REPORT ON GUAYULE POTENTIAL AND RESEARCH IN SOUTH AUSTRALIA.

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I N D E X

1. Introduction

Guayule (Parthenium argentatum Gray) is a native of the Northern Mexican desert and Big Bend National Park, Texas, U.S.A.. It is a member of the daisy family and was familiar to the Aztecs who used it in making crude rubber balls. About one-third of rubber used is from Hevea brasiliensis, the rubber tree which grows predominantly in South-East Asia. The remainder of the rubber is from the petroleum based synthetic rubber industry. The Soviets still produce some rubber from the Russian dandelion and the Mexicans presently are producing small amounts of guayule. The other two thousand or more plant species known to contain rubber are not exploited commercially.

Guayule has had an interesting and varied history. Early this century, wild guayule stands in Northern Mexico and Texas were harvested for rubber production and in 1910 guayule was the source of nearly 50% of all natural rubber consumed in the U.S.A. and 10% of the world consumption. Overuse of wild plants (71 million kilograms of guayule rubber were imported into the U.S.A. in 1912 alone) and failure to replant led to a virtual disappearance of the new industry's raw material source and mills were forced to close. The revolution in Mexico also helped to close down the industry.

In the late 1920's, Britain's control of Malaya and its resultant rubber monopoly suddenly increased rubber prices threefold. In Mexico and California guayule rubber became profitable again and production resumed. Major Dwight D. Eisenhower, assigned to study guayule in connection with national security, recommended further development of the industry but the depression of the thirties postponed the project until its short-lived resurrection in 1942. When rubber supplies from South East Asia were cut off during World War Two, the U.S.A. spent $30 million on the successful Emergency Rubber Project to develop guayule as a domestic source of rubber again. The crop was grown on high quality farmland in California and after the war the farmers wanted their land returned. With the renewed availability of cheap rubber from Asia and the new availability of completely synthetic polyisoprene rubber, the government withdrew its funding and ordered the 11 000 hectares of guayule to be burnt.

At the request of the Council for Scientific and Industrial Research, investigations commenced in July 1942 at the Waite Agricultural Research Institute in South Australia to assess the feasibility of producing rubber from guayule in South Australia. Because of the close co-operation with the US research, the local investigations were not continued after the cessation of war. Because of the limited amount of time, labour and funds during the war, very few conclusive results were obtained although considerable progress was made on germination techniques and identification of the best soil and climate conditions. At that time, using the "Canberra" strain (now considered inferior) the best non-irrigated yields of rubber were 1 200 kg/ha.

Various small scale plantings have taken place in Western Australia in 1929, 1943 and 1959. More recently, in 1977, the CSIRO started small trials in Western New South Wales to determine the appropriate soil and climatic conditions for guayule.

Several countries around the world (e.g. U.S.A. in Arizona and California, Israel) are now conducting research programmes involving guayule. Both the Firestone Tyre and Rubber Company and Goodyear have commenced trial plantings of guayule in the United States and Mexico has a pilot production plant. It plans to process 3 million tonnes of wild guayule shrubs growing on 4 million hectares, harvesting annually 350 000 tonnes of shrub, yielding 35 000 tonnes of rubber.

Research in the U.S.A. is being conducted at Texas A & M University, New Mexico State University, the Los Angeles State and County Arboretum and the University of Arizona School of Arid Land Studies. Total plantings in the U.S.A. are in excess of 150 acres (100 acres by Firestone and 50 acres by Goodyear alone).

International Rubber Study Group in late 1980 estimated a likely shortfall in supplies of natural rubber of some 50 000 tonnes in 1980 and 1981. World consumption of natural rubber is predicted to grow by a 1.4 percent average annual growth rate over the 10 years 1979 to 1990 (the same growth rate as for synthetic rubber).

Estimates for the North American market are as follows (thousands of tonnes):

	1980	1985	1990
Synthetic	2127	2665	2946
Natural	710	874	957

2. Reasons for Renewed Interest in Guayule.

The U.S. National Academy of Sciences 1977 report listed the following reasons for initiating research into guayule. Indeed, the report specifically nominated South Australia as one location at which trial plantings should be undertaken.

(i) The prices of both natural and synthetic rubber are increasing and seem likely to climb much higher. The increase in demand for natural rubber due to population increase and changes in technology is not likely to be matched by any increase in Hevea production. It is believed that the rubber tree has virtually reached the limit for genetic improvement of yield after a ten-fold improvement since the Second World War. In 1978, the Malaysian Rubber Research and Development Board concluded that the demand for natural rubber will outstrip supply by 1 million tonnes in 1980 and by 2 million tonnes in 1985.

However, with the depressed state of the world economy and particularly of the motor vehicle industry, the world shortfall was only about 50 000 tonnes in 1980. The Board also predicted in 1978 that prices would reach $1.10 per kg in 1980. An indication of import prices (fob not market price) in Australia in recent years can be seen below:

Natural Rubber Australian Import Prices (fob)

1971-2	30 cents/kg
1972-3	34 cents/kg
1973-4	52 cents/kg
1974-5	44 cents/kg
1975-6	52 cents/kg
1976-7	71 cents/kg
1977-8	78 cents/kg
1978-9	96 cents/kg
1979-80	124 cents/kg

(ii) Although synthetic rubber is cheaper, natural rubber is essential to industry. Its elasticity, resilience, tackiness and resistance to heat are unmatched by any synthetic rubbers now available. Conventional automobile tyres, for example, contain about twenty percent natural rubber and radial tyres which now dominate the market contain as much as forty percent, as do truck and bus tyres. Large tyres on aircraft, tractors and earthmoving vehicles are made almost entirely of natural rubber. Guayule rubber could serve for all these uses because its chemical and physical properties are virtually identical to those of Hevea rubber. No chemical difference between the two have been detected in several studies, even with sensitive techniques that can demonstrate as little as 0.5% of structural difference.

