Appendix A
Selected New Industrial Crops

Bladderpod

Scientific name: *Lesquerella* species

Major compounds produced: The seeds contain 11 to 39 percent oil of which 50 to 74 percent are fatty acids containing hydroxy groups. The predominant hydroxy fatty acids produced are lesquerolic acid, densipolic acid, and auricolic acid. Individual species of *Lesquerella* tend to specialize in the production of one of the three hydroxy fatty acids to the exclusion of the other two. After oil extraction, a high-protein meal that is relatively high in lysine remains.

Replacement: Imported castor oil (mainly the hydroxy fatty acid ricinoleic acid).

Major uses: Hydroxy fatty acids are used primarily in plastics. The oil from *Lesquerella* can be used to produce a plastic that is tougher than those currently available.

Agronomic characteristics: *Lesquerella,* a member of the Cruciferae family, contains about 70 species and is native to dry areas from Oklahoma to Mexico. It produces thick stands in the wild, is relatively tolerant of cold, and can survive with annual rainfall of 10 to 16 inches (25 to 40 cm). Observed yields of species in the wild have ranged from about 979 lb/acre of seed (1 ,100 kg/ha) to 2,000 lb/acre.

Technical considerations: The chemical structures of the hydroxy fatty acids produced by *Lesquerella are* similar, but not identical, to that of ricinoleic acid (castor oil). Extensive testing and evaluative studies will need to be conducted to determine if these hydroxy acids can substitute for ricinoleic acid. About 20 species of *Lesquerella* have been field tested in Arizona. L. fendleri appears to be the most promising for domestication. It displays significant genetic variation leading to easier selection for agronomic characteristics. However, L. fendleri suffers from seed dormancy and seed shattering, which increases research and commercialization difficulties. The meal contains glucosinolates.

Economic considerations: Brazil and India are the major producers of castor beans. Between 1983 to 1986, production in those two countries has ranged from 524,000 metric tons (MT) to 886,000 MT, with 1986 output of 586,000 MT. This erratic production has contributed to highly variable prices for castor oil. U.S. imports of castor oil have increased somewhat, but because the United States is a major purchaser, too large an increase in imports would significantly raise the price. Castor oil is classified as a strategic oil and is stockpiled.

Social considerations: It is possible to grow castor beans in the United States but because of the high toxicity and allergic reactions experienced by field workers, it is not done. No other plant tested has been found to produce high levels of ricinoleic acid. *Lesquerella* is adapted to dry climates and requires fertilizer levels equivalent to other alternatives that could be grown in the same area.

Extent of research conducted: *Lesquerella* was identified early as a high producer of hydroxy fatty acids in the Northern Regional Research Center (NRRC) screening of potential industrial plants, but only recently has research interest been shown. The Agricultural Research Service of the U.S. Department of Agriculture and the United States Water Conservation Laboratory in Phoenix, Arizona, have collected germplasm. Plant breeding to improve yields, and water management studies are being conducted at Phoenix. Much of the research to date has been evaluating the seeds for oil content and concentration. Some utilization research is being conducted at the NRRC in Peoria (substituting Lesquerella for ricinoleic acid). The Cooperative State Research Service (CSRS) through the Office of Critical Materials is spending $20,000 on crushing and assessment work at the NRRC.

SOURCES: 36,43,44,46

Buffalo Gourd

Scientific name: *Cucurbita* foetidissima

Major compounds produced: Seeds of wild species are 21 to 43 percent oil by weight with a mean of 33 percent. Some hybrids that have been developed have seeds that are 38 to 41 percent oil with a mean of 39 percent. Among the hybrids analyzed, the fatty acid distribution was palmitic-7.8 percent, stearic-3.6 percent, oleic-27.l percent, and linoleic-61.5 percent. Among wild species, there is an inverse relationship between linoleic and oleic acid concentration. The meal that remains after oil extraction is about 30 percent protein by weight. It is relatively low in lysine. The roots contain high levels of starch. By dry weight, first-year roots are 47 to 64 percent starch, and second-year roots are 50 to 65 percent starch.

Replacement: Epoxy fatty acids derived from sunflower oil, soybean oil, and petroleum. The root could be used as a feedstock for ethanol production.

Major uses: The fatty acid distribution of the oil is very similar to that of sunflowers. Buffalo gourd oil could be used for the same industrial uses as sunflower and soybean oil; it could be converted to epoxy fatty acids and used in the plastics and coatings industry. The meal could be used as livestock feed. The starch could be used as a feedstock for ethanol production.

Agronomic characteristics: Buffalo gourd is a wild member of the squash and pumpkin family. It is native to the arid and semiarid regions of North America and could be grown in the Ogallala aquifer region. It can survive in regions with as little as 6 inches (150 mm) of rain, but probably will require at least 10 inches (250 mm) of water to achieve economical yield levels. It is relatively intolerant of cold temperatures, and cannot tolerate poorly drained soils. Buffalo gourd can be grown either as an annual or a perennial. Utilizing a perennial cultural system optimizes seed yield (oil production) and limits root (starch) yield. The annual mode of production optimizes root yield. Conservative estimates of seed yield are 1,780 lb/acre (2,000 kg/ha). Some experimental plots using hybrids have averaged 2,760 lb/acre (3,000 kg/ha) with one plot producing 2,914 lb/acre (3,274 kg/ha). Starch yields of 6,061 lb/acre (6,810 kg/ha) have been achieved experimentally.

Technical considerations: Increased yields, efficient harvesting techniques, and improved disease resistance are needed.

Economic considerations: Fatty acids derived from the oil of buffalo gourd, like sunflowers and soybeans, must be chemically converted to epoxy fatty acids. It is the cost of this conversion, more than the cost of the raw oil, which limits the use of natural oils to provide epoxy fatty acids. Buffalo gourd may not have an advantage over sunflower or soybean oil for these uses. As a feedstock for ethanol production, buffalo gourd might have potential. It takes approximately 1.8 to 1.9 kilograms of starch to produce one Liter of ethanol. Therefore, it is possible to produce approximately 404 gal/acre (3780 l/ha) of ethanol from the roots. It is estimated that buffalo gourd priced at about $25 per ton would be competitive with grains for ethanol production.

Social considerations: Buffalo gourd is adapted to arid climates and irrigation requirements are lower than those of many other crops which could be grown in those regions. It provides extensive ground cover and, particularly if grown as a perennial, could reduce erosion on susceptible soils. Buffalo gourd is a plant that might have more uses in developing countries than in the United States. The starchy root can be dried and used as cooking fuel rather than wood, and the oil from the seed is edible.

Extent of research conducted: Buffalo gourd research is conducted at the University of Arizona.

SOURCES: 10,13,15,43,44

Chinese Tallow

Scientific name: *Sapium* sebiferum
Major compounds produced: The seeds are 25 to 30 percent hard vegetable tallow and 15 to 20 percent oil. The tallow is a single triglyceride containing palmitic and oleic acids. The oil contains oleic, linoleic, and linolenic acids.
Replacement: Imported cocoa butter
Major uses: Potentially the tallow could be used as a substitute for cocoa butter and the oil could possibly be used as a drying oil for paints and varnishes.
Agronomic characteristics: The Chinese tallow tree is a member of the Euphorbiaceae family and is native to subtropical China. It currently is grown in the South Atlantic and Gulf Coastal Plains and in some areas of southern California as an ornamental. It is best adapted to semitropical climates. Chinese tallow is tolerant of salinity and can be grown on poorly draining soils. Seed production can begin in the third season of growth and yields up to 10,000 lb/acre can be achieved. The seeds ripen in the fall. The tree can live 50 years.
Technical considerations: Need to increase yields, and utilization research.
Economic considerations: The United States imports 70,000 to 80,000 metric tons of cocoa butter each year, valued at about $348 million. One study estimates a possible net return of $3,200 per hectare per year after 5 years.
Social considerations: Chinese tallow will grow on more marginal lands. Since it is a perennial and requires a long time to yield, it may be more suitable to plantation type of growth.
Extent of research conducted: The Small Business Innovation Research program of the National Science Foundation (flowering, biology, ecology, and genetics), the NRRC (oil characterization), and the Short Rotation Woody Crops Program of the Department of Energy (agronomic) have provided research funding.

