Fats and Oils as Chemical Intermediates: Present and Future Uses

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ABSTRACT

Currently, fats and oils possess about 40% of the paint binder, 50% of the surfactant, and 15% of the plasticizer markets. Other markets considered here, with estimated fats and oils percent share of these markets in parentheses, are: adhesives (1%), Agrichemicals (10%), engineering thermoplastics (2%) and synthetic lubricants (20%). With the expected growth for these markets and with fats and oils retaining the same percent share, an additional 3000 million pounds of fats and oils would be needed in 1990. In the likely event that the fats and oils share is accelerated, an additional 7500 million pounds would be required. These requirements could be met by an additional 10 or 25 million acres of soybean production, respectively, which can be easily attained by U.S. agriculture or by diversion of other crops or animal fats from edible use or export.

INTRODUCTION

The fats and oils industry in the U.S. has a volume of about 20 billion pounds annually, a little more than half going into edible products and about one-quarter each going into industrial chemical products and into exports (Table I) (1). Animal fats are the largest contributors (55%) to the industrial chemical markets, but both edible (20%) and industrial vegetable oils (23%) contribute significantly (2). Currently, fats and oils possess ca. 40% of the paint binder, 50% of the surfactant, and 15% of the plasticizer markets (2). Industrial applications for fats and oils,with special emphasis on plastics and coatings and on new fatty derivatives for these applications, have been reviewed (3,4).

There does not appear to be any reason that more vegetable oils could not be made available for greater use in industrial products. Land is available (2,4). Crop production costs are relatively small and less than subsequent processing costs (2). Prices for fats and oils have not increased at the same rate as those for petrochemicals (5).

It is time to evaluate the relationship of fats and oils as renewable resources relative to petrochemicals as non-renewable resources, and to determine if fats and oils are committed only to their historical uses or, additionally, to new value-added products needed by our technological society. Such evaluation is necessary in view of our increasing dependence upon imported oil and the resulting trade deficits.

THE CURRENT SITUATION IN SYNTHETIC ORGANIC CHEMICALS

Total production of synthetic organic compounds in the U.S. amounts to 163 billion pounds, with the single largest end-use market being plastics and resins at 30 billion pounds (Table II) (6). Chemical exports at one time helped to maintain a favorable trade balance. However, chemical export volumes increased only 33% between 1970 and 1976, although export values increased ca. 194% (7). The U.S. share of world chemical exports has eroded from 24%

TABLE I

U.S. Production, Imports, Domestic Disappearance, and Exports of Selected Fats and Oils (1)[a,b]

	Volume, million pounds			
Oil or fat	Production	Imports	Domestic disappearance	Exports
Food vegetable oil				
Coconut	—	1,115	1,075	31
Corn	669	10	581	93
Cottonseed	1,141	—	535	611
Palm	—	661	611	57
Palm kernel	—	157	111	—
Peanut	363	—	232	46
Safflower	—	—	36	—
Soybean	8,578	—	7,454	1,608
Sunflower	13	—	—	—
Animal fat				
Lard	1,055	—	808	249
Tallow, edible	532	—	534	23
Tallow, inedible and grease	5,443	6	3,180	2,849
Industrial vegetable oil				
Castor	—	118	107	—
Linseed	217	—	164	14
Tall oil	1,181	–	1,015	176
Tung	—	22	20	—
Vegetable oil foots	—	—	76	—
Marine animal oil				
Fish, sperm, and mammal oil	134	9	55	117
Total[c]	19,326	2,098	16,594	5,874

[a]Exclusive of butter fat and oil equivalent of exported oilseeds.

[b]For crop year 1976/77. Crop years vary from commodity to commodity and are defined in Reference (1).

[c]The totals given represent minimum values since all-inclusive data are not available.