(iii) The long range outlook for cheap petroleum feedstocks for the production of synthetic rubber is hardly favourable considering the increase in oil prices. Natural rubber would also seem desirable in that it is a renewable resource whereas oil cannot be replenished.

(iv) South East Asia is very unsettled politically. Over 85 percent of the world production of natural rubber comes from Malaysia, Indonesia, Thailand and Sri Lanka. Liberia, Nigeria, Zaire and India are the major remaining sources of supply. It could be in the interests of national security for Australia and America to produce their own rubber. Domestic production is desirable from market control and balance of payments points of view.

(v) New technologies for cultivation and processing and the existence of weedicides, now ensure that problems encountered in the earlier production work are no longer relevant.

(vi) Natural rubber production from Hevea brasiliensis is a very labour intensive operation. As labour costs inevitably increase, the advantages of a mechanized production system as with guayule will improve.

(vii) Pacific Rubber Growers have reported that twenty percent of hevea trees have been removed in traditional supply countries in favour of palm trees, and there has been little replanting of hevea. There is also the constant threat of leaf blight which destroyed the industry in its native habitat in South America.

3. Guayule

Guayule is a bushy, perennial shrub up to about 1 metre high. It is long-lived and hardy, with a life expectancy of 30 to 40 years under arid conditions.

The plant possesses a taproot which may penetrate the soil up to 6 metres in depth. An extensive fibrous root system may spread to 3 metres laterally. The well-developed root system accounts partly for its drought resistance. In severe droughts, guayule may become dormant. Leaf fall often occurs with the onset of drought. One of the main advantages of guayule is it can remain in the field without losing its rubber, and thus can be left in the field during a drought without loss of the plant or its product.

In the guayule plant about two-thirds of the rubber is in the stems and one-third in the roots. There is no extractable rubber in the leaves. Rubber comprises approximately 10% of the dry weight of native guayule plants. However, there is considerable genetic variability. Selected strains that were cultivated prior to World War II had approximately 20% rubber after 4 years growth, and further improvements have been reported since, with yields up to 26 percent.

When guayule grows actively it produces little or no rubber. If the plant is stressed, growth slows down and products from photosynthesis are diverted into rubber production. The main stress factors involved are low temperatures and decreasing moisture. The rubber produced by the plant is not used by it.

Its main advantage, as with most of the hydrocarbon-producing plants, appears to be its ability to be cultivated in marginal areas which are not suitable for crop production. It thus offers the possibility of using presently un-utilised land for agriculture or providing an alternative crop for farmers in the marginal wheat belt area, the Mallee, the Riverland or on Kangaroo Island.

Resins constitute 10-15% of the plant (dry weight). These resins includes terpenes, sesquiterpenes, diterpenes, glycerides and low molecular weight polyisoprene hydrocarbons.

(i) Reproduction

Pollination is by wind and insects. Guayule is a prolific seed producer - seed is set throughout summer and autumn. Under cultivation, harvests of seed of 300 kg per hectare were common and collections as high as 1100 kg were recorded. By the end of the first year, abundant seed is produced in plantations.

(ii) Propagation

Guayule is normally propagated by nursery grown seedlings, although grafts and cuttings can be successful.

If stored properly, seeds will remain viable for several decades. Young seeds require simple treatment to break the dormancy.

Exposed ends of broken roots may give rise to adventitious shoots if moisture is available.

(iii) Breeding

Guayule belongs to a genus with 16 species and it can be crossed with all of them. Guayule can cross normally as well as apomictically (i.e. without the union of male and female elements). The latter can be used to produce off-spring identical to the parent plant. There is also the possibility of crossing guayule with other *Parthenium* species.

In research conducted in the U.S.A. in the 1940's, plant breeding showed great promise for improvement of guayule rubber production.

(iv) Soil

Guayule grows naturally on soils of moderate to high fertility which are calcareous or have a neutral reaction. In Mexico, the densest stands of guayule are on limestone soils. The latter may be similar to the mallee saltbush soils of South Australia and south-western New South Wales.

Characteristics of soils most likely to be suitable for the cultivation of guayule are:

Texture -	A light to medium texture is preferable. A sandy loam texture is the most suitable.
Structure -	The structure should be loose, permeable and friable. Good consistence and tilth ar very desirable. The soil should be relatively free from stone and gravel.
Moisture -	Good moisture holding capacity is essential
Drainage -	The drainage should be good throughout the profile.

(v) Climate

Guayule can produce rubber in the very dry climates of its natural habitat (a sub-tropical temperate climate with low or erratic rainfall). However, it is not yet clear if it can be cultivated economically in regions as arid as its native habitat. Under dry land conditions where droughts are common, guayule is hard to establish and may take longer than 7 years to develop commercially useful quantitites of rubber.

C.S.I.R.O. investigations showed that the most suitable area for guayule would have an average rainfall of 350 mm. The climate would be a wet-dry one; most rainfall would occur in the winter-spring period with little or none in the summer. Guayule needs to be free from very high or very low temperatures.

(vi) Rainfall

In the natural habitat of guayule in the U.S.A., rainfall varies from 250 to 500 mm per year with a summer dominant characteristic.

Work from the U.S. Emergency Rubber Project during World War II showed that 280 to 640 mm of rainfall annually were needed for commercial production. On a long rotation (4 to 8 years) 410 to 460 mm of rainfall annually were sufficient. Other research has shown that dryland guayule cannot be grown successfully with less than 375 mm of rainfall per year and overall the range of 375 to 500 mm of rainfall annually appeared to produce the best rubber yielding guayule in the U.S.A.

In conditions of extreme drought, it may require from 4 to 7 years for guayule to reach a commercially exploitable size.

Guayule can survive arid conditions, but if the annual rainfall is less than 350 mm, supplemental irrigation may be needed to give worthwhile yields in a reasonable period. However, it has been found that whilst plant growth is greater under high precipitation or irrigation, the percentage of rubber falls and the rubber yield per hectare is not much different.

Under dryland cultivation it is desirable to have supply of moisture at the beginning and during the first half of the growing season (spring-summer) and also to have a dry period of at least two months duration before the cold season commences.

The experience of the United States during the 1940's indicates that guayule will grow in climates with winter rains as in California or with summer rains as in Texas. The varieties best adapted to one area, however, did not do particularly well in the other area. Most literature suggests around 400mm of rainfall as optimal for guayule growth. There appears to be no literature reference to guayule surviving a several month period of summer drought except for well established stands in the wild.

(vii) Temperature

The characteristics of the climate where guayule grows in the U.S.A. are winter (mean) 10°C; summer (mean) 17°C; maximum 43°C and minimum -8°C. Guayule does not occur where mean air temperatures are above 21°C. There is a 250 day growing season.

The Waite Institute's research on guayule in South Australia has shown that, with sufficient moisture, there is active growth above 15°C, no new growth at less than 10°C and plants are not affected by frosts at temperatures above -13°C.

Guayule grows well at temperatures of 25° to 40°C. It will tolerate higher temperatures provided water is adequate. The first few weeks, young transplants are watered (with one inch of water) once or twice a week. When the seedlings are around 6 months old, they are watered every 3-4 weeks to maintain active growth. Once the plants are approaching maturity, longer periods of drought would stimulate rubber production and be tolerated by the plants. Temperatures below freezing are tolerated to about -13°C. Below those temperatures damage may occur.

Overseas research has shown that the best growth of guayule occurs at 32-38°C. This research concluded that the mean temperature should be above 13°C and that below 16°C mean temperature, growth rate is slow and plant mortality high.

The general variations of temperature during the growing season have little effect on the growth rate of guayule. Hot days and cool nights favour rubber production.

Wild guayule can survive temperatures below 0°C. Cultivated guayule, especially when it is young is frost sensitive. However, if plants are hardened off by gradually decreasing temperatures or reduced available moisture, they can withstand temperatures below -10°C.

4. Agricultural Techniques

There is a great deal of information on certain aspects of guayule production, but other aspects still require investigation.

Guayule seed consists of an embryo and some attached parts which tend to inhibit germination. There may also be some inherent dormancy, but this can be overcome by treatment with hypochlorite. While treated seeds germinate readily, it has been found that they have low emergence energy and hence are unable to compete with weeds. Nursery production of seedlings is therefore desirable.

(i) Nurseries

Treated seed is sown with superphosphate on a level, light textured soil in the seed bed in November-December, and covered to about 0.6 cm depth. Watering is necessary during germination and up to transplanting. Approximately 2.5 million useable seedlings can be produced per hectare of nursery space, sufficient to plant about 15 hectares.

(ii) Transplanting

Seedlings are transplanted at 4 to 9 months, but can be held up to 2 years in nursery beds. Prior to transplanting, the plants should be hardened by cool temperatures or low soil moisture. The seedlings are cut to a height of 5 cm and the roots trimmed at 15 cm. Although transplanting can occur at any time of year, best results are obtained when minimum temperatures were above $10^{0}C$ and maximum temperatures below $35^{0}C$.

Land preparation involves ploughing to 15-25 cm depth using conventional tillage equipment for all land preparation operations. Planting is done with a machine planter at spacings 70 X 60 cm.

(iii) Crop Production

Weed control is essential, especially in the first two seasons. This can be either mechanical (when the plants are small) or by herbicides. Several cultivations may be necessary in each of the first few years to control weeds and maintain soil condition.

Fertilizer application does not appear necessary since guayule is not a serious soil depleting plant. Although irrigation may be desirable in certain conditions, it does not appear to increase markedly the yield of rubber.

Guayule is resistant to the root-knot nematode, but susceptible to other diseases such as wilt, root rot and dieback. Guayule can be damaged by insects such as grasshoppers, particularly in its seedling stage.

5. <u>Harvesting Techniques</u>

Under dryland cultivation, harvesting might take place every 4 or 5 years. With irrigation, this could be reduced to 2 or 3 years, but at the expense of rubber yield.

Guayule is harvested as a whole plant (including roots) with a digger-harvester such as a modified sugar-beet harvester. The plant is then windrowed and baled for transport to the processing plant. Alternatively, a forage harvester could be used. The crop can be cut and baled (or chopped?) after 3 to 5 years and the possibilities of ratooning rather than replanting are being explored. The harvested material does not store well, suggesting that production and processing facilities should be close together as in sugar cane.

Some research has examined the possibility of coppicing, which would allow at least two crops from the same plant in a shorter period of time. Other research has examined the possibility of harvesting one year old plants after direct seeding in the field: this reportedly produced nearly 1200 kg/ha/year.

6. <u>Extraction Techniques</u>

In contrast to <u>Hevea</u> and other <u>Euphorbia</u> plants, in which rubber is found in the form of a latex in connected channels which run vertically down the parenchyma, in guayule the latex is found in small particles in isolated, thin-walled cells with no possibility of flowing. Guayule also produces up to 15 per-cent of resin which is found in the channels along the stalks. A typical composition of harvested guayule is as follows:-

	Range	Likely Proportion*
Moisture	45-60%	
Rubber*	8-26%	20%
Resin*	5-15%	10%
Bagasse*	50-55%	50%
Leaves*	15-20%	20%
Cork*	1-3 %	
Water Solubles	10-12%	

*Dry Weight Basis

Because the latex is found in isolated cells from which rubber must be extracted physically or chemically, this requires a thorough extraction of fibres from the shrub to permit the recovery of the greatest possible amount of rubber. Furthermore, the rubber must be purified and standardised in order to attain high standards of quality.

After numerous experiments on the laboratory level, in April 1976 a pilot plant was designed and built in Mexico for the testing of a new guayule industrialisation process. The central objective of this process is total utilisation of the shrub as shown in the block diagram in Figure 1. In this manner, recovery of the diverse by-products will allow an increase in the economic yield.

The shrubs are first dipped in hot water for 10 minutes at 75^{O}C. This coagulates the rubber and removes foreign material and leaves, which contain no rubber but do contain copper, manganese and resinous compounds that contaminate the rubber. The plants are then passed through a hammer mill and a Bauer mill (a device used in paper making) which break open the rubber filled cells. The pulping is done in water with caustic soda added. The material is transferred to a slurry tank where the water-logged bagasse sinks, the rubber worms float and are skimmed from the surface. They are then run through a second tank where they are rinsed and then treated with a detergent. Guayule worms contain 17 to 25 percent resins which are removed with acetone. The acetone is then distilled and recycled. During this process the rubber may be treated to modify the product.

7. Products

Along with each tonne of purified rubber, guayule produces about two tonnes of bagasse, one tonne of leaves and half a tonne of extracted resins.

The resins could be treated in a simple distillation column to recover volatile hydrocarbons of important commercial value. The remaining resins could be processed to recover adhesives, drying oils, rubber additives and other chemicals, but it is more likely that the oil would be used as a fuel (particularly diesel).

Guayule leaves are covered by a hard, cuticle wax with a melting point of 76^{O}C which is one of the highest ever recorded for a natural wax, making it competitive with carnauba wax.

The bagasse can be used to produce paper pulp or for conversion to alcohol fuels. Alternatively, it might be used to supply the energy required in the process by direct burning, as with sugar cane production.

8. Current Activity Overseas

Mexico have a programme of research into guayule and are operating several rubber mills using wild guayule. The U.S.A. is taking the lead in considering research into guayule. An Ad Hoc Panel (under the auspices of the National Research Council - a unit of the (U.S.) National Academy of Sciences) was set up to investigate the economics and potential of guayule, and the U.S. has committed $60 million for research over the next four years.

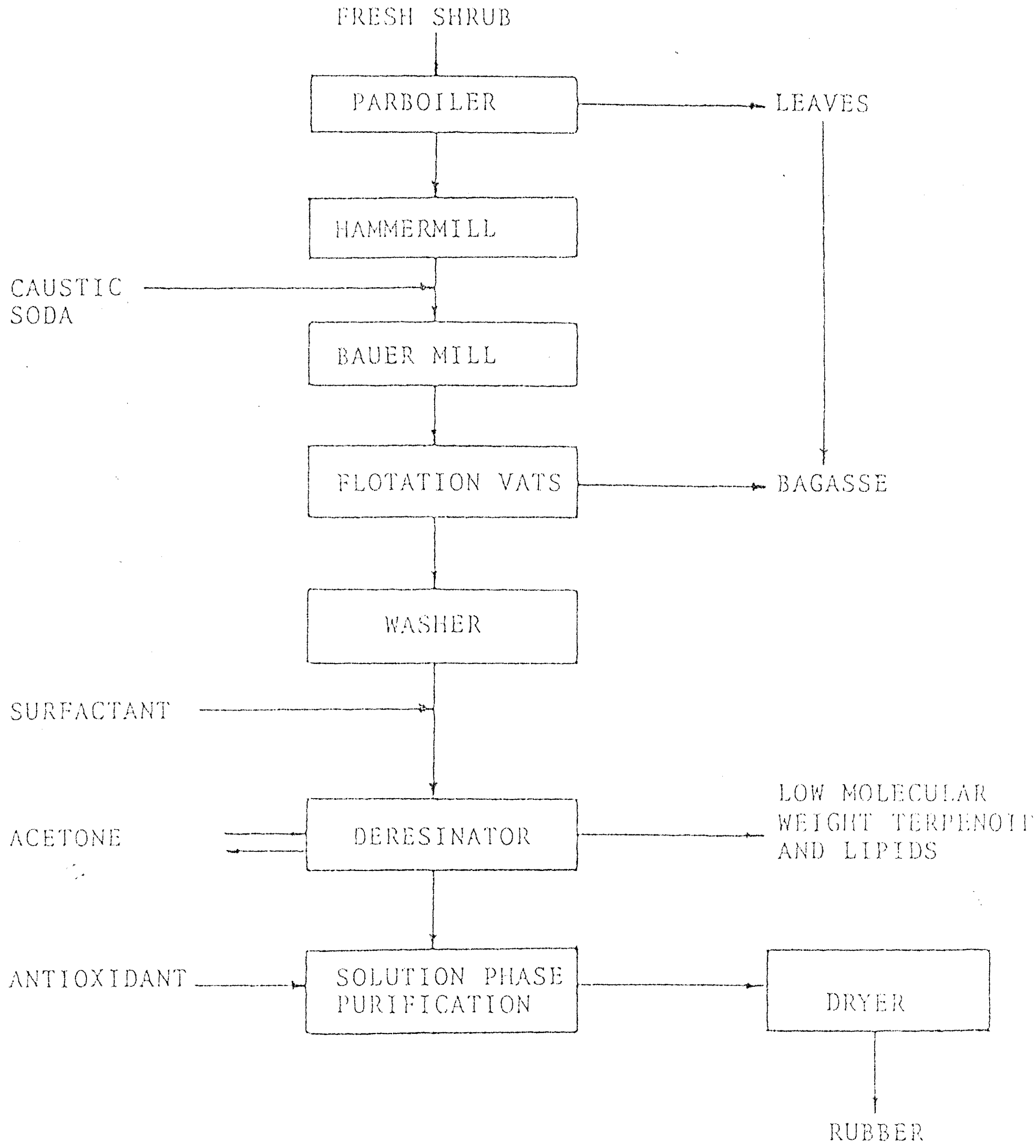

FIGURE 1: Mexican Process for Guayule Rubber Extraction

The Panel concluded:

"Guayule development should begin with a well-planned well-co-ordinated research programme aimed at applying modern technology and science. An evaluation of production, performance and economics is needed. Therefore, it is recommended that the Federal Government initially fund a feasibility study, technology assessment and environmental impact analysis of guayule."

In addition to arguing commercialisation of guayule the panel recommended that the U.S.A. and Mexico collaborate on guayule research to take advantage of their mutual expertise. The panel also recommended that experimental plantings be established in the South-West and that the Government centralise all its records on guayule research at an institution in the region.

"The initial goals are rather modest. Their implementation would probably require initial funding of about $2 to $4 million annually. This could support fifteen to thirty full-time investigators and provide for the construction of pilot processing facilities. With this amount of support, in five to ten years they should determine if guayule is practicable".

A Bill was put to the U.S. Senate on June 30th, 1977 to amend the Public Works and Economic Development Act of 1965 to authorise a programme of research development and demonstration of guayule rubber production as an economic development opportunity for the South Western States. This Bill would authorise to be appropriated for the fiscal year beginning October 1st, 1979 and for each of the four succeeding fiscal years, the sum of $60 million to carry out research. The bill was referred to the Committee on the Environment and Public Works and was passed.

At the present time, the following companies or organisations are involved in guayule research overseas:

- Goodyear has been growing guayule on its experimental farm in Arizona since 1978 in a small way and recently added 5 acres of plantings, giving it a total of about 50 acres.

- Mexico has operated a pilot plant (1 tonne per day of Shrub) at Santillo since 1976. Reports suggested that a commercial scale facility was to be completed in 1980.

- Firestone has a seedling nursery and plantings at its Texas test centre, with 100 acres under cultivation.

- Uniroyal was planning tests in conjunction with Texas A & M University.

- Goodrich is evaluating guayule in its labs and is ready to participate in a test programme.

- Research in the USA is being conducted at Texas A & M University, New Mexico State University, the Los Angeles State and County Arboretum and the University of Arizona.

The Los Angeles Arboretum have developed improved methods of handling seedlings. They are working on methods of direct seeding but have not developed an acceptable method as yet. They are also testing methods of mowing or pollarding the plants for harvest to avoid re-establishment costs, and are testing a bioregulator which appears to dramatically increase rubber production when sprayed on the plants prior to harvest. All of these procedures are still experimental and not recommended for commercial application. Most of the seed possessed by Pacific Rubber Growers consists of variety N593, the most popular commercial variety grown in the first part of this century. It is not the highest yielding variety available but it is quite hardy and will provide uniform stands. Nevertheless neither it nor any other currently available variety can yield a profit when grown commercially under either 1940 or current technologies (representatives of both Goodyear and Firestone Rubber Companies confirm that conclusion). Firestone is, however, interested enough in guayule to be establishing 2,000 acres in Texas and have developed plans for building a pilot extraction plant.

