is for a small pioneering firm to sell out to a larger firm because of asset appreciation or lack of capital necessary to achieve the next level or stage of scale-up. The third route is for the technology to be developed within a large firm and for the large firm to undertake the investments involved in commercial scale up. The plant extracts industries no doubt will exhibit a variety of paths to commercial scale-up, probably involving all three routes.

The most crucial problem for development of the plant extracts industries is *not* the route followed for commercial scale, but whether the process will become stalled before the commercial scale-up occurs. As suggested earlier, smaller firms can be expected to be most innovative with regard to industrial processes such as plant extracts. However, these firms tend to have fragile financial bases and may lack the engineering expertise necessary to develop a plant extracts process beyond pilot scale, Larger firms tend to have greater industrial engineering expertise but may not be attracted to industrial production activities that lack secure patent protection or compete with existing product lines.

One of the major types of data necessary to judge the future of plant extracts industries—the likely degree of economies of scale and lumpiness of investments—generally was absent in the workshop papers under review. These data would help policymakers anticipate the likely route to commercial scale-up and the problems that might emerge during the process of industrial maturation.

A final comment I would like to make about the organization of the nonfarm plant extracts industry is to provide a general observation about patterns of industrial innovation in other advanced industrial societies, The problems involved in nurturing new industries are by no means unique to the United States. However, it can be observed that the United States has become one of the most traditional societies in recent years in reorganizing industry and fostering new industries. Virtually all other advanced industrial societies are experimenting with State-private corporations, or other "mixed" enterprises or forms of State-corporate cooperation, as means to achieve industrial policy goals. For example, the Japanese, through their Ministry of International Trade and Industry, are carefully aiming public R&D funds at selected industries for the explicit purpose of stimulating industrial innovation and gaining national advantage over other international trade rivals (especially the United States). More overt patterns of public-private cooperation and State-private industrial partnerships have occurred in France (3). Even the United Kingdom, under the conservative Thatcher regime, has initiated a number of State-owned corporations, in conjunction with private investments, in areas such as biotechnology and biomedical technology. The United States thus virtually stands alone in its laissez-faire posture toward industrial reorganiza-

tion, and a growing number of analysts have suggested that this laissez-faire posture will result in U.S. industry being outcompeted by foreign firms which have the force of government finance, R&D, and diplomacy at their disposal (14).

The implication with regard to plant extracts is that Congress may need to consider what now are regarded in the U.S. as novel forms of government-industry cooperation to nurture new industries in the long-term public interest. Partially government-owned firms need not, of course, remain publicly owned for an extended period of time; these firms may be sold to private investors after they become sufficiently established and profitable and hence attractive to private firms. Nevertheless, U.S. policymakers may need to reexamine their orientation toward industrial policy and make judicious use of public sector financial, R&D, and organizational resources to nurture new industries such as plant extracts.

Policy and Political Issues

This final section explores some selected public policy and larger political issues that were raised in several of the papers, especially that by Tankersley and Wheaton, and in the OTA workshop discussions. The first such issue involves the connection between an emerging plant extracts industry and the level of Federal commodity programs for basic grains and other agricultural commodities. Agricultural diversification implied by a growing plant extracts industry would expand markets and reduce the need for increasingly expensive commodity programs. To the degree that U.S. agriculture (especially in the Great Plains and Midwest) becomes increasingly specialized in the production of a handful of feedgrains, foodgrains, and oilseeds—much of which is destined for export—the agricultural sector will face price and income instability and may need commodity price supports and deficiency payments. Agricultural diversification will reduce the supply of these grains and oilseeds that have been chronically overproduced and reduce government expenditures for mitigating economic dislocation in the farm sector.

At the same time that one might argue that agricultural diversification will reduce commodity program expenditures, one should urge caution in drastically modifying these programs. Reduction of the scope of these programs will be a relatively long process. Commodity groups that are advantaged by Federal commodity programs can be expected to protect their prerogatives for an extended period of time. One should be aware of the extended time frame over which agricultural diversification will occur and of the underlying reasons why these commodity programs were enacted and why they will be needed some time into the future.

The role of commodity programs has been cast into sharp relief during the present farm recession. Without government intervention, the agricultural recession would have resulted in more dramatic dislocations among farmers. For example, in most areas of the country farmland prices have already declined by about 15 percent. As asset values decrease, farmers' collateral for loans shrinks and bankers may be forced to foreclose on farmers for whom current losses overwhelm equity in farm assets. Federal commodity programs are thus a necessary evil to prevent a severe depreciation in the value of farm assets and to prevent massive farm foreclosures.

In summary, there are several interrelated arguments about farm commodity programs. First, a time of farm recession is not propitious for the initiation of public policies to reduce commodity program payments. Second, there probably will be some continuing need for price and/or income sup ports for basic foodgrains, feedgrains, and other commodities which are characterized by low price and income elasticities of demand and, hence, by price and income volatility for farmers. Third, it would be politically unrealistic to suggest that farm commodity programs can be dramatically curtailed, especially in the very near future, over the objection of powerful commodity organizations. Fourth, agricultural diversification, such as through encouragement of plant extracts industries, will, in the long run, reduce the need for and expenditures on traditional agricultural commodity programs.

A second policy/political issue of concern to plant extracts is a short cautionary note with regard to the geopolitical implications of nurturing these industries. It is becoming increasingly apparent that foreign trade issues are not matters of mere abstract economic forces. Foreign trade is becoming increasingly central to the economic health of all advanced industrial societies which must be increasingly concerned about the international competitiveness of their industries and about their foreign trade balances. Import substitution is, in a sense, a form of import protectionism—albeit a much more benign form than increased import duties or import quotas—and Federal policy makers will need to be cautious about the geopolitical problems that could result from government support of import substitution efforts.

A final policy issue is that Congress should recognize that some plant extracts processes have more potential than others and that public support should be given selectively and carefully. To illustrate, I would like to use the example of protein from tobacco (Wildman). I do not wish to imply that this process is without merit or undeserving of public support; however, I feel there are certain key problems with the development of such an industry that were not adequately addressed in the paper by Wildman. First, as brought out in the OTA discussion, there are public acceptability problems associated with food uses of tobacco. Second, and perhaps more important, there are market problems with any type of vegetable protein for human consumption, as has been made dramatically apparent during the past 10 years of initiatives to market soy protein as a substitute for meat. Soy protein had great promise; nutritionally, the product was quite adequate, and soy protein promised to widen greatly access to high-quality protein because it was cheaper than meat. However, in a global marketing sense, soy protein essentially failed for one simple reason: There are two types of people in the world—those who can afford any type of protein and those who cannot—and those persons who can afford protein greatly prefer to buy it in the form of meat. Thus, the great promise of protein for humans from tobacco may take a long time to be realized. LPC protein for animal feed may thus have greater short- to medium-term potential than human food protein from tobacco. This example illustrates that the actual market potential of a plant extracts commodity may be less than it appears on the surface. Policy makers will have to acquire more detailed social science and marketing information on many plant extracts commodities to determine more accurately their market potential.

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