TABLE II

1976 Production of Synthetic Organic Chemicals[a]

Category	Production, million pounds
Cyclic intermediate	19,796
Plastics and resins	29,680
Rubber-processing chemicals	384
Elastomers	5,386
Plasticizers	1,587
Surface active agents	4,582
Pesticides	1,364
All other	100,093
Total	162,872

[a]Source: USITC Publication 833 (6).

in 1960 to 14% in 1975, even though the dollar value has increased from $7.5 billion to $61 billion (7).

Agricultural exports have dropped to a lesser extent; U.S. exports of these were 22% in 1960 and 18% in 1975 of world exports (8).

But the U.S. is not just an agricultural nation and exports should not be in the form of raw farm products only. Value-added products in the form of plastics, detergents, lubricants, and other perhaps as yet undiscovered materials can all be made from agricultural, renewable resources and could be exported to help maintain a better trade balance.

FATS AND OILS

U.S. consumption of fats and oils in 1976 was 16.5 billion pounds, about two-thirds going into edible uses and one-third going into industrial products (Table III) (9). The single most important source for fats and oils in the world as well as the U.S. is soybean oil, a coproduct of the soybean meal used for animal feed (Fig. 1). It is important to note that edible oils have considerable utility in industrial uses. The amount of soybean oil consumed as the glyceride is about 200 million pounds, but the amount is actually 500-600 million pounds when byproduct soybean fatty acids recovered from refining operations are included.

Our main interest here is in the industrial product markets (Table IV). An estimate has been made of the contributions that fats and oils make to these markets, and the markets will be examined individually in the following discussion.

Adhesives

Adhesives and sealants are expected to grow from a 9 billion pound (wet weight), $2.2 billion market in 1975 to a 14 billion pound market in 1985 (10). Packaging, wood converting and furniture markets, construction, and transportation are the major end-uses, and all are expected to grow at a 4-6% annual rate to 1985.

Another study predicts that the 3.8 billion pounds (dry weight basis) of adhesive materials consumed in 1976 will increase to 6 billion pounds by 1985, with an annual growth rate of 4.6% (11).

The major raw materials for adhesives include phenolics, urea-melamine, and various natural products; but the fastest growing segment of the market is in hot-melt adhesives, expected to have an annual growth rate of ca. 16%. These adhesives are used in packaging, bookbinding, footwear, product assembly, and carpet backing, and they could penetrate pressure-sensitive adhesives markets. Hot-melt adhesives could have a worldwide volume of 1 billion pounds per year by 1982, up from 370 million pounds in 1973 (12).

Hot-melt adhesives is one area in which fats and oils derivatives have a share in the form of about 20 million pounds of dimer acids per year. The major share of the market is held by ethylene-vinyl acetate copolymer, polyethylene, and polypropylene. Polyesters and elastomers such as polyisobutylene and thermoplastic rubbers also have a part.

TABLE III

U.S. Consumption of Selected Fats and Oils, 1976[a]

Fat and oil	Total	Consumption, millions of pounds: Edible	Inedible
Soybean	7577	7363	214
Inedible tallow and grease	3367	—	3367
Tall	1039	—	1039
Coconut	990	492	499
Palm	699	673	26
Cottonseed	579	572	7
Peanut	250	248	2
Linseed	217	—	217
Castor	95	—	95
Other	1711	1476	234
Totals	16,524	10,824	5700

[a]Source: Current Industrial Reports M 20 K (76)-13 (9).

Agrichemicals

In 1974, world sales of agrichemicals amounted to over $4 billion, and an annual growth rate of 10% was projected (13). This market was divided into the following areas:

	Share, %	Projected annual growth rate, %
Herbicides	38	15
Insecticides	32	9
Fungicides	24	3
Plant growth regulators	6	12

The United States and Canada account for 45% of total world sales.

Another report, by Predicasts, Inc., suggests that annual growth rates will be less than those given above but, nevertheless, it indicates that U.S. consumption of pesticides (insecticides, herbicides, and fungicides) is expected to rise to a value of $5 billion and a volume of 1.2 billion pounds by 1990 (14). Sales of synthetic biological insecticides could reach 100 million pounds annually by 1990 and could account for 90% of pesticide shipments. The biggest growth market will be in exports, which will account for more than one-third of shipments.