Pacific Rubber Growers is the only known source of large quantities of guayule seed in storage. The Los Angeles Arboretum and people at the University of Arizona at Tucson have a number of varieties under cultivation and can easily provide small quantities of seed for research purposes. Present costs are $100.00 per pound of clean seed. There are over 1/2 million seeds per pound which should provide enough seedlings for up to 50 acres of land.

9. Economics of Guayule Production

There is no guayule production at present except in Mexico where it grows wild and labour is cheap. With the present state of knowledge of guayule production and technology, guayule cannot compete with Hevea rubber production. Only with a large increase in price of Hevea (presumably due to low supply and high demand) and/or lower production costs and higher yields could it become economical.

In a large scale attempt to grow guayule in Spain in 1960 the expected cost of production was about U.S. 79¢ per kg. Despite extremely low wage levels in Spain presumably even this figure could not be achieved before the project was abandoned.

An estimate made in the U.S.A. by Mr. L. G. Polhamus, U.S.D.A. of cost of production for guayule was very approximately $750 per hectare. That estimate was made in 1961 for operations in 1944. Given the best unirrigated South Australian yields of 1140 kg/hectare of latex the establishment of growing cost would place an initial value on the latex of 67c/l. Despite the fact that relatively low-yielding strains were used in South Australia in the Second World War, upgrading the costs to today's value of money and adding harvesting and processing costs suggests that guayule rubber cannot presently compete with Hevea rubber without significant yield improvements.

Therefore, the main question to be resolved is whether guayule can be grown economically at the present time or in the future. One of the major expenses in guayule production is the cost of establishment of plantations. The cost of seedlings produced in a nursery could vary from between $10 to $20 per thousand, which at a spacing of 70 x 60 centimetres or 28 000 seedlings per hectare could cost $280 to $560 per hectare.

It has been estimated that a minimum economic plantation size of guayule might be about 4 000 hectares, which on a four year rotation basis would require 1 000 hectares to be planted each year and be sufficiently large to enable the construction of an extraction factory in the centre of the fields. The harvest from 1 000 hectares each year would be approximately 25 000 tonnes of fresh shrub at an age of 4 years.

A manager and several workers with seasonal employees would be required to work the fields. The additional temporary help would be required at cultivation and planting. For planting seedlings, total costs of $120 000 have been allocated in Table 1 for cultivating, planting out and caring for 1 000 hectares of plants. In the second and following years, the costs of maintaining this field have been assumed to decrease to $70,000 and $60 000 respectively. Land rent has been fixed at 10 percent of the assumed cost of $300 per hectare, and $20 000 per 1 000 hectares has been allowed for other miscellaneous overheads (weedicides, irrigation, etc.).

When harvesting is done with heavy machinery for digging and baling, the cost would be expected to be relatively low. Allowing for the depreciation and operating cost of such machinery and labour costs, a figure of $50,000 per 1 000 hectares has been set in Table 1.

Table 2 shows that the estimated agricultural cost for a crop is $670 per hectare in the establishment year and totals $1 060 per hectare over the four year growth period, an average of $265 per hectare per year. Table 2 shows the annual operating cost during the initial period in which 1 000 hectare plantings are commenced over a period of 4 years. This cost compares reasonably well with a US 1961 cost estimate of $750 per hectare over a 4 year period.

	COSTS ($per hectare)			
	Crop First Year	Crop Second Year	Crop Third Year	Crop Fourth Year
Seedlings	500	-	-	-
Cultivation	30	20	10	10
Planting Out	40	-	-	-
Field Care	50	50	50	50
Land Rent ($300@10%)	30	30	30	30
Harvesting	-	-	-	50
Other Overheads	20	20	20	20
	670	120	110	160

TABLE 1: ESTIMATION OF AGRICULTURAL COST OF PRODUCTION

	First Yr. Field	Second Yr. Field	Third Yr. Field	Fourth Yr. Field	TOTAL
Year 1	670 000	30 000	30 000	30 000	760 000
Year 2	120 000	670 000	30 000	30 000	850 000
Year 3	110 000	120 000	670 000	30 000	930 000
Year 4	160 000	110 000	120 000	670 000	1 060 000
Year 5 onwards					1 060 000

TABLE 2: AGRICULTURAL COSTS OF PRODUCTION ($)
(1 000 ha per annum for 4 years)

With projected yields of 25 tonnes of fresh shrub per hectare at the age of 4 years, and with yields of products per fresh shrub tonne as indicated below, the annual production of rubber would be approximately 2 500 tonnes and of resin 1 250 tonnes.

It should be noted that this yield of rubber is equal to approximately 20 weight percent based on dry weight of plant, a yield already achievable with existing guayule strains (625 kg/ha/yr). Clearly, with improvements in yield as a result of the development of better varieties and agricultural techniques (including the use of bio-inductors) this production level should be significantly improved.

	Yield (Tonne per Tonne of Fresh Shrub)	Annual Production (Tonnes)
Rubber	.10	2 500
Resin	.05	1 250
Bagasse	.25	6 250
Leaves	.10	2 500

Using a conservative value of $1 per kilogram for rubber and $150 per tonne for the resin (equivalent to a crude oil price of $20 per barrel) indicates an annual value of production of approximately $2.7 million, ignoring any possible credits for bagasse, waxes or seeds.

The costs of milling are uncertain, but reasonable comparisons could be made with the cost of sugar cane milling. An estimated staff of 10 people would be required to run an automated extraction factory operating on a continuous basis, with estimated labour costs $200 000 per annum. With the use of some of the bagasse for providing heat for the processing, total operating costs would be of the order $400 000 per annum. Allowing $10 million for the construction cost of the plant depreciated over 20 years, gives total processing costs of $900 000 per annum, as shown in Table 3. Thus the cost of cultivating and processing guayule is estimated to be $1 960 per hectare over four years.

This compares with the estimated value of production of $2700 per hectare after year four.

Cost estimates by CSIRO prior to cessation of their research programme in 1980 indicated:

- agricultural costs — 25-30 cents/kg rubber
- processing costs — 25 cents/kg rubber

Total costs — 50-55 cents/kg

The above estimates suggest costs of production of:

Year	Agricultural Costs ($000)	Processing Costs ($000)	Depreciation ($000)	Total Costs ($000)	Income ($000)	Cash Fl ($000)
1	760	-	-	760	-	- 760
2	850	-	-	850	-	- 1610
3	930	-	-	930	-	- 2540
4	1060	400	500	1960	2700	- 1800
5	1060	400	500	1960	2700	- 1060
6	1060	400	500	1960	2700	- 320
7	1060	400	500	1960	2700	+ 420
8	1060	400	500	1960	2700	+ 1160
9	1060	400	500	1960	2700	+ 1190
10	1060	400	500	1960	2700	+ 2640
11	1060	400	500	1960	2700	+ 3380
12	1060	400	500	1960	2700	+ 4120
13	1060	400	500	1960	2700	+ 4860
14	1060	400	500	1960	2700	+ 5600
15	1060	400	500	1960	2700	+ 6340

TABLE 3: CASH FLOW STATEMENT, GUAYULE PRODUCTION

	Rubber only	Rubber Plus resin
Agricultural	$0.42/kg	$0.28/kg
Processing	$0.36/kg	$0.24/kg
Total	$0.78/kg	$0.52/kg

10. Australian Interest in Guayule

During the Second World War there was a drastic rubber shortage due to the fall of Malaya. This initiated research in Australia. At the request of the Council for Scientific and Industrial Research, investigative work was commenced at the Waite Agricultural Research Institute in July 1942 to assess the possibility of producing rubber from guayule in South Australia. Research did not progress after the cessation of the war. The work is totally summarised in two papers published by Crocker and Trumble 1945 and Shapter 1952. Because of the limited amount of time, labour and funds due to the war, very few conclusive results were drawn. The main conclusion was that it could actually grow here. Some interesting details are -

- A method of treatment to improve germination was developed.
- Guayule was planted at many centres throughout this State, both irrigated and non-irrigated and some suggestions were made regarding the best areas under non-irrigated conditions.
- Weed control was a major problem.
- The "Canberra" strain of guayule was used. Reportedly there are now strains which yield ten times the amount of "Canberra".

In Western Australia there have been several plantings of guayule throughout the last three decades, all unsuccessful. In 1972 the W.A. Department of Agriculture reviewed (and rejected) guayule production. They stressed three significant factors -

- There was no suitable climate for guayule in Western Australia. In its native area although the temperature is similar to Western Australia (and South Australia also, i.e. hot summers and mild winters) that area receives 70-90% of its rainfall in summer. No area in Western Australia has similar mean temperature, temperature amplified and rainfall pattern.
- Guayule grows on <u>calcarceous sandy loams to loamy sands</u> in its natural habitat. In South Australia it was best grown on fertile calcareous soils. In W.A. it was promoted on cheap, infertile acid sands. The principle criterion appeared to be that the land was cheap and available. This is not necessarily sensible because guayule is a high cost and (hopefully) high return crop.

. Price of natural rubber was low.

The CSIRO began work again in Australia early in 1977. The primary objective was to determine the appropriate soil and climatic conditions for guayule growth and rubber production. The best U.S. varieties, some capable of 20% rubber accumulation, were evaluated, and agronomic practices were developed. The stimulation of rubber production by environmental conditions and by chemicals was also under investigation.

By 1981 it was planned to be able to indicate where guayule grows best, which varieties were suitable, and what were the most appropriate practices for Australian conditions. However, because of a lack of commercial interest in the crop, work ceased in 1980 by the CSIRO.

In late 1980, the N.S.W. Government announced it was to become involved in a major research programme on guayule. Although details have not been released, it is understood these trials are in conjunction with Firestone and other overseas researchers.

In South Australia, research work started in early 1980 on a range of latex-bearing plants (including guayule) for the production of hydrocarbons. This programme includes propagation, establishment and agricultural studies at Roseworthy Agricultural College; tissue culture studies at the CSIRO Division of Horticultural Research, and processing and extraction studies at the S.A. Institute of Technology.

Imports into Australia are listed under four classifications (natural rubber latex, natural rubber latex with synthetic latex, natural rubber crepe not smoked, natural rubber not elsewhere included), the latter classification representing about 85 percent of 1979-80 imports.

A summary of import statistics follows:

	(tonnes)	($million)	$/kg
1971-2	50 000 (est)	15	0.30
1975-6	53 000 (est)	25	0.47
1976-7	42 400	30.9	0.73
1977-8	42 900	33.3	0.78
1978-9	43 900	42.3	0.96
1979-80	44 600	55.2	1.24
1980-1 (to Sept)	12 305	14.6	1.19

The major benefit to Australia of a guayule industry could be the development of a renewable energy resource which replaced some requirements for crude oil imports (for oil refineries or petrochemical plants) or other products (such as natural or synthetic rubber) which would indirectly allow purchases of crude oil overseas without affecting the balance of payments. Australia currently imports each year over $50 million of natural rubber and $13 million of synthetic rubber. Local production of synthetic rubber from petroleum amounts to $36 million, and petroleum is also used to manufacture large quantities of other chemicals. This plant thus has the potential to reduce significantly Australia's imports of petroleum products. In addition, of course, many thousands of jobs would be created in agriculture, forestry and processing.

With Australian imports of 50 000 tonnes per annum of natural rubber, this requirement could be met by 20 plantations of a size similar to that used in the above exercise, namely 4 000 hectares. This would give a total requirement of 80 000 hectares.

11. Direction of Guayule Research

Assuming it was decided to produce guayule rubber (based on the such premises that it may economical in three to five years time and for national security reasons) a significant amount of research would be required to bring it to the same standards of technology and production enjoyed by other agricultural crops. Although it is important to continue testing the quality and performance of guayule rubber, the current bottleneck lies in the earlier stage of agricultural production. Research should take the following directions:

1. It is important to isolate and breed guayule strains that contain uniformly high quantities of rubber. Preliminary projects to achieve this are already being undertaken at the University of Arizona and Los Angeles Arboretum. This process should be speeded substantially by a technique developed by the Varian Corporation in which carbon - 13 nuclear magnetic resonance spectroscopy is used to determine the amount of rubber in the shrub's branches.

2. Genetic manipulation may not be the only way to improve the content of rubber. The U.S.D.A. Agricultural Research Service has found that the rubber yield can be at least doubled by spraying the shrubs with certain chemicals that have previously been shown to increase the concentration of carotenoids in citrus fruits.

3. Innovations in chemical weed control, insect control and rubber technology as well as new insights into the biochemistry of rubber formation in plants can be expected to increase yields. Interestingly, guayule wages "chemical warfare" against competing plants - a common characteristic of desert plants.

   Guayule roots secrete a substance that retards growth of nearby seedlings.

4. Climate. Guayule withstands high desert temperatures. Its growths slows below 16^{o}C and it becomes semi-dormant below 4^{o}C. Freezing sometimes kills it. Although it is a desert plant, best rubber production is with reasonable rainfall (around 400mm). Dormancy is guayule's defence against drought. Under high precipitation (or irrigation) plant growth is much greater, but the percentage of rubber falls so that the net rubber per acre is not very much greater. Irrigation would place guayule as a horticultural crop which is very unlikely to be profitable. Much research must be done to determine the best climatic area for guayule.

5. Agronomic "tricks" such as harvesting only the tops and leaving the roots to resprout might shorten the current three-to-four-year cycle before rubber harvest is optimal. Mechanical planting and harvesting techniques must be developed if production is to be economical.

6. By-products industry. Along with each tonne of purified rubber the guayule plant produces 2 tonnes of bagasse (mainly crushed stems), one tonne of leaves and half a tonne of extracted resins. Each of these could find a commercial use as a by-product. The bagasse can be used for paper, pressed board and cardboard manufacture. Guayule leaves are covered by a hard cuticle wax whose melting point (169°F) is one of the highest ever recorded for a natural wax, making guayule wax competitive with carnaūba wax. Resins contain terpenes and could probably find some use. The minute guayule seeds could be a source of protein and fat and the leaves might serve as an occasional browse for sheep and goats. But whatever the contribution of by-products guayule will stand or fall on the quality and quantity of its rubber.

7. Extraction technology. The development of efficient, low energy, chemical extraction techniques is important to reduce the processing costs and to ensure quality control of product.

12. A South Australian Research Programme

It is believed that there are many advantages from conducting a development-oriented research programme in this State. There are a number of factors in favour of S.A. in conducting guayule research:

(i) Existence of considerable body of research and experience.

(ii) Suitability of S.A. for guayule growing (rainfall and temperature).

(iii) Existence of related research programmes at:

- CSIRO Division of Horticultural Research
- Roseworthy Agricultural College
- SAIT Division of Chemical Technology

(iv) Keenness of Government to undertake a joint private enterprise - Government research programme.

(v) Existence in S.A. of international rubber companies (Uniroyal and Bridgestone) with possible interest in independent source of natural rubber.

Essential elements of a research programme would be:

(i) Involvement of Uniroyal or Bridgestone.

(ii) Employment of Senior Researcher and Field Assistant by the Dept. of Agriculture, and Research Assistants at CSIRO and SAIT.

(iii) Involvement of CSIRO, Waite Institute, SAIT and Roseworthy College in overall programme.

(iv) Development of good research links with overseas and interstate researchers.

(v) Establishment of a supervisory group to set research goals and monitor progress.

The length of the research programme would need to be 3 to 5 years, although evaluation of progress and justification for continuing could be made after the second or third year.

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