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STUDY ON SYNTHETIC VERSUS NATURAL PRODUCTS
PILOT PROJECT ON THE RUBBER INDUSTRY
AND ITS IMPACT ON THE ENVIRONMENT 1/

by

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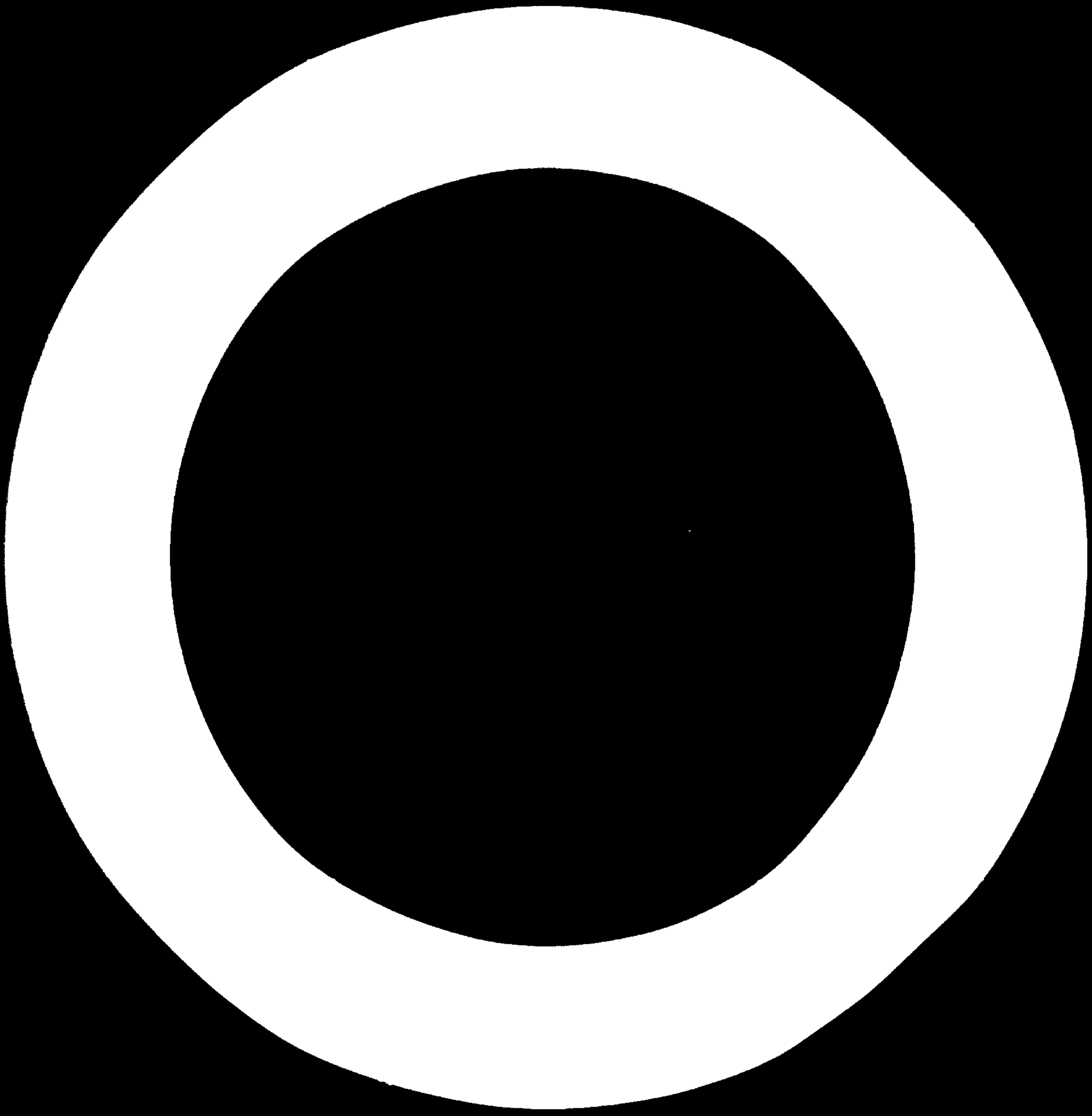

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Introduction

INTRODUCTION

This paper was prepared at the request of UNIDO to provide background and a frame of reference for a study of the rubber industry and its impact on the environment. Such a study is being conducted jointly by UNEP and UNIDO as a pilot project of its more general study of synthetic versus natural products. This paper was presented to the Expert Group Meeting sponsored by UNIDO in Vienna on September 16 - 20, 1974.