Abramitis (15) has noted the significance of fats and oils to these markets and has reviewed the uses of emulsifier and surfactant materials in formulating pesticides, of fatty nitrogen compounds as pesticides *per se,* of fatty amines and quaternaries as insecticides, and of alcohols, esters, and amines as tobacco sucker inhibitors and chemical pruning agents. Fatty acids can serve as starting materials for insect attractants such as gossyplure and muscalure. A recent news release describes the use of triacontanol to increase yields of certain vegetable crops (16).

Long chain quaternary compounds have gained increasing importance as antimicrobials to replace hexachlorophene as a germicide and organomercury compounds in mildewcides and slimicides (17). U.S. biocide sales amounted to $380 million in 1977, with $110 million in consumer products (swimming pool products, cosmetics) and the remainder in industrial products (paint, preservatives, cooling water) (18).

Coatings

Because of environmental considerations, conventional solvent systems will hold only an estimated 18% of the

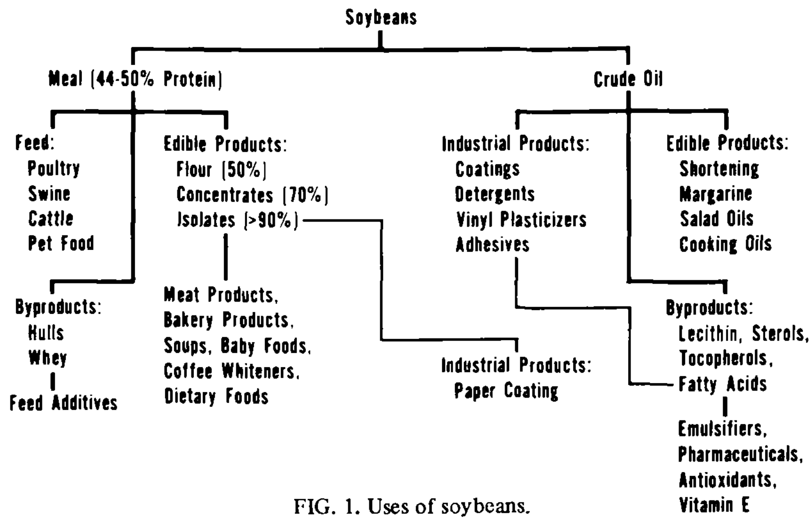

FIG. 1. Uses of soybeans.

coatings market by 1980, down from 64% in 1972-73. High solids and powder coatings as well as latexes and other water-based systems will fill the void (19). Latex paints will grow 6% per year over the next 5 years and will have ca. 30% of the market in 1980 (20). Water-based industrial latex coatings are expected to cost 10-15% more than solvent-based systems.

Raw materials for the coatings industry include propylene, which will be available in the future in ample supply but at a higher cost. Major resins for latex paints include polyvinyl acetate as well as the acrylics. Components of alkyd resins include phthalic anhydride, various polyols, and vegetable oils. Vegetable oils still hold a surprising 40% of the paint binder market (2). A total of 545 million pounds of vegetable oils were used as paint binders in 1976 (21). It seems likely that vegetable oils will take over an increasing proportion of the market as petrochemical costs overtake those for the natural products – provided that satisfactory water-based or high-solids systems can be developed. Linseed oil emulsion and water-dispersible polyesteramide paints have already been developed by the Northern Center (3).

Princen has reviewed new types of coatings and the renewable resources that can be produced to make these coatings; he has pointed out that such products are competitive with petroleum-based chemicals and are available without reduction in food or feed output (4).

Propylene as a building block for the coatings industry will probably still be available for years to come (22). Feedstock for propylene manufacture will shift from mainly natural gas to gas oil and naphtha feedstocks from crude oil in the 1980s. This estimate assumes that crude oil will be available and that it can be imported at a reasonable price.