SOURCES: 29,39,46

Coyote Bush/Desert Broom

Scientific name: *Baccharis* pilularis (coyote bush), *Baccharis* sarothroides (desert broom).
Major compounds produced: Approximately 10 percent of the dry weight of the plant *are* resins.
Replacement: Wood rosins
Major uses: Could be used in rubbers and chemicals.
Agronomic characteristics: *Baccharis is* a member of the Composite family. The genus consists of over *300* species of dioecious, sometimes evergreen shrubs, which are native to North and South America. The genus contains arid-adapted species. *Baccharis* pilularis is native to Baja and southern California, where it

is often grown as a landscape plant. Attempts to grow it in Tucson, Arizona, were unsuccessful due apparently to a sensitivity to high temperatures and low humidity in combination with overwatering. *Baccharis* sarothroides is better adapted to the drought, heat, cold, and high salinity of its native Sonoran Desert environment.

Technical considerations: Hybrids of B. pilularis and B. sarothroides have been achieved. All of the hybrid plants obtained displayed pistillate (female) sexual expression. Excess production of pappus on female plants is a nuisance and a fire hazard, and staminate (male) sexual expression is preferred. Research is needed in this area as well as in the production yields of resins.

Economic considerations: Currently, annual U.S. production of rosin, is about 600 million pounds. High quality wood rosin comes from aged pine stumps, but this supply is diminishing. Tapping of live trees to obtain gum rosins is very labor intensive and expensive, and production from this source is also declining. Currently, U.S. production of rosins comes mainly from recovery of tall oils, byproducts obtained from the manufacture of chemical wood pulp. It is estimated that the United States consumption of resin will be 781 million pounds (355 million kilograms) by the year 1990.

Social considerations: *Baccharis* tolerates arid conditions and requires less irrigation than crops that are currently grown in the Southwest.

Extent of research conducted: In 1975, at the University of Arizona, Tucson, B. pilularis and B. sarothroides were crossed to achieve an interspecific hybrid, which combined the arid land adaptability of B. sarothroides with the compact growth of B. pihdaris. The hybrid was released by the University of Arizona Experiment Station as an ornamental shrub, under the name of Centennial.

SOURCES: 43

Crambe

Scientific name: *Crambe* abyssinica

Major compounds produced: The ***seeds are 30*** to 45 percent oil, 50 to 60 percent of which is erucic acid, a C_{22} monounsaturated fatty acid. After oil extraction, there remains a meal that is about 28 percent protein.

Replacement: Imported high erucic acid rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially, the oil could be hydrogenated to yield a hard wax that could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for use in high-pressure lubricants and industrial paints and, to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed or as an adhesive for plywood.

Agronomic characteristics: *Crambe* is a member of the Cruciferae family and is native to the Mediterranean region. It is planted in the spring, has a short growing season of 90 to 100 days, and can be grown in all of the 48 lower states of the United States. *Crambe* tolerates dry conditions well but will not tolerate heavy, wet soils. Seed yields in experimental plots have ranged between 1,000 to 2,500 lb/acre, with the Meyer cultivar yielding 2,163 lb/acre. Commercial yields are expected to be about 1,500 lb/acre. Delayed harvest can lead to seed shattering.

Technical considerations: There appears to be no technical barriers to the direct substitution of *Crambe oil* for high erucic acid rapeseed oil. *Crambe is* susceptible to the fungus *Alternaria* brassicicola and turnip mosaic virus, and broadleaf weeds can be a problem. Currently there are no herbicides approved for use on *Crambe;* approval for Treflan is being sought. The seeds are very small and very lightweight, placing a premium on proper seed handling. Leakproof equipment may be needed. The seeds are covered by a hull which must be removed prior to processing. Dehulling equipment similar to that used for *sunflower* seeds is needed. A lack of cold-tolerant varieties diminishes the opportunity to plant *Crambe* as a winter crop in the Southeast. *Crambe seeds* can contain up to 8 percent glucosinolates, sulfur-containing compounds attached to glucose molecules, which have been linked to thyroid disturbances, liver damage, throat abscesses, appetite depression, tongue swelling, and abortion. Meal with high levels of glucosinolates can generally be fed to beef cattle (ruminants), but not to swine and poultry. The U.S. Food and Drug Administration has approved crambe meal (obtained by solvent extraction) use in beef finishing ratios at concentrations of less than 4.2 percent of the total weight of the ration.

Economic considerations: World production of rapeseed oil has increased nearly 35 percent since 1984, although much of that increase is due to canola (edible) quality oil, and not industrial-quality oil. The current U.S. market for high erucic acid oil is approximately 40 million pounds per year. Most of this oil is used to produce erucamide, used as an antislip agent in plastics. An estimated 65,000 to 85,000 acres of *Crambe is* needed to supply this market. Development of a market for industrial nylons made from brassylic acid is estimated to require planting of nearly *300,000* acres.

The estimated production costs per acre, in the Midwest (including land, but excluding transportation costs beyond the farm gate and farm management and risk charges), are $147, Crambe/winter rapeseed will compete with winter wheat in the Plains Region. Net earnings of wheat, deficiency payments included, are about $200 per acre. Estimated processing costs for rapeseed oil range between $0.16 and $0.31 per gallon of oil depending on seed volume and oil content, processing plant size, extraction method used, and whether the plant was newly constructed or retrofitted to process rapeseed. Because *Crambe oil* content is less than rapeseed, and the seeds must be dehulled before processing, it is expected that processing costs for *Crambe* will be slightly higher than for rapeseed.

Social considerations: *Crambe* will grow in drier areas than rapeseed and may therefore be more suitable for growth in the Plains Region of the United States. Fertilizer needs are comparable to wheat.

Extent of research conducted: Both *Crambe* and winter rapeseed are crops that the Office of Critical Materials (OCM) is actively trying to commercialize. Congress has appropriated $325,000 for fiscal year 1989 to be used for this purpose. Eight States (Missouri, Kansas, New Mexico, Idaho, Iowa, Nebraska, North Dakota, and Illinois) have formed a consortium in cooperation with the OCM to perform research necessary to lead to commercialization. Funding by these States is estimated to be $2 for every $1 of Federal support.

SOURCES: 15,20,35,36,42,46,49,51,53

Cuphea

Scientific name: *Cuphea* species

Major compounds produced: The seeds are from 25 to as much as 40 percent oil. Some species have oil that contains up to 80 percent lauric acid, a C_{12} saturated fatty acid. Other species contain high levels of C_{10} fatty acids such as capric acid. The meal is high protein.

Replacement: Imported coconut oil (lauric acid, capric acid) and imported palm kernel oil (lauric acid).