I. PURPOSE

The purpose of this study is to establish the extent to which environmental considerations should influence the world's future choice between natural and the synthetic rubbers, with full weight given to technical, sociological, and economic factors, as well as waste disposal problems.

II. HISTORICAL BACKGROUND

Prior to World War II, natural rubber (NR) was the sole source of raw material for the healthily growing and vital rubber goods manufacturing industry. The war-caused cessation of NR supplies from their prime source in Southeast Asia provided the impetus to build a large synthetic rubber (SR) industry in the U.S.A. and Canada on a crash basis. This industry initially was based primarily on a styrene-butadiene copolymer designated SBR. The war effort was highly successful in that acceptable synthetic rubbers were produced to augment NR stockpiles and to avert serious military or civilian problems. By 1948, however, NR production had regained its pre-war level, and NR consumption resumed a steady 3 to 4% per year growth pattern, while SR production fell off sharply.

In 1950, a dramatic reversal of the synthetic rubber trend took place. The Korean War, sharply increased NR prices, and U.S. Government stockpiling of NR were important factors. At about the same time, two improvements to SBR, "cold" polymerization and oil-extension, greatly improved the competitive status of this major synthetic. The net result was that, while NR consumption continued to grow at a comfortable and historical rate of about 3 to 4% per year, as shown in Figure I, the synthetic rubbers began a period of fast growth (8% per year) to supply the needs of a rubber goods industry that was growing at over 6% per year. These trends have continued for over 20 years at a remarkably steady pace. The acceptability of the synthetics was enhanced by the development in the 1960's of the "stereo-regular" polymers, polybutadiene (BR) and polyisoprene (IR), which have unique and valuable properties of their own.

III. PROCESS BACKGROUND

Natural rubber is produced primarily in upland tropical areas by the cultivation and tapping of the Hevea tree. The latex is tapped from the tree, coagulated by acidification, dried and baled. To an increasing extent, the processing operation is carried out at centralized locations. The average yield of dry rubber, world-wide, is around 1200 lbs./hectare from the somewhat more than 6 million hectares under cultivation; however new breeding techniques and the optimal use of fertilizers, pesticides and yield stimulants can greatly increase this value as these practices become more widespread.

Synthetic rubber is a typical product of the "petrochemical revolution" in that it is produced almost totally and most economically from petroleum. The original general-purpose synthetic, SBR, is still the major-volume "work-horse" of the industry. Its principal raw material, butadiene, is produced in large quantities from petroleum refinery or field natural gas streams by catalytically dehydrogenating the normal butylene or normal butane fractions, followed by purification by extraction. To an increasing extent, however, butadiene is being produced world-wide as a co-product in the production of ethylene by the thermal cracking of petroleum naphtha or gas oils. In this case, the ratio of butadiene to ethylene is fairly fixed, so that demand for ethylene may well set the butadiene production volume. The other SBR raw material, styrene, is produced by alkylating benzene with ethylene over an aluminum chloride catalyst, and then catalytically dehydrogenating the resulting ethyl benzene to styrene. Benzene and ethylene are basic petrochemical building blocks produced in large volumes world-wide from petroleum.

In the most widely-used SBR polymerization process, a mixture of roughly 2.5 parts of butadiene with 1 part of styrene is emulsified in water at about 5°C. Small amounts of the appropriate catalysts, activators and modifiers are added, and a polymer latex is formed over the course of about 12 hours. Oil, carbon black and/or inhibitors may be added to the latex, and the polymer is then recovered by coagulation, drying and baling as in the case of NR. While the general quality of SBR is inferior to that of NR, SBR fits into a large area of the market where its properties are completely adequate and where its low price and easy availability have earned it a sizeable position.

The processes to produce the stereo-regular polymers, BR and IR, from such hydrocarbon monomers as butadiene and isoprene involve the use of a metal-organic catalyst, such as aluminum triethyl-titanium tetrachloride or butyl lithium, in a very pure dry hydrocarbon system. The reaction takes place in a few hours at nominal temperatures, but a hydrocarbon solvent is required to keep the solution viscosity within reasonable bounds to permit efficient removal of the heat of reaction. Extensive pre-treatment of all reactor materials to remove moisture and trace impurities is required. The reactor solution is discharged into hot water to facilitate recycling of the unreacted materials and diluent; the resulting crumb polymer is then dried and baled.