Corrosion Inhibitors

It is reported that 1% or more of the gross national product is lost to industrial corrosion (23). There is good reason to expect, therefore, that the corrosion inhibitor market will double to a total volume of $24 billion by 1985. Fatty derivatives will have a small but significant part of the market in the form of fatty amines, C-21 dibasic acids, and dimer/trimer acids.

Evaporation Retardants

Fatty alcohols are known to reduce evaporation of water when present as a mono-molecular layer on the water surface (24). There is considerable doubt that this application will ever be practical, but if it does it will be a large volume use of the fats and oils industry.

Engineering Thermoplastics

U.S. production of engineering thermoplastics, including acetal, nylon, polybutylene terephthalate, polycarbonate, and modified polyphenylene oxide, amounted to almost 670 million pounds in 1977 (25). Automotive applications took some 150 million pounds, of which 72 million pounds were nylon. Engineering thermoplastics will be used in automotive applications in ever increasing amounts to help in reducing the weight and in improving the fuel economy of the American automobile. The average 17 lb of these plastics per car now used will increase to 32 lb by 1982.

The nylons used in this application are mostly based on nylons 6 and 66. However, there are other nylons to be considered and these are from vegetable oil sources. Nylon 11 is available commercially and is produced from castor oil. Nylon 9, nylon 13, and nylon 1313 have been produced on a pilot scale from the respective soybean (26) and crambe oils (27). These have very low moisture absorp-

TABLE IV

U.S. Markets for Fats and Oils

Market	Estimated current volume, million pounds	Estimated fats and oils participation, percent	Estimated market growth rate, percent per year
Adhesives	3800	1	5
Agrichemicals	900	10	3-15
Coatings	1360	40	4
Engineering thermoplastics	670	2	4
Fabric softeners	70	90	9
Plastics additives	1600	15	9
Surfactants	4600	45	4
Synthetic lubricants	300	20	10

TABLE V

U.S. 1976 Plasticizer Production (6)

Plasticizer	Production, thousand pounds	
Epoxidized esters, total		117,392
Epoxidized linseed oil	6361	
Epoxidized soybean oil	91,437	
Other	19,594	
Isopropyl myristate		3366
Oleic acid esters, total		9934
Sebacic acid esters, total		1705
Stearic acid ester, total		12,108
Others[a]		118,850
Total (16.6% of all plasticizers)		263,355
All plasticizers		1,587,434

[a]Includes data for azelaic, citric and acetylcitric, myristic, palmitic, pelargonic, ricinoleic, acetylricinoleic, glyceryl, and glycol esters and other acyclic plasticizers.

tion, and hence have good dimensional stability in humid environment.

Including all types in addition to engineering thermoplastics, there may be up to 350 lb of plastics in the average car by 1985, up from the present 160 lb (28).

Fabric Softeners

About 70 million pounds of cationic softener base compounds are consumed annually in the U.S. (29). These may be fatty quaternary ammonium compounds, amido alkoxylated ammonium sulfates, or amido imidazolines. The market is expected to grow at 8-10% per year. The compounds are mainly based on tallow fatty acids.

Plastic Additives

The major synthetic resins will be continuing to grow following the pattern established over the 1967-1977 period, during which polypropylene had an average annual growth rate of 15.2%; high density polyethylene, 13.1%; urethanes, 12.3%; ABS and SAN copolymers, 12.1%; vinyl chloride polymers and copolymers, 9.3%; and low density polyethylene, 8.9% (30). All of these require fatty acid-based chemicals to some degree, either as processing aids or as modifiers.

Fatty acids, their salts, and other derivatives have a small but important market as additives in the 30-billion-pound plastics industry, including fillers, stabilizers, peroxides, plasticizers, lubricants, and miscellaneous processing aids. The additive market will grow at a rate of ca. 9% per year, a slightly greater rate than for the plastics market itself, as a result of increased incorporation of fillers that are used in part to overcome the increasing cost of plastics (20). According to an Arthur D. Little report, the plastics industry will be growing three times as fast as the gross national product through 1981 (31).

Next to fillers in volume are the plasticizers, which will increase to a 4.5 billion pound market by 1990 even though their share of the additive market will decrease to 24% from the present 31%. Stabilizers will increase to more than 500 million pounds, processing aids to 350 million pounds, and flame retardants to 800 million pounds.

Among the processing aids are several metallic stearates: zinc stearate for crystal polystyrene; sodium stearate for high-impact, modified polystyrene for polypropylene, calcium stearate for polypropylene, and magnesium stearate for ABS polymers. Erucamide and other amides are valuable as antiblocking agents in polyethylene film. Epoxidized soybean oil is a valuable plasticizer/stabilizer for poly(vinyl chloride). Azelate and sebacate esters contribute to low temperature flexibility and permanency (Table V) (6).

Fats and oils not only will continue to supply such markets, but their use will expand. Needs exist for low cost plasticizers having improved properties such as permanency, lower extractability, and better low temperature, flame retardancy, heat stability, and biodegradability properties.

There may be a shift in the chemical base used for plasticizer synthesis to fats and oils at some time in the future. The phthalates have become an ubiquitous environmental contaminant. They apparently show subtle toxic effects and do not degrade at a satisfactory rate. Several groups are conducting studies, and the use of phthalates may come under question (32-34).

Surfactants

An estimated one-half of the total U.S. surfactant market is derived from fats and oils (2). The estimate is based on the Tariff Commission reports on synthetic organic chemicals, which classifies surface active agents into benzenoid (i.e., petrochemical) and nonbenzenoid (i.e., aliphatic) compounds (6). The latter category includes the surfactants derived from ethylene and propylene oxides as well as the mixed linear alcohols prepared by ethylene telomerization, and therefore represents compounds from both petrochemical and fats and oils sources. Mixed linear alcohols are produced to the extent of perhaps 500 million pounds, and ethylene and propylene oxides are used to make surfactants to the extent of about 700 million pounds per year (35).

Nevertheless, it is interesting to note the ratio of nonbenzenoid/benzenoid surfactants since 1960, even though the ratio is not clear-cut division of petrochemical vs. fats and oils sources. The ratio has increased from 0.5 to 0.6 in the 1960-1964 period to values of 2.6-3.3 and higher in the 1970s, largely as the result of environmental considerations to impart better biodegradability to surfactants.

Production increases for soybean and palm oils are expected to result in a world surplus of fats and oils, and there will be a downward trend for prices of soap-making fats (36).

Yet some say that petrochemicals will increase their share of detergent markets at the expense of fats and oils (37). The C_{12}-C_{15} mixed linear alcohol surfactants are expected to increase their share of the market from 24% to 48% in the period 1975-1990. During the same period, soaps would decline from 39% to 25% of the market. Even though natural soap would be losing out in its share of the market, it would probably maintain its present level of production. In contrast, tallow alcohol sulfates and alkylphenol ethoxylates are expected to decrease in both level of production and market share. These projections are based on the concept that cost of petrochemicals would increase at the same rate as inflation until 1980, then at an additional 4% per year to 1990. Because of the value-added concept, it is stated that the petrochemical industry should be able to outbid the energy sector in an auction for limited petroleum resources (37). Only 25% of the surfactant cost is directly related to the price of crude oil.

The emphasis on petrochemicals seems to ignore fats and oils as alternate resources, that these resources are renewable, and that the projected production increases will result in a world surplus of fats and oils. Even today, coconut oil in the amount of 500 million pounds per year is being used to make dodecanoate soaps, dodecyl alcohol surfactants, and other industrial products. Inedible tallow alone provided 764 million pounds for soap products in 1976.

Recent expansion of fatty alcohol production in West Germany will be based on vegetable oils and not petrochemicals because of high petroleum prices (38).

Synthetic Lubricants

These are receiving much attention as the result of the

TABLE VI

Future U.S. Market Volume for Fats and Oils with Continuation of Present Share of Markets

Market	Projected 1990 volume, million pounds	Estimated fats and oils participation	
		Percent	Volume, million pounds
Adhesives	7500	1	75
Agrichemicals	1800	10	180
Coatings	2400	40	960
Engineering thermoplastics	1200	2	24
Fabric softeners	230	90	210
Plastic additives	5300	15	800
Surfactants	8000	45	3600
Synthetic lubricants	1100	20	230
		Total	6079

TABLE VII

Future U.S. Market Volume for Fats and Oils with Acceleration of Market Share

Market	Projected 1990 volume, million pounds	Estimated fats and oils participation	
		Percent	Volume, million pounds
Adhesives	7500	5	375
Agrichemicals	1800	25	450
Coatings	2400	80	1900
Engineering thermoplastics	1200	4	50
Fabric softeners	230	95	220
Plastic additives	5300	30	1600
Surfactants	8000	70	5600
Synthetic lubricants	1100	30	330
		Total	10,525

success of recently introduced "Mobil-1." The latter contains ca. 70% of a trimer from decene-1, 20% of a polyol ester, and various additives. The polyol ester is the heptanoate ester of trimethylol-propane (39). Other companies have also introduced or will be introducing synthetic lubricants of this and other types. These lubricants could develop a 40 million gallon annual market by 1987 (40). Not enough of the short chain fatty acids will be available from natural sources, and synthetic short chain fatty acids will be made in increasing amounts from petroleum. The demand for such acids could reach 150 million pounds by 1986. Coconut oil is the primary natural source, and synthetic acids will soon be available from Celanese and Emery (41).

Diester lubricants are also expected to have a strong part, and the dibasic azelaic acid and sebacic acids should have increased demand. However, a larger part of the market will be taken up by the presently cheaper adipate esters.

THE FUTURE FOR FATS AND OILS

At the current U.S. volume and rate of participation for fats and oils, about 3000 million pounds are consumed in the markets shown in Table IV. At the growth rate indicated in Table IV, the projected 1990 volume for these markets is given in Table VI. If the participation of fats and oils is continued at the present rate, the total volume of fats and oils needed for these specific markets would be on the order of 6000 million pounds – an increase of 3000 million pounds over the present consumption.

If participation of fats and oils in the future markets is greater than in the present markets – a highly probable event - then the total volume of fats and oils is on the order of 10,500 million pounds – an increase of 7500 million pounds (Table VII). Some of the major increases that might be expected for fats and oils participation include a rise from 40% to 80% in coatings, from 15% to 30% in plastic additives, and from 45% to 70% in surfactants.

There should be no problem in supplying the increased amount of fats and oils that will be required, and the increase will come from several sources. As mentioned earlier, land is available, crop production costs are small, world surplus will prevail, and prices will be favorable. An additional 100 million acres of cropland, now idle or used for pasture, are available, and 600 million acres of pasture might be converted to cropland in part, if necessary (42).

To help visualize the significance of the increases needed by 1990, the assumption can be made that the needs might be met by soybean plantings:

Increase needed, million pounds	Soybean plantings required, million acres
3000	10
7500	25

These soybean plantings would constitute a significant but not necessarily disproportionate amount of actual plantings. Actual soybean plantings have been increasing regularly to keep up with the demand for soy protein:

Year	Plantings, million acres
1976	50
1977	59
1978	64 (est.)
1979	71 (est.)

Furthermore, in view of the present and projected world surplus of fats and oils, it is appropriate to suggest that markets other than the traditional ones need to be examined in some detail to exploit fully the potential of these renewable resources. Although fats and oils cannot be expected to fill the requirements of the entire synthetic organic chemical industry, they can and should complement other resources such as coal and forest crops. Some nontraditional markets for fats and oils have been suggested here and elsewhere (2,3), but there is an urgent need for research and development to create new markets and to ensure that the best possible, value-added markets are established for these valuable and renewable resources. Only through research on renewable resources, including fats and oils, can the United States be expected to increase its degree of self-sufficiency and economic health.

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