Major uses: Currently, palm oil and coconut oil are used both as edible oils and for industrial purposes, primarily in soaps and detergents (as surfactants) and in lubricants.

Agronomic characteristics: The *Cuphea* genus is a member of the Lythraceae family and consists of approximately 250 species native to Mexico and Central and South America. One species, *Cuphea* viscosissima, is native to the United States. Several species are adapted to temperate climates. Experimental plots have yielded 250 to 2,000 lb/acre of seed (280 to 2,240 kg/ha). There are both insect and self-pollinated species.

Technical considerations: The major problems are seed shattering and seed dormancy. Seed yield per se does not appear to be a significant problem, but because of the inability to retain the seeds, harvesting is difficult and yields diminished. Hundreds of populations in several species of *Cuphea* have been sampled, but so far none have demonstrated genetic variability for seed retention. Chemical mutagenesis of seeds to induce genetic variation for seed shattering has been attempted. The results have been disappointing thus far. Seed dormancy in some species has made it difficult to grow populations large enough to continue further evaluations. Species that are insect pollinated have long floral tubes, which preclude access by honeybees to the nectar. Suitable insect pollinators have not been found, causing the discontinuation of research on most of the insect-pollinated species of *Cuphea*. *Cuphea oil* is colored, but this appears to be a minor problem that can be alleviated during processing, if required. It is not known whether the meal contains any antinutritional elements that would prevent its use as a livestock feed. Because *Cuphea* is projected as a domestic source of lauric acid (a very well-established market), extensive utilization research may not be necessary. If the problem of seed shattering cannot be overcome, it is unlikely that *Cuphea* could be commercialized.

Economic considerations: Coconut oil is the major source of lauric acid, but over time, it has been losing market share due to erratic supplies caused by adverse weather conditions and declining productivity of aging coconut plantations in the Philippines. Some new, higher yielding varieties of coconut palms have been developed and are beginning to be planted. It is expected that when these trees mature, coconut oil production will increase. An alternative source of lauric acid is palm kernel oil from Malaysia and Indonesia. Production of both palm oil and palm kernel oil is increasing and potentially could increase significantly more, largely due to increased planting of new varieties of the African palm, which produce high yields of oil, can be grown in marginal lands, and are highly resistant to pests and diseases. It is expected that supplies of palm oil and palm kernel oil will increase substantially when these new varieties mature. The increased production of palm kernel oil coupled with coconut oil is expected to double the supply of lauric acid oils by 1995.

Currently the United States uses about 650 million pounds of tropical (palm, palm kernel, and coconut) oils for food uses (about 5 percent of the U.S. edible oil market). This level of use is about 35 to 40 percent of the total U.S. imports of tropical oils; the remaining imports are for industrial uses. Europe consumes higher levels of tropical oils for food uses than does the United States; increased consumer concern over saturated fats in Europe could potentially decrease European demand. Industrial uses will need to increase significantly to prevent a worldwide glut of lauric acid oils, if supply of palm kernel and coconut oil continues to increase, while the demand for edible uses of these tropical oils decreases.

Oversupply would result in depressed prices for these oils and for potential domestic substitutes such as *Cuphea.* Higher lauric acid yields for *Cuphea (80* percent) than for coconut oil (40 to 45 percent) may result in a premium for *Cuphea* oil. However, higher transportation and processing costs might offset some of this premium if *Cuphea* is grown in the Northwest. An alternative option for commercialization of *Cuphea* might be to be to develop the species that are high in capric acid instead of those high in lauric acid. Coconut oil contains only 3 to 7 percent capric acid. Although the market for capric acid is smaller than for lauric acid, capric acids fetch higher prices. Thus, varieties higher in capric acid might be more attractive.

Social considerations: *Cuphea* is intended to be an import substitute for tropical oils (coconut and palm kernel oil). These crops are major exports of Indonesia, Malaysia, and the Philippines, developing countries that are of some strategic importance to the United States. The possible impact that loss of these markets might have on the economic stability of these countries is not well-understood.

Extent of research conducted: Early research on *Cuphea* was conducted at the University of Gottingen in Germany. Beginning in 1983, breeding, genetics, and agronomy research was undertaken in the United States. Initial germplasm collections (267 accessions) were made at the USDA/ARS Water Conservation Lab in Phoenix, Arizona. Currently, the germplasm program has been moved to the ARS Laboratory in Ames, Iowa, and has been expanded to include accessions from 50 to 60 *Cuphea* species. A germplasm collection expedition to South America is being planned. In addition to germplasm collection, researchers at Ames, in conjunction with Iowa State University, are attempting to improve the nutritional content of *Cuphea seeds.* There may be some potential to use these seeds as food supplements for infants and the elderly. Researchers at Oregon State University are attempting to develop cultural management practices, prevent seed shattering, and increase the lauric acid content of the oil. Some financial support for *Cuphea* research at Oregon State University is being provided by the Glycerine and Oleochemical Division of the Soap and Detergent Association. The USDA is contributing approximately $100,000 to the project. Some research is conducted at the ARS Laboratory at Tifton, Georgia, to improve agricultural and management practices, and some work is being conducted at ARS Laboratory in Phoenix, Arizona, to develop hybrids. It is estimated that there are approximately four scientist-years total being devoted to *Cuphea* research, Research hours are being allocated among three USDA/ARS positions (one each at Ames, Iowa; Phoenix, Arizona; and Tifton, Georgia) and three research positions at Oregon State University.

SOURCES: 3,12,21,22,34,36,38,44

Guar

Scientific name: *Cyanopsis* tetragonobla

Major compounds produced: The seeds produce a gum. The meal is 35 to 50 percent protein, which contains toxins and is low in lysine.

Replacement: Imported guar

Major uses: Currently used as a strengthening agent in paper, and as a stabilizer in cosmetics, ice cream, salad dressings and oil-drilling muds.

Agronomic characteristics: Guar is a leguminous herb that grows well in semiarid regions, and can be grown in areas of the Southwestern U.S. It tolerates alkaline and saline conditions, and when it receives sufficient rain (15.7 to 35.4 in or 40 to 90 cm) yields of 625 to 805 lb/acre (700 to 900 kg/ha) seed can be obtained. Guar does not tolerate cold. The growing season ranges from 105 to 150 days. The plant itself could be used for forage.

Technical considerations: A major difficulty with guar is its susceptibility to a variety of pests and diseases including the fungus *Alternaria, the* bacteria *Xanthomonas,* and root knot nematodes. There is also a need to improve yields.

Economic considerations: U.S. imports of guar seeds have been decreasing. This decrease may be in part because production of guar is already occurring in the United States and production needs of the country may be close to being met. There may not be a need for expansion of guar production, unless export markets or new uses can be developed. (See table D-5 in app. D for US. ***imports*** of guar.)

Social considerations: Guar is a legume and has nitrogen-fixing qualities.

Extent of research conducted: Not extensive.

SOURCES: 43

Guayule

Scientific name: *Parthenium* argentatum

Major compounds produced: Guayule produces a high-molecular-weight rubber and resins that are extracted from the whole plant.

Replacement: Imported *Hevea* rubber and synthetic rubber

Major uses: High-molecular-weight rubber is particularly valuable in uses which require elasticity, resilience, tackiness, and low heat buildup such as in tires; resins can be used in the chemical industry; extraction residues could potentially be used as livestock feed.

Agronomic characteristics: The genus *Parthenium* includes 17 species, all native to North or South America. Both annuals and perennials are known. Guayule is the most studied species. It is native to the Chihuahua desert region of the Southwestern United States and

Northern Mexico and produces a high-quality rubber similar to *Hevea. In* wild stands, rubber percentages have ranged between 3.6 and 22.8 percent of the dry weight, and resin yields have ranged between 2.5 and 9.8 percent by dry weight of plant tissue.

Technical considerations: The major difficulty with guayule is the yield of rubber. Rubber accumulation seems to be a factor of geoclimatic conditions, with water and temperature stress stimulating rubber production. Recently researchers have found the enzyme (rubber polymerase) responsible for synthesizing rubber. This enzyme can be stimulated to produce higher levels by spraying certain chemicals on its leaves, so some of the yield problems might be overcome.

Guayule has been crossed with other species of *Parthenium*, most notably with *P.* **fruticosum, to** obtain a hybrid. The hybrid contained a lower percentage of rubber than guayule, but the biomass of the hybrid was higher than that of guayule, indicating that total rubber production of the hybrid might be greater than for guayule. In addition, high-molecular-weight rubber (high-quality natural rubber) dominates low-molecular-weight rubber, indicating that the hybrid can produce high-quality natural rubber. Successive generations of crosses, however, displayed decreasing seed germination percentage. Improving seed germination and direct seeding procedures are needed.

Guayule differs from both *Hevea* and other latex-producing plants in that the rubber is contained in single thin-walled cells located on the stems and branches of the shrub. This results in the need for a physical or chemical separation of the rubber from other components in the harvested shrub. Excessive handling results in decreased rubber quality. Improvements are needed in harvesting technology. In addition to problems of yield, large-scale testing of the high-molecular-weight rubber in tires is needed, and uses for coproducts, low-molecular-weight rubber, and other chemical components need to be developed.

Economic considerations: Guayule is intended to replace natural rubber imports from Asia, primarily from Malaysia and Indonesia. From 1983 to 1987, U.S. imports of rubber have averaged 777,000 metric ton per year, and price per pound was about $0.39. It is estimated that for guayule to be competitive with natural rubber, prices for rubber must double, or guayule yields must increase to about 1,200 pounds of rubber per acre. Markets for byproducts also must be found, and production and processing costs must be lowered by at least one-third their present levels. These changes are expected to result in a positive cash flow for farmers and to make guayule competitive with natural rubber, but they may not necessarily make guayule competitive with other crops that could be grown.

Social considerations: Guayule tolerates arid conditions and requires less irrigation than crops that are currently grown in the Southwest. Guayule appears to be more suited to large scale production than production on small farms. Because of the volume involved, the special processing needs, and the fact that natural rubber is a strategic material, guayule may require building new processing plants, which would create new jobs.

Extent of research conducted: Guayule has been used for centuries by native Americans, and by 1910, guayule provided 10 percent of the world's supply of natural rubber. From 1910 to 1946, the United States imported approximately 68 million kg of guayule rubber from Mexico. During World War II, interest in research and development of guayule rubber was high in the United States. However, after the war ended, shipments of *Hevea* rubber from Asia resumed, synthetic rubbers were developed, and interest in guayule was severely dampened.

U.S. interest in guayule was revived in the 1970s, and in 1981, the Department of Defense (DoD) guaranteed a $20 million loan to the Gila River Indian Community (GRIC) to grow several hundred acres of guayule, develop a prototype rubber-processing plant, and develop rubber to be tested. Due to several problems encountered by GRIC, USDA took over the project in 1986. The GRIC continued to grow the guayule, and the Firestone Rubber & Tire Co. was contracted to build an $8.3 million prototype processing plant. The plant was scheduled to begin operations in August of 1989, following a 16-month delay due to solvent leaking into the atmosphere. The pilot-plant size is about 150 ton/yr and will provide rubber for DoD testing and coproduct research. The plant is intended to process 275 acres of guayule into 50 tons of natural rubber, 100 tons of resins and low-molecular-weight rubber, and 1,600 tons of plant residue. There are approximately 300 acres of guayule available for processing, but rubber yields may be low because the plants ideally should be harvested at 3 to 5 years of age and they are now 9 to 10 years old.

Agronomic and breeding research is being conducted at the University of Arizona, University of California-Riverside, Texas A&M University, and New Mexico State University. Coproduct research is being conducted by the Institute of Polymer Science at the University of Southern Mississippi. Investments between 1978 and September 1986 have been about $31.9 million, with the DoD providing $13.1 million, USDA providing $13.2 million, other Federal agencies providing $2.9 million, and the Firestone Tire & Co. providing $2.7 million. Investments for 1987 to 1988 were $19.3 million, with $15 million from DoD and the rest from USDA. Funding for fiscal year 1989 includes $500,000 for breeding and genetics being administered by the ARS, and another $668,000 in Native Latex Grants being administered by CSRS. The Latex Grants are being spent as follows: $240,000 for breeding and genetics research, $160,000 for germplasm collection and research, $150,000 for coproduct research, and $138,000 for unspecified research. It is estimated that about $38 million will need to be spent between 1989 and 19% to establish a domestic natural rubber industry.

SOURCES: 2,26,28,32,34,46,47

Gumweed

Scientific name: *Grindelia* camporum

Major compounds produced: Diterpene resins, similar to pine resins, can be extracted from the entire plant. The major resin is grindelic acid and its derivatives. Approximately 5 to 18 percent of above-ground dry weight are crude resins with highest concentration in the flowers. After extraction, the bagasse residue is nontoxic and contains 8 to 10 percent protein.

Replacement: Pine resins

Major uses: The resins are used in the naval stores industry (generic name for large class of chemicals including turpentine and wood rosins). Uses for these resins include adhesives, varnishes, and paper sizings. The residue could be used as livestock feed.

Agronomic characteristics: *Grindelia* (a member of the Composite family) consists of about 195 species of herbs and shrubs native to North and South America. Many of the species are found in the Southwestern United States. Commonly called gumweed, the genus consists of annuals, biennials, and perennials. Gumweed is xerophytic and halophytic. It is most active during hot rainless summer months and can flower and produce two crops in a single growing season. It is probably unsuitable to the cooler climates and shorter growing seasons found in more humid regions of the United States. The species most studied is *Grindelia* camporum, a native of the Central Valley in California. Gumweed needs about 30 in (67.5 cm) of precipitation to produce reasonable yields. Yields in experimental plots have been about 2.2 to 2.5 tons of biomass per acre and up to 5 tons/acre if harvested twice.

Technical considerations: *Grindelia are* naturally outcrossing species and are self-incompatible. Genetic selection for traits in outcrossing species often results in problems of inbreeding depression. With *Grindelia*, it maybe possible to increase resin yields, but it would beat the expense of biomass, resulting in a total resin yield that is not significantly higher. Increased yields will be necessary for commercial feasibility, but may be difficult to obtain.

Economic considerations: Currently, U.S. production of rosin is about 600 million pounds. High-quality wood rosin comes from aged pine stumps, but this supply is diminishing. Tapping of live trees to obtain gum rosins is very labor intensive and expensive, and production of gum rosins from this source is declining. Currently, U.S. production of rosins comes mainly from recovery of tall oils, byproducts obtained from the manufacture of chemical wood pulp. It is estimated that U.S. consumption of resins will be 781 million pounds (355 million kg) by the year 1990.

The estimated cost of growing *Grindelia is* about $380 per acre. This includes 30 inches of irrigation, a quantity lower than the requirements of currently grown crops in the production region. If the crop is harvested twice, approximately 5 tons of biomass per acre per year could be achieved. Assuming a double harvest and a processing cost of $35 per ton, the total cost of production is estimated to be $555 per acre. Given a resin content of 10 percent, the break-even cost would be about $0.56 per pound. The current cost of wood rosin is about $0.40 per pound. The cost of the *Grindelia* resin is higher than wood rosin. *Grindelia* resin also is of a lower quality than wood rosin and would have to be further refined to be similar in quality. To achieve economic feasibility, yields will need to be higher, production costs lower, and uses for the bagasse byproduct, perhaps as livestock feed, would be needed.

Social considerations: *Grindelia* tolerates arid conditions and would require less irrigation than crops that are currently grown in the Southwest.

Extent of research conducted: The National Science Foundation funded the collection and evaluation of 10 to 15 species of *Grindelia* from the Southwestern United States. In 1982, a population of 300 plants was started at the University of Arizona's Bioresources Research Facility in Tucson. Private-sector funding from the Diamond-Shamrock Corp. and from Hercules, Inc. has supported product evaluation and development research at the University of Arizona.

SOURCES: 16,25,29,44

Honesty (Money Plant)

Scientific name: *Lunaria* annua

Major compounds produced: The seeds are 30 to 40 percent oil, and contain approximately 48 percent erucic acid, 24 percent C_{24} fatty acids, 18 percent oleic acid, (all monounsaturated) and 10 percent other fatty acids. The meal is high protein.

Replacement: Imported industrial rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially the oil can be hydrogenated to yield a hard wax, which could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for

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use in high-pressure lubricants and industrial paints, and it can be used to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed or as an adhesive for plywood.

Agronomic characteristics: Honesty is a member of the Cruciferae family and consists of both annual and biennial varieties. Initiation of flowering requires long daylight hours in the annual varieties and cold winters in the biennials. Seed yield estimates are unavailable.

Technical considerations: This plant is still essentially a wild plant and an extensive breeding effort is needed before commercialization could even be contemplated. The meal contains glucosinolates which have been linked to several physiological problems.

Economic considerations: The potential oil markets are essentially the same as for *Crambe* and winter rapeseed (i.e., 40 million pounds of high-erucic acid oils used to produce primarily erucamide).

Social considerations: It is a perennial that provides ground cover and potential protection against erosion.

Extent of research conducted: Most research to date has been at the Saskatchewan Research Council in Canada.

SOURCES: 21,22,36,46

Jojoba

Scientific name: *Simmondsia* chinensis

Major compounds produced: The seeds contain 45 to 55 percent oil, 95 percent of which is in the form of linear wax esters (fatty acids connected directly to fatty alcohols instead of to glycerol or glycerides). Eighty-seven percent of the fatty acids are of chain length 20 or 22 (eicosanoic acid is C_{20} and docosanoic acid is C_{22}), and there are small quantities of palmitoleic acid (C_{18}) and oleic acid (C_{16}). The fatty acids are monounsaturated. The meal that remains after oil extraction is about 30 percent protein, reasonably high in lysine, and deficient in methionine.

Replacement: Banned sperm oil and possibly petroleum-derived products.

Major uses: Currently, jojoba oil is being used in the cosmetics industry in a variety of uses ranging from shampoos to moisturizers, lipsticks, and shaving creams. It is apparently non-toxic and does not cause eye irritations. Isomerization of jojoba oil yields a soft opaque cream resembling face creams.

Hydrogenation produces a crystalline solid, which has properties resembling beeswax, candelilla, carnauba, and spermaceti, all waxes that are commercially used now. Crystallographically, hydrogenated jojoba oil is similar to polyethylene and can be combined with either polyethylene or polypropylene or both to yield mixed plastics that have lower melting points and are harder than the pure plastic, plus still retain the tensile strength of the pure plastic.

Sulfurized jojoba oil is similar to sulfurized sperm oil and could potentially be used as a high-pressure lubricant. A major difficulty is that it solidifies at temperatures below 50 °F (10 ‘C) limiting it to high-temperature applications. Before being banned, sperm oil was used to prevent foaming in industrial fermentation processes, such as the production of penicillin G. Jojoba oil also has antifoaming properties and could potentially be used in similar processes. Reactions of jojoba oil with sulfur chloride forms factice, which is used in manufacturing varnishes, adhesives, printing ink, and flooring materials.

Jojoba waxes could possibly be used in floor finishes, coatings, furniture polishes, candles, soaps, crayons, and so forth. The seeds contain tannins that could potentially be extracted and used in the leather industry.

Agronomic characteristics: Jojoba is an evergreen native to the Sonoran Desert region of the Southwestern United States and Mexico. It appears to live at least 40 years. Latitude and day length do not appear to be limiting factors. Jojoba can grow with 8 to 18 inches (20 to 46 cm) of annual precipitation, but for economic production, jojoba should receive 18 to 24 inches (46 to 61 cm) of precipitation, which might require irrigation. It requires porous soil with good drainage and will not tolerate water logging. Jojoba grows in soils ranging from pH 5 to 8 and appears to be tolerant of salinity. In the wild state, jojoba plants are associated with a symbiotic fungus *(Glomus* deserticola) found in the roots. It is thought that this fungus aids in the uptake of phosphorus, zinc, copper, and other elements. Current average seed yields are approximately 200 pounds/acre (224 kg/ha) from 4-to 5-year-old-shrubs, and 3,000 pounds/acre (3,360 kg/ha) from 11- to 12-year-old shrubs. Approximately 2.5 pounds (1.1 kg) of seed are needed to produce 1 pound of oil.

Technical considerations: Jojoba bushes are either male or female and are wind pollinated. However, male and female plants cannot be identified until first flowering, which takes 1 to 4 years. During the first few years, continual removal of male plants and replanting of female plants is needed. This can cause fields to be nonuniform and creates problems with harvesting. Today, most new fields are planted from cuttings or tissue cultures rather than seeds, which helps to reduce or eliminate the problems of identifying males and females. Flowering is triggered by cold or drought stress. A cool fall, followed by a warm wet winter can cause early flowering. If the weather then turns cold (25 °F or lower during the blooming season of January to March), the crop could be lost. Jojoba can tolerate high temperatures (greater than 100°F), but not prolonged temperatures of below 23 °F. Weed control appears to be more of a problem than pests and diseases, but as more plants are planted over larger geographic areas, some pest and disease problems are beginning to occur. A major cost associated with jojoba is harvesting. Seeds on the same bush do not ripen at the same time requiring multiple harvests. The meal contains simmondsins and tannins which are unpalatable to livestock and potentially toxic. Utilization research performed has been experimental; to be accepted for industrial uses, full-scale utilization research must be performed. Yields need to be improved.

Economic considerations: Currently, the United States plants nearly 42,000 acres to jojoba and produces between 100 to 300 tons of jojoba oil per year. Total U.S exports have been 70 MT in 1985, 134 MT in 1986, and 124 MT in 1987. Japan imports approximately 100 tons and West Germany and the Netherlands together import another 100 tons for use in the cosmetics industry. Value of exports per pound have been steadily decreasing from approximately $8.50 in 1985 to about $6.50 in 1987.

Social considerations: Jojoba grows in arid regions and requires minimal irrigation. Since it is perennial with long payoff times for investment, it may be better suited to large-scale production than small-farm production.

Extent of research conducted: Research on jojoba is conducted at university and ARS labs in the Southwest, particularly the Arid Land Studies at the University of Arizona.

SOURCES: 11,14,29,30,36

Kenaf

Scientific name: *Hibiscus* cannaabinus L.

Major compounds produced: The plant produces a fiber with a cellulose content similar to wood but lower in lignin.

Replacement: Wood pulp

Major uses: Potential uses for kenaf include newsprint, carpet padding, paper for use in stamps, money, magazines, poultry litter, and cardboard. Green, chopped kenaf can be fed as forage.

Agronomic characteristics: Kenaf is an annual, nonwood fiber plant native to east-central Africa. It grows to heights of 12 to 18 feet in approximately 150 days. It can yield between 6 and 10 tons of dry matter per acre. Seed germination requires soil temperatures of at least 55 ‘F. It is somewhat tolerant of saline conditions. Rainfall of about 5 inches is needed shortly after germination to ensure good growth, but after that, kenaf is relatively tolerant of dry conditions.

Technical considerations: Weeds generally are not considered a problem because of kenaf's rapid emergence and growth; the dense populations needed result in shaded ground conditions. However, favorable conditions are needed to promote this rapid growth, and pre-emergent herbicides maybe needed. Kenaf thrives in high temperatures when abundant soil moisture is available, however, it will not tolerate standing water or water-logged soils. The most serious pest kenaf faces is root nematodes. Most kenaf cultivars are photoperiod sensitive and do not flower until day length decreases to about 12.5 hours of light in the fall. Kenaf may require nitrogen, phosphorus, potassium, and calcium inputs. In very dry areas, some irrigation may be needed.

In the Southern Rio Grande Valley, initial experiences indicate that rain-fed kenaf produces about 75 percent of irrigated yields. Research to improve harvesting equipment is needed. Development of uniform size and shape is still needed. Storage needs to be improved. The system envisioned is a cross between that used for wood chips and that used to store bagasse. Because of heat buildup, added attention must be paid to air circulation and/or water cooling.

Major research is still needed to develop products that use kenaf. It has been shown that kenaf can be used to make newsprint. The newsprint made from kenaf is generally whiter and stronger than paper made from wood pulp, and it does not yellow as badly. Kenaf can be converted to pulp under high temperature and pressure. Making newsprint from kenaf requires fewer chemicals and about two-thirds the energy needed to make wood pulp newsprint. Kenaf newsprint uses less ink and does not smudge as much as wood pulp newsprint. Kenaf improves the strength and brightness of recycled paper.

Economic considerations: The United States imports approximately 7 million tons (60 percent of total use) of newsprint a year at a cost of about $4 billion. Constructing this much production capacity would require a large capital investment as it costs approximately $400 million to erect a 600 ton/day capacity plant, which would produce about 0.2 million tons of newsprint per year.

New technologies are opening the way for trees not previously used for newsprint (i.e., aspen and fast-growing eucalyptus) to now be converted to newsprint. Increased recycling of newsprint will require less new wood pulp. Additionally, paper mills are accustomed to working with year-round crops, such as trees, and have large investments in forests. Because of high transportation costs, paper mills generally process material in the immediate area. Utilizing a seasonal crop such as kenaf presents problems. Failure of a kenaf crop could result in high transportation costs to supply adequate processing materials. The potential for crop failure will place a higher priority on storage facilities, which increases the costs of using kenaf.

Kenaf can be used as a supplement to pine for pulp mills already in existence. It is estimated that it will cost approximately $10 million to install equipment needed to utilize kenaf in conjunction with softwood or recycled newsprint pulp at current mills. For kenaf to supply the entire U.S. newsprint market of 12.5 million tons of newsprint per year, approximately 1 million acres would need to be planted to kenaf.

Uses other than newsprint need to be found. Since newsprint represents about 7 to 10 percent of the pulp and paper industry, there are likely many other opportunities that could potentially be developed. In addition to uses as paper and cardboard, kenaf could potentially be used as poultry litter (broiler producers spend about 0.3 cents per pound live weight on litter, and in 1987, poultry production was about 21.5 billion pounds).

Production costs for kenaf average about $20 to $30 per ton, and the cost of harvesting is about $10 to $15 per ton. Currently it is anticipated that farmers will be contracted to grow kenaf and that harvesting will be custom done because of requirements for cleanliness of the product. Kenaf is expected to sell for $50 to $60 per ton. Comparison of estimated returns of kenaf and other crops in Georgia indicate that kenaf (both irrigated and non irrigated production) is expected to have lower net returns than tobacco, cotton, and peanuts (irrigated and nonirrigated) and higher net returns than sorghum, wheat, and oats (irrigated and nonirrigated). Nonirrigated kenaf is expected to have slightly higher net returns than nonirrigated corn, but irrigated kenaf is estimated to have lower net returns than irrigated corn. In the Rio Grande Valley region of Texas, kenaf is more competitive with other crops, particularly the grains. Deficiency payments for cotton decrease the competitiveness of kenaf, but nevertheless, it is felt that the most likely area for initial production of kenaf on a commercial basis will be in Texas.

Social considerations: There is potential for some new mills to be built, particularly if production occurs in Texas, and this has the potential to create new jobs and economic activity in those areas. Kenaf stalks are harvested free of leaves, with the leaves remaining in the field. This could result in 1 to 2 tons of dry leaf matter, which is rich in nitrogen, left on the field. Potentially, 60 to 120 pounds of nitrogen per acre could be returned to the soil in the form of organic matter.

Extent of research conducted: Research on kenaf began in 1956 at the Northern Regional Research Center in Peoria, Illinois (an ARS lab). Over 500 fiber crops were screened, and kenaf was selected as the most promising for further research. In 1978, ARS dropped its research program on kenaf with the hope that private industry would continue the research since it had been shown that newsprint could be made from kenaf.

The American Newspaper Publishers Association did continue some research and began commercial runs of newspapers printed on kenaf paper. The kenaf demonstration project was begun to commercialize kenaf. The ARS and the CSRS in cooperation with Kenaf International, Canadian Pacific Forest Products, and CE Sprout-Bauer Co. joined to form the Joint Kenaf Task Force (JKTF). Phase I of the demonstration project began in 1986 with the USDA providing $141,000 and the JKTF members providing $263,000 for growing, harvesting, fiber handling, pulping, and papermaking trials. Phase II was begun in 1987 and undertook commercial trials. The estimated cost to the JKTF was $644,000, with the USDA providing $300,000 of that support. Phase III is currently underway and involves agricultural research and research to develop additional uses for kenaf.

Congress appropriated $675,000 in funds for fiscal year 1989. The money is being spent as follows: $150,000 each to the ARS labs in Weslaco, Texas, and Lane, Oklahoma; $75,000 to Mississippi State University; $300,000 administered by the CSRS for fiber separation ($200,000), harvest system modification ($20,000), dry-form fruit boxes ($50,000), recycling research ($20,000), and poultry litter research ($10,000 to Texas A&M). The Kenaf Paper Co. of Texas (consisting of Kenaf International, Bechtel Enterprises, Inc., and Sequa Capital Corp.) has begun construction on a $35 million plant in Willacy County, Texas. The plant will handle 84 tons/day, produce approximately 30,000 tons of newsprint annually, and require 4,500 acres of kenaf. The plant is expected to begin full operation is 1991 and to employ about 160 people.

SOURCES: 4,7,9,23,24,29,41,45,46,48,54

Meadowfoam

Scientific name: *Limnanthes* species

Major copounds produced: The seeds are 20 to 30 percent oil, containing 90 percent C_{20} and C_{22} fatty acids, which are primarily monounsaturated. Of the diunsaturated fatty acids, the double bonds are widely separated, which potentially leads to greater stability. The meal is high protein.

Replacement: Products derived from petroleum.

Major uses: Currently, Japan imports the oil for use in cosmetics. Potentially, the oil can be converted to liquid wax esters, which can be used in lubricants. Reacting the oil with sulfur yields factice, a solid chemical rubber. Meadowfoam could potentially be a source of suberic acid, which is currently obtained from castor oil.

Agronomic characteristics: Meadowfoam is native to the Pacific Coast Region of North America.. It is planted in the fall and harvested in June or July. Meadowfoam is best suited to mild climates; seed germination occurs in soil temperatures that range between 40 and 60 °F. Some meadowfoam species are insect-pollinated, while others are self-pollinated.

Technical considerations: Self-pollinated meadowfoam species are generally agronomically preferable, however those that have been examined have given lower yields and display less genetic variation than insect-pollinated species. No suitable self-pollinated species have been found, thus attention is focused on insect-pollinated species, such as *Limnanthes* alba, which displays genetic variation for seed retention. Seed shattering is a serious problem with several species. Cool, wet weather may decrease insect activity, decreasing pollination. Yields need to be improved to increase commercial potential.

The major constraint for meadowfoam is the lack of a well-defined market. The fatty acids found in meadowfoam oil are not a replacement for any fatty acids currently being used. Initial tests of use in lubricants have revealed problems of corrosion, foaming, and wear scarring. Extensive utilization research is needed to develop meadowfoam. The meal contains glucosinolates, which causes physiological problems when ingested. The oil is colored and needs to be cleaned, when desired. The lack of a large germplasm collection has limited research.

Economic considerations: Limited attempts to grow meadowfoam commercially have been made. In 1986 and 1987, approximately 1,000 acres of the meadowfoam variety Mermaid were planted in Oregon. Due to the lack of appropriate processing facilities, the seeds were shipped to Lubbock, Texas, for oil extraction, then shipped to California for export to Japan.

In 1985 to 1986, the Oregon Meadowfoam Growers Association sold 12 tons of oil to Nikko Chemical Ltd. of Japan. An additional 3 tons of oil was shipped to the same company in 1986 to 1987. Croda, Japan, an oil, fats, and chemical supplier has also purchased approximately 3 tons of meadowfoam oil. In February 1989, Croda, Japan received permission from the Japanese Ministry of Health and Welfare to use meadowfoam oil in cosmetics. Toxicology and skin-sensitivity tests have been performed in the United States, and no major problems have thus far been encountered.

Farmers appear unwilling to grow meadowfoam if there is no well-defined market, and manufacturers are unwilling to reformulate their procedures if there is not a consistent high-quality supply. In addition to the amounts of oil exported to Japan, samples have been sent to Canadian firms and the European Economic Community for market development. Currently the Oregon Meadowfoam Growers Association has a 1 year stock of oil and seeds on hand.

Total processing and transportation costs are $0.55 per pound of oil (compared with about $0.03 per pound for soybean oil). Production costs were about $440 per acre.

Social considerations: Different species of *Limnanthes are* adapted to poorer soils and some act as xerophytes and require less water than other grains grown in the same area.

Extent of research conducted: Most of the industrial application research is performed at the Northern Regional Research Center in Peoria. Researchers at Oregon State University are working on varietal improvement and commercial development. The ARS is spending approximately $350,000 on meadowfoam research at Peoria and Oregon State.

SOURCES: 5,22,31,36,43,46

Milkweed

Scientific name: *Ascelepidaceae* genus

Major compounds produced: Latex can be extracted from the whole plant. The latex produced is mainly cardiac glycosides, which are generally cytotoxic and affect the heart, lungs, kidneys, gastrointestinal tract and brain. Nonpolar (hexane) extracts constitute about 4 percent of the above-ground dry weight and consist primarily (85 percent) of triterpenoids and derivatives and 2 percent natural rubber. Polar (methanol) extracts account for about 18 percent of the dry weight and contain primarily sucrose (34 percent), polyphenolics (6 percent) and inositol (5 percent). The remaining residue after extraction contains pectin and is about 16 percent protein. The protein content of the residue is comparable to that of alfalfa, and contains high levels of lysine, but also contains toxic constituents.

Replacement: Petroleum-derived products

Major uses: The latex can be used in glue and chewing gum. The floss fiber can potentially be used to replace goosedown.

Agronomic characteristics: The *Asclepiadaceae* genus contains about 140 species. Most of the species native to North America are perennials, although a few annuals are known. *Asclepias* curassavica is planted as an ornamental plant in semitropical and semiarid regions. *Asclepias* speciosa (showy milkweed) ***is*** widely tolerant of habitat and could be grown in the United States in most of the area west of the Mississippi River. It produces more latex than *A.* curassavica.

Technical considerations: A major difficulty with establishing millkweed is that of weed control. During the seedling stage, much energy is devoted to root establishment which aids in drought tolerance but results in the slowly growing, above-ground portion being noncompetitive with faster growing weeds. The average yields of the test plots were about 4.3 MT/ha, but increasing the planting density is expected to increase yields to about 7 to 9 MT/ha. Outdoor, uncovered storage resulted in a significant decrease in methanol (polar) extractable compounds, but the nonpolar (hexane) compounds remained stable. Better storage methods resulted in little loss of either extractable.

Economic considerations: Experimental plots of milkweed, using wild milkweed seed, had variable production costs of $169 per acre ($418 per hectare). Highest expenditures were for weed control. Reduction in the costs of weed control would significantly reduce production costs. In addition, harvesting costs were high, but could potentially be lowered by growing on larger plots to take advantage of economies of scale for machinery. Both pectin and inositol are high-value products produced by milkweed, but extraction and purification is expensive and not commercially competitive at the present time.

Social considerations: Milkweed is itself considered a weed and production may need to be carefully managed to prevent it from becoming a pest.

Extent of research conducted: Native Plants, Inc. conducted some initial research on milkweed, but has discontinued research. The University of Nebraska conducts research on the fiber floss,

SOURCES: 1,52

Rapeseed

Scientific name: *Brassica* napus

Major compounds produced: The seeds are approximately 42 percent oil, of which 45 to 57 percent is erucic acid. The remaining meal is high protein.

Replacement: Imported industrial rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially, the oil could be hydrogenated to yield a hard wax, which could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for use in high-pressure lubricants and industrial paints and, can be used to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed, or as an adhesive for plywood.

Agronomic characteristics: Rapeseed is a member of the Cruciferae family. It can be grown either as a winter or a spring crop and potentially could be double cropped in the Southeast and southern Midwest regions. Generally, it can be grown anywhere that spring and winter wheat is grown. Rapeseed cannot tolerate extreme cold, and the winter varieties have a restricted planting period. The seedlings must be 2 to 3 inches high before the first frost if they are to survive. Rapeseed does not tolerate poorly drained soils; high rainfall can reduce yields. Expected average commercial yields of winter rapeseed are about 2,000 lbs/acre under dryland conditions and about 3,000 lbs/acre when irrigated. Spring variety yields are about one-half that of the winter varieties,

Technical considerations: Two types of rapeseed can be grown: industrial-quality rapeseed and food-quality rapeseed. Food-quality rapeseed is marketed as Canola oil and generally contains less than 2 percent erucic acid, while industrial-quality rapeseed generally contains at least 40 percent erucic acid. Canola-quality rape and industrial-quality rape cross pollinate resulting in a hybrid that is visually indistinguishable from the parents, but that contains an intermediate level of erucic acid (too high for food uses and too low for industrial uses). Production of the two types of rapeseed must be physically separated. To combat the problem, States such as Washington and Idaho have established rapeseed production districts.

Rapeseed is highly susceptible to flea beetles, cutworms, and various fungi. Asynchronous flowering can result in variable seed maturity, with some mature pods shattering while other pods are still green, causing harvesting difficulties and yield loss. The meal contains glucosinolates and has restricted use as a livestock feed.

Economic considerations: World production of rapeseed oil has increased nearly 35 percent since 1984 (see table C-2, app. C). Most of the rapeseed grown are low erucic acid, low glucosinolate varieties used primarily for edible oil (Canola), however Eastern Europe and Canada produce significant amounts of industrial-quality rapeseed also. The supply appears to be relatively stable due to the large number of producers so that adverse conditions in one country do not necessarily result in a severe supply shock for rapeseed oil. Current U.S. demand for industrial-quality rapeseed (approximately 40 million pounds) is mainly for erucamide and would require an estimated 50,000 acres of domestically produced rapeseed. Development of markets for brassylic acid, such as for the industrial nylon 1313, could increase the demand for high-erucic acid oil sufficiently to require planting of nearly 300,000 acres.

Social considerations: About 3,000 to 8,000 acres of winter rapeseed are annually grown in Idaho. The large increase in imports of rapeseed oil over the last few years is due mainly to increases in Canola-quality and not industrial-quality rapeseed oil (table D-3, app. D). Winter rapeseed provides ground cover over the winter and may decrease soil erosion.

Extent of research conducted: The Office of Critical Materials (OCM) is actively trying to commercialize winter rapeseed. Congress has appropriated $325,000 for fiscal year 1989 to be used for this purpose. Eight States (Missouri, Kansas, New Mexico, Idaho, Iowa, Nebraska, North Dakota, and Illinois) have formed a consortium in cooperation with the OCM to perform research necessary to lead to commercialization. These

States are providing an estimated $2 for every $1 of Federal support for this research.

SOURCES: 19,27,35,36,38,42,46,49,51

Stokes Aster

Scientific name: *Stokesia* laevis

Major compounds produced: The seeds contain 27 to 44 percent oil, with 64 to 79 percent of the oil consisting of vernolic acid, a fatty acid that contains an epoxy group. The meal is high protein.

Replacement: Conversion of oils containing nonepoxy fatty acids, such as soybean, sunflower or linseed, into epoxy fatty acids. Replacement for petroleum-derived epoxy compounds.

Major uses: Currently, epoxy fatty acids are used primarily in the plastics and coatings industries. The epoxy groups of fatty acids act as plasticizers (to provide flexibility) and as stabilizers (by inactivating agents that might cause degradation). In general, the epoxy sites are highly reactive sites where adjacent triglyceride molecules attach to form interlocking polymer networks.

Agronomic characteristics: Stokes aster is a member of the Composite family. It is a perennial native to the Southeastern U.S. and could potentially be grown in the eastern half of the United States and the Pacific Northwest. Potential seed yield has been estimated to be 1,780 lb/acre (2,000 kg/ha).

Technical considerations: Very little agronomic work has been done on stokes aster, and it is still essentially a wild plant. A well-defined market for epoxy fatty acids exists, but the epoxy fatty acids obtained from stokes aster are not identical to those obtained by conversion of sunflower, linseed, or soybean oil, or those derived from petroleum. Quality control and utilization research is needed.

Economic considerations: Approximately 100 to 180 million pounds of soybean and linseed oil are converted to epoxy fatty acids annually. While the raw material is relatively inexpensive, the chemical transformation of the fatty acids contained in sunflower and soybean oil to epoxy fatty acids is relatively expensive.

Social considerations: As a perennial, stokes aster has potential implications for erosion control.

Extent of research conducted: Apparently little research is being performed on this species.

SOURCES: 20,22,33,36,46

Vernonia

Scientific name: *Vernonia* anthelmintica and *Vernonia* galamensis

Major compounds produced: Seeds from V anthelmintica are 23 to 31 percent oil, 68 to 75 percent of which is vernolic acid, an epoxy fatty acid. Seeds from V. galamensis are 42 percent oil containing 72 to 73 percent vernolic acid. Meal from V. galamensis contains 42.5 percent crude protein, 10.9 percent crude fiber, and 9.5 percent ash.

Replacement: Conversion of oils containing nonepoxy fatty acids, such as soybean, sunflower, or linseed, into epoxy fatty acids. Replacement for petroleum-derived epoxy compounds. Replacement for organic solvents in paints.

Major uses: Currently epoxy fatty acids are used primarily in the plastics and coatings industries. The epoxy groups of fatty acids act as plasticizers (to provide flexibility) and as stabilizers (by inactivating agents that might cause degradation). In general, the epoxy sites are highly reactive sites where adjacent triglyceride moleeules attach to form interlocking polymer networks. Research is being conducted to use *Vernonia* as a diluent for alkyld resin paints.

Agronomic characteristics: *Vernonia species are* members of the Composite family. V. anthelmintica is native to India, and *V.* galamensis is a herbaceous annual from Africa. Attempts to grow *V.* anthelmintica in the United States have thus far been unsuccessful, causing researchers to begin focusing their attention on V. galamensis. Yields of V. galamensis in Zimbabwe have been as high as 2,290 pounds of seed/acre.

Technical considerations: Seed shattering has been a problem with *Vernonia,* but recently a wild species has been discovered with good seed retention, which may alleviate this problem. Photoperiodism may limit production in temperate regions. Short days are required for flowering, but in colder climates, short days are soon followed by frost, which prevents seed formation. A variety that flowers earlier has been found, so this problem may be overcome, The meal from *Vernonia* species contains antinutritional agents such as vernolepin, which may limit use as a livestock feed. The meal from V. anthelmintica was found to be deficient in methionine and lysine and could no be used as livestock feed without additional amino acid supplements. Meal from *V.* galamensis has higher levels of lysine, methionine, and phenylalanine than meal from V. anthelmintica, but feeding studies have not been conducted.

Economic considerations: Approximately 100 to 180 million pounds of soybean and linseed oil are converted to epoxy fatty acids annually. While the raw material is relatively inexpensive, the chemical transformation of the fatty acids contained in sunflower and soybean oil to epoxy fatty acids is relatively expensive. About 325 million gallons of alkyld resin paints are used in the United States each year. *Vernonia oil* could be used as diluent in place of organic solvents in these paints. Expected use is one pint of oil per gallon of paint.

Social considerations: *Vernonia* is a potential replacement for industrial uses of soybeans. It could be used to reduce volatile organic compounds resulting from solvents used in paint, with positive impact on air quality.

Extent of research conducted: *Vernonia* was identified by the original USDA/ARS screening in the 1950s. The Northern Regional Research Center has conducted some utilization research. Trial plantings of *Vernonia* were made in Georgia in 1964, but little interest was expressed in developing this species. Recent agronomic research has been conducted in East Africa and the Carribean rather than in the United States. Utilization research is being conducted at the Coatings Research Institute at Eastern Michigan University. The California South Coast Air Quality District, the U.S. Agency for International Development, the State of Michigan, and Paint Research Associates (an industry-financed research group) are providing $425,000 for this research. Some research is also being conducted at Lehigh University.

SOURCES: 8,18,33,36,37

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