Polybutadiene (BR) is not an easily-processed material on its own, but in combination with SBR, it has found sizeable markets, as, for instance, in tire treads where it will outwear NR. Polyisoprene (IR) has very nearly the same chemical and physical structure as NR and is often called "synthetic natural". Its properties closely approach those of NR, but in no one property is it superior. The required raw material, isoprene, is a branched five-carbon conjugated diolefin that is directionally more difficult to produce than butadiene, which is an unbranched four-carbon conjugated diolefin; hence, the raw material cost for IR would be expected to be a greater than for BR.

The transformation of raw rubber into usable commercial products is essentially the same whether NR or any of the major SR's is used. The raw rubber is mixed with sulfur (the vulcanizing agent), an organic accellerator, zinc oxide and a fatty acid (to activate the accellerator) and an antioxidant. Other likely ingredients include fillers (particularly carbon black but possibly talc or other inorganic pigments), and processing aids such as oil, wax, reclaim, etc. The final compound, frequently containing almost half non-rubber ingredients, is mixed thoroughly and then shaped into the desired finished form by molding, extruding or calendaring. In many cases, such as for tires, the mix is applied to fabrics, wire or other structural materials. The final raw product is then heated in a mold or oven to over 300°F for a pre-determined length of time to vulcanize it to a permanently-elastic finished product.

IV. GENERAL CONSIDERATIONS

A precise comparison of NR with the various synthetic rubbers is not possible. Some of the reasons are:

1. Each of the products has its own range of properties which makes it significantly different from other products. In many applications, substitution with another rubber would be unacceptable for quality reasons. There are other areas, however, where substitution is acceptable with suitable compounding changes.

2. Detailed process and cost information is considered proprietary by the producers of both synthetic and natural rubbers, and must therefore be estimated from the limited amount of published information.

3. Two world-wide problems, the energy crisis and inflation, will have differing economic and political effects upon the various rubbers. The effect of crude oil prices is particularly difficult to evaluate until some stability in the petroleum market place has been achieved.

4. The comparison of an agricultural product, NR, vital to the economies of the developing countries where it is grown, to an industrial product, SR, generally produced within the developed countries where it is consumed, is fraught with problems of foreign exchange effects, the livelihoods of millions of people, national pride, availability of capital and technology, etc. The solution to these problems may well overshadow purely techno-economic considerations.

V. WORLD RUBBER REQUIREMENTS

As shown in Figure I, the total world consumption of raw rubber has grown at a remarkably steady rate of about 6.8% per year for the past 35 years. If there is no diminution of this rate, the 10.3 million tons of raw rubber consumed in 1973 would grow to 16 million tons by 1980 and to 32 million tons by 1990. New factors, however, such as the greatly increased cost of petroleum and the trend to radial tires and smaller cars, are expected to reduce this future growth rate. The forecast of the International Rubber Study Group, made in June 1974, is that world consumption of raw rubber (excluding East Europe and China) would grow at an annual rate of about 4.7% from 1973 to 1980. As shown in Figure II, this would mean an increase in the 1973 consumption of 8.4 million tons to a level of 11.5 million tons by 1980. A further extension of this 4.7%/year growth rate would indicate a requirement of 18 million tons of total rubber by 1990. It has also been assumed in Figure II that the needs of East Europe and China will grow at this same rate, bringing the total world needs to 23 million tons by 1990. While these levels represent very significant future increases in rubber-producing facilities of some type, it can be noted that such forecasts in the past have usually been too conservative.

VI. RESOURCE UTILIZATION

An analysis of the material and energy requirements of the various raw rubbers discloses that NR is basically derived from a renewable resource, namely, tree latex, while the synthetics are almost totally dependent upon a non-renewable resource, namely, fossil hydrocarbons. NR's reliance upon non-renewable resources is relatively small, consisting primarily of fossil hydrocarbons used for the production of fertilizer and for the energy required in the processing factories, plus a small amount of non-renewable chemicals used for growth stimulation, latex preservation and coagulation.

The major raw materials for the synthetic rubbers, on the other hand, are derived almost totally from non-renewable petroleum. While some soap required in the manufacture of SBR might be considered largely renewable, a wide range of the other organic and inorganic chemicals required for initiating, controlling and stopping the polymerization reaction, coagulating the latex, inhibiting the product against oxidation, etc., are basically made from non-renewable resources. The energy needs of the synthetics are also vastly greater than those for NR due to the intensive chemical processing involved.

In Figure IIIA, a "resource balance" is presented to illustrate the energy and raw material requirements for oil-extended SBR (Type 1712). This shows that about 3.5 tons of crude oil or its equivalent is required for each ton of finished rubber product. Of this crude oil, about 42% is required for raw materials and about 58% for the energy needed for driving motors, heating stills and driers, etc. The other major synthetics, non-oil-extended SBR, BR and IR, as shown in Figures IIIB, C and D, respectively, require even more non-renewable resources than oil-extended SBR. The values shown should be used only to indicate general magnitudes; the values would probably be somewhat lower, for instance, if butadiene were produced as an ethylene co-product by thermal cracking rather than from normal butane, as was assumed here. It should also be noted that most of the energy requirement could be satisfied by using coal or atomic energy for the generation of steam and power.

The resource balance for NR, shown in Figure IIIE, shows a much lower requirement for non-renewable resources, - roughly 0.3 tons/ton of NR for the rate of fertilizer application indicated. This could grow as optimal agronomic practices become more widespread.

Two other areas of overwhelming difference between NR and the synthetics are in land utilization and labor requirements. While 100,000 tons per year of SR can be produced comfortably on 40 hectares of unproductive land by about 300 people, the same amount of NR would require at least 40,000 hectares of high-yielding trees worked by about 100,000 people. Thus social and political effects are extremely important in addition to the normal technical and economic measures of comparability.

VII. COSTS OF PRODUCTION

As mentioned earlier, an accurate comparison of the cost of producing NR vs. the various major synthetic rubbers is difficult, since no producer is willing to reveal either detailed process information or cost data. Plants built under license are customarily legally restrained from divulging such proprietary information.

Another factor making comparisons difficult is the recent sharp turn-about of the chemical industry that supplies the main raw materials to the SR plants. For some years, key materials such as butadiene and styrene were selling in a highly-competitive market at prices so low that new plant capacity for merchant sales could not be justified. Butadiene and styrene could be purchased for considerably less than 8 U.S. ¢ per pound. By 1973, the industry's spare capacity was finally used up, and shortages and black markets suddenly appeared. Later in 1973, the petroleum crisis and the subsequent quadrupling of Mid-East crude oil prices occurred. The current situation is one of confusion which will continue until crude oil prices stabilize and new raw material production capacity is built to meet the future demand. Neither the previous period of depressed prices nor the current period of inflated prices can be taken to be representative of normal conditions.

An attempt has been made to estimate the theoretical prices for SR and its raw materials that <u>should</u> have prevailed in 1973, prior to the sharp crude oil price rise, if the industry was to attract new investment for expansion. A return on investment of 20% before income taxes has been assumed. On this theoretical basis, it is estimated, as shown in Table I, that butadiene should have been priced at about 11 ¢ per pound, isoprene at about 13 ¢ per pound and styrene at about 8 ¢ per pound, when produced in large plants. When these raw material prices were used to estimate the theoretical production costs of the SR's, as in Table II, oil-extended SBR (1712 type), produced at 100,000 tons per year, would have been valued at about 17 ¢ per pound, and non-oil-extended SBR (1500 type) at about 20 ¢ per pound. The "stereo" rubbers would have been more costly, with estimated values of 22 ¢ and 24 ¢ per pound, respectively for BR and IR. In plants of 25,000 tons per year capacity, the values would have been 3 to 3½ ¢ per pound higher for the SBR's and about 4 ¢ per pound higher for BR and IR. In an industry such as this, small plants are at a distinct economic disadvantage.

In comparison with the above, it is estimated *) in Table III that NR could have been produced profitably on an efficient plantation estate for about 18 ¢ per pound, c.i.f. New York.

A summary of the comparative costs of all of the above products is shown in Table IV. Within the range of the rough accuracy of the figures shown, it can be concluded NR could be produced competitively with the largest-volume and cheapest SR, namely, oil-extended SBR. NR is apparently cheaper to produce than any of the non-oil-extended SR's and it is considerably cheaper than IR, the polymer that was intended to duplicate NR.

Prices that would need to prevail in 1980 to attract new investment can only be guessed at. Inflation, which is likely to continue, will gradually increase the prices of both SR and NR and possibly to similar degrees. Excluding the effect of inflation, however, increases in the price of petroleum have a much greater effect upon SR than upon

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*) See Bibliography Reference No.1

NR. If the crude oil price of about $3.00/Bbl. which prevailed in 1973 increases to $12.00/Bbl. and other fuel costs increase proportionately, the SR prices would need to increase by approximately 50%. Thus, the theoretical price of oil-extended SBR (1712 type) mentioned above would increase from 17 to 26 ¢ per pound, non-oil-extended SBR from 20 to 30 ¢ per pound, BR from 22 to 33 ¢ per pound and IR from 24 to 36 ¢ per pound due to oil price increases alone. Under these same circumstances, the effect upon NR costs would be less than 1 ¢ per pound. Higher oil prices provide a distinct advantage to NR producers in competing with SR of any type.

Two uncertain factors in projecting future costs should be mentioned. One is that butadiene price could be lower than assumed above if its production as a co-product of ethylene outstrips its requirement for SR production outside of North America. In that case, its price might be set by the out-of-pocket cost of the material it would need to supplant, namely butadiene produced deliberately from butylene or butane in the U.S.A. The other factor involves the fact that, while the SR industry has already taken advantage of most of the possible cost-reduction opportunities, such as increased scale of operations, improved yields, etc., the NR industry has technology available to it, and being used on an ever-increasing scale, to lower NR costs significantly by the use of higher-yielding varieties of trees, better agronomic practices and the technique of chemical yield stimulation.

VIII. SOURCES OF POTENTIAL POLLUTANTS

The sources of potential pollutants resulting from the manufacture of each of the large volume SR's is shown in the resource balances, Figures 1IIA, B, C and D. The largest volume of potential pollutants derives from the fossil fuel used to produce the power, steam and fuel gas needed to carry out the SR processes. While most of this energy is now generated by the combustion of petroleum oil or gas, much of it could be derived from coal or atomic energy. The combustion of these products is carried out under carefully-controlled conditions;

hence, the major potential pollutants are minor amounts of CO, SO_2, etc.

The second largest source of potential pollutants is from the petroleum fractions which are lost or converted to fuel products during their conversion to SR raw materials and finally to SR itself. No substitution could easily be made for these petroleum fractions without major process changes and significant economic penalties.

As the resource balances show, each SR process requires a number of organic and inorganic chemicals and catalysts, in addition to the hydrocarbon raw materials. These chemicals and catalysts generally end up as liquid or solid wastes for which proper disposal facilities must be provided. Some materials, such as most of the soap used in the SBR emulsion process and the oxidation inhibitors added to the finished rubbers, end up in the rubber product itself. Eventually, of course, these also end up, along with the SR itself, as solid wastes, either as particulate abraded from the finished rubber products or as discarded rubber products.

NR produces much less potential pollutants of the type generated by the SR's, since the chemicals required are limited to relatively small quantities of fertilizer, growth stimulants, coagulants and latex preservatives, and the energy requirements are limited to those needed to produce those chemicals as well as to coagulate, dry and bale the NR product. NR does, however, have a significant problem of satisfactorily disposing of the latex serum remaining after coagulation, since the serum contains proteins, lipids and other non-rubber organic materials.

IX. COSTS OF POLLUTION CONTROL

Information is very meager on the cost of the pollution control methods which are now or may need in the future to be applied to the SR producing plants. All existing SR plants contain considerable equipment designed to reduce air and water pollution to acceptable standards for the prevailing local conditions. As environmental standards become more severe, additional pollution control may be needed, with the cost dependant upon the nature of the pollutants and the severity of the standards.

A study made for the U.S. Environmental Protection Agency*) indicated that a total water treating system employing the "best available" technology could cost up to 10% of the SR plant investment and would involve an increase in selling price of the product of about 0.5 ¢ per pound. An analysis of the cost figures given in Table II confirms this. The EPA study points out that existing SR plants already contain all or most of the pollution control equipment required. It, therefore, seems unlikely that the cost of new pollution control measures will have a significant effect upon the decision to produce or not to produce SR's, or upon the type of SR to be made.

The cost of pollution control for NR is currently very small. As the latex coagulation operation becomes more centralized, however, expenditures for pollution control will probably become necessary, depending upon the local conditions. The methods to be used, however, appear to be straight forward and the costs will be nominal.

X. CONSIDERATIONS AFFECTING THE CHOICE OF RUBBER

The foregoing information has shown clearly that NR requires a great deal less non-renewable resources for its production than SR, and that its pollution potential from chemicals and combustion products is significantly less than for SR. What is more, NR can apparently be produced profitably at a price competitive with the cheapest SR and lower than the other SR's. If these were the only considerations that applied, NR could be expected to take over the lion's share of the future market. There are other considerations, however:

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*) See Bibliography Reference No. 9

1. Technically, each of the rubbers has areas of use where it is superior. P.W. Allen of The Natural Rubber Producers' Research Association says "SBR supply has probably little, if any, dependence on the price of natural rubber; it has carved out its own markets, has its own supply/demand/price pattern and direct competition with natural rubber is not now a key issue." C.F. Ruebensaal of the Uniroyal Corp. states that "Despite its volume, natural rubber has been primarily a specialty rubber, because it has been used where its low hysteresis and high elasticity were required. As a result, its price bore little relationship to historical price levels of general-purpose synthetics." He states, however, that this could change with the growth of radial tires, since they can be made from either NR or the general-purpose SR's. It is apparent, nevertheless, that no one rubber, natural or synthetic, is likely to take over the market place. On the other hand, there are and will continue to be large areas of usage where NR and the SR's are competitive, alternative raw materials.

2. Synthetic rubber, produced in many cases by the tire manufacturers themselves, provides the rubber industry with a vital second source of supply and with a way to stabilize the price of their mjaor raw material. Years ago, the annual performance of a rubber manufacturer often depended more upon astuteness and luck in purchasing NR than upon any other factor. The industry has a tremendous incentive to assure that their major raw material can be purchased at a stable and reasonable price; their competitive performance can then hinge upon their technical and managerial skills. It is unlikely that the rubber goods manufacturers will ever willingly go out of the SR producing business.

3. There is an incentive to rubber-consuming countries to produce their own rubber to improve their foreign exchange balance and to increase employment. Similarly, the oil-producing countries may well turn to SR production as a way of investing their huge foreign exchange income and of upgrading the value of their crude oil.

4. The dedication of millions of acres of arable land at an increasing rate to NR production must be weighed against the alternative use of such land for the production of food such as palm oil or coconuts, both as cash crops and as vital sources of food for a growing world population.

5. Since new NR plantings require six years after transplanting the seedlings until the first tapping, the prospect for 1980 NR production is already set by the plantings currently being made. As shown in Figure II, the NR producing countries are now predicting that NR production will reach 5.0 million tons in 1980, up from the 3.4 million ton level of 1973. To achieve this requires an annual growth rate of 5.7% as compared with a 4.0% rate achieved during the past 10 years. A continuation of this 5.7% rate would mean reaching 8.7 million tons by 1990. At that time, if the total raw rubber requirements have been forecasted correctly, NR would represent 38% of total world rubber requirements compared with 33% in 1973, and 35% predicted for 1980. The growth in NR production required to take over all future growth of total rubber requirements after 1980 would need to be over 10%/yr., to reach a level of 13.4 million tons by 1990. Such a large increase in growth rate does not appear reasonable; however, even to reach the more nominal targets, a huge dedication of new investment and new acreage will be required and it will need to begin very soon.

6. Assuming that: 1) NR production will grow at the accelerated rate of 5.7%/yr., 2) total rubber requirements will grow at 4.7%/yr., and 3) East Europe and China will increase their SR production such that their NR requirements will remain constant at the current 0.75 million ton/yr. level, then the requirement for SR in the world excluding East Europe and China will need to grow at a rate of only 3.6%/yr. as shown in Figure II. While this is much slower than the recent 8.5%/yr. rate, it still means that SR production (excluding East Europe and China) will need to be increased from 5.7 million tons in 1973 to 7.3 million in 1980 and to 10.3 million tons in 1990.

Considering the assumptions listed above, this would seem to be a minimum forecast level, and the actual requirements for new SR production may well exceed this minimum. In addition to very large capital requirements for future SR expansion, the consumption of fossil hydrocarbons for SR production could reach a level of 25 to 50 million tons per year by 1990. While petroleum supplies are undoubtedly going to be depleted at some time in the future, the use of petroleum for producing materials such as SR represents a premium value outlet as compared with its use for power generation or industrial heating. It should be noted that 50 million tons of petroleum represents considerably less than 1% of the total world energy demand forecast for 1990.

7. In addition to its destruction of non-renewable resources, SR production is the source of significant potential environmental pollution. It has been indicated, however, that such pollution can be reduced to acceptable levels by proper treating techniques at a cost that will not seriously affect the cost of production.

In summary, it appears that it will be necessary for both NR and SR to continue their growth at a substantial rate for the foreseeable future. Whether the future growth rate of each is at 3%, 5% or 8% per year level depends on many technical, economic, political, sociological and ecological factors. It appears unlikely, however, that either NR or SR could possibly take over all of the future growth, or, alternatively, that either could stop growing entirely without serious consequences to the rubber industry and therefore to the overall world economy.

XI. OPTIMUM UTILIZATION OF RESOURCES

The least destruction of non-renewable natural resources and the lowest potential for environmental pollution occurs when NR rather than SR is used to supply the raw rubber needs of the world.
There is a real environmental benefit, therefore, to maximizing the utilization of NR. As stated above, however, it is forecast that both NR and SR will need to be produced in increasing quantities to meet the anticipated world rubber demand.

There is a very strong incentive, particularly as petroleum prices and ecological pressures increase, to produce raw rubber as efficiently as possible. For the mature SR industry that has just been through a highly competitive period, it is unlikely that there is much potential for a significant reduction in material or energy needs. The NR industry may have some potential for energy reduction in the latex processing area; however, the economic incentive for increased NR production may well result in increased use of fertilizer and growth stimulants at the expense of non-renewable resources.

In the production of SR, there is a strong ecological incentive to use the technology which has the least detrimental effect upon the environment. A listing of the various commercially - proven alternative technologies is given in Table V. Unfortunately, the difference between the various SR processes in their use of non-renewable resources and in their production of pollutants is relatively small. The choice of the type of SR to be produced in a new plant would be dominated by economic and quality considerations, rather than by ecological factors. Similarly, the processes used to manufacture butadiene, isoprene and styrene are all heavily dependent upon non-renewable resources, with rather small differences in ecological effects between the alternate technologies that could be resorted to in each case. Directionally, isoprene appears to be more wasteful of non-renewable resources than butadiene or styrene, since it is technically more complex to produce from petroleum. For this reason and also because it possesses no technical advantages over NR, polyisoprene (IR) would, from an environmental standpoint, appear to be the least desirable of the SR's.

A major technology shift would involve the use of agricultural fermentation products to produce butadiene or isoprene. Butadiene was made very successfully on a large scale from ethyl alcohol in the U.S.A. during World War II, and it is being made that way today in India. Except under unusual local situations, this route is very much more expensive than the petrochemical route. Each pound of butadiene would require about 0.45 U.S. gallons of 95% ethyl alcohol as a raw material. Such alcohol can be produced by the fermentation of molasses or grain, although it can be produced more cheaply from petroleum-derived ethylene. With ethyl alcohol selling at 60 ¢ per gallon , a price which is unattractive to the grain and molasses fermenters, the raw material cost alone for butadiene would be 27 ¢ per pound! In the case of isoprene, SNAM-Progetti offers a process which uses acetone and acetylene as the raw materials. The acetone (0.97 pounds per pound of isoprene) can be produced from molasses or grain by fermentation, and the acetylene (0.43 pounds per pound of isoprene) can be obtained from coal and limestone by the electric arc process. As in the case of ethanol, fermentation acetone has not been able to compete economically with petrochemical acetone. In general, agricultural products which have alternate uses, such as for human or animal feed, cannot be converted to organic chemical raw materials on an economical basis when compared with the petrochemical route. The differences are so great that it is unlikely that this situation will change even in the face of a greatly increased cost for crude oil.

The reclamation of vulcanizable rubber from discarded rubber products is a well-established industry. Unfortunately, reclaimed rubber derived from either NR or SR products by current methods is not an acceptable substitute, quality-wise, for either NR or SR. Instead, it has found a valuable but limited market as a compounding ingredient to aid processibility in the manufacture of certain rubber products. The procedure for reclaiming rubber (collecting, grinding, removing fibers and metals, digesting with hot strong chemicals or high pressure steam, masticating and packaging) is expensive and high in energy-consumption. Thus while reclaimed rubber has found a small place for itself in the rubber manufacturing picture, it is not likely to become a major factor in reducing the consumption of new rubber by the rubber industry unless new technology is discovered.

Another well-established procedure, that of recapping worn tire carcasses to permit their reuse, does have the effect of reducing the consumption of non-renewable resources while still taking care of the transportation needs of the economy. Wider use of this technique may automatically occur as new tires become more expensive. A major problem with recapping is the achievement of high-quality workmanship in the thousands of small local recapping establishments such that highway safety and reliability are not impaired.

XII. GENERAL CONCLUSIONS

From the foregoing, the following conclusions can be drawn:

1) From an environmental standpoint, NR production should be encouraged, since it is less destructive of non-renewable resources and less productive of potential pollutants than SR production.

2) From an economic standpoint, NR can be produced in efficient plantations as cheaply or cheaper than SR; this relative advantage will increase as petroleum prices increase.

3) From a technical standpoint, NR has the qualities necessary to permit it to take over more than 40% of the world rubber market.

4) From a social or political standpoint, the limitation on the growth of NR production may well be the availability of suitable land and capital when compared with alternate uses of the land for food production or the capital for industrialization.

5) Even with NR production increasing facter than in the past and even with the growth of total rubber requirements slowing somewhat due to the advent of smaller cars, radial tires, etc., there will still be a need for a significant increase in SR production in the future.

6) Regulations to control pollution from the rubber production and rubber fabrication industries will become more prevalent and more severe; however, the cost of satisfactory pollution control will not seriously increase the cost of rubber products.

7) In choosing the type of SR for which new facilities will be built in the future, strong consideration should be given to processes which consume the least non-renewable resources.

TABLE I

ESTIMATED PRODUCTION COSTS OF RAW MATERIALS IN 1973

	Butadiene From Butane	Isoprene From Amylenes	Styrene
Plant Size T/yr.	100,000	100,000	150,000
Plant Investment, $Millions	30	30	24
Production Costs, ¢/Lb.			
Raw Materials	2.7	3.9	3.7
Direct Conversion	3.8	4.4	1.1
Sales and Adm. Overhead	0.6	0.7	0.4
Depreciation at the rate of 8%	1.1	1.1	0.6
Return - " - 20%	2.7	2.7	1.5
Total	10.9	12.8	7.3

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TABLE II

ESTIMATED PRODUCTION COSTS OF MAJOR SYNTHETIC RUBBERS IN 1973

	SBR				BR		IR	
	Oil Masterbatch (1712 Type)		Non-Pigmented (1500 Type)		Non-Pigmented		Non-Pigmented	
Plant Size, T/yr	100,000	25,000	100,000	25,000	100,000	25,000	100,000	25,000
Plant Investment, $Millions	22	8	25	9	30	11	30	11
Production Costs, ¢/Lb.								
Raw Materials	8.2	8.2	10.2	10.2	11.4	11.4	13.5	13.5
Direct Conversion	4.2	6.1	5.0	7.1	4.9	7.2	4.9	7.2
Sales and Adm. Overhead	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.1
Depreciation at the rate of 8%	0.8	1.2	0.9	1.3	1.1	1.6	1.1	1.6
Return at the rate of 20%	2.0	2.9	2.3	3.3	2.7	4.0	2.7	4.0
Total	16.1	19.3	19.4	22.9	21.2	25.3	23.3	27.4

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TABLE III

ESTIMATED PRODUCTION COST OF ESTATE NATURAL RUBBER IN 1973

	¢/Lb.
CAPITAL INVESTMENT FOR PLANTATION AND PROCESSING PLANT	25.
PRODUCTION COSTS	
Tapping and Collecting	5.1
Fertilizer and Application	1.0
Processing	1.25
Management	1.05
Other Costs	1.4
Total Estate Costs	9.8
Export taxes, levies	1.0
Profit (20% of investment)	5.0
Transport, insurance, landing charges	2.2
New York Landed Price	18.0

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TABLE IV

SUMMARY OF ECONOMICS

		IN 1973	
RAW MATERIALS	PLANT SIZE T/YR	INVESTMENT $MM	SELLING PRICE ¢/LB
BUTADIENE (FROM BUTANE)	100,000	30	11
STYRENE	150,000	24	8
ISOPRENE	100,000	30	13
RAW RUBBERS			
SBR (COLD OIL MASTERBATCH)	100,000	22	17
	25,000	8	20
SBR (COLD NON-OIL EXTENDED)	100,000	25	20
	25,000	9	23½
BR (NON-OIL EXTENDED)	100,000	30	22
	25,000	11	26
IR (NON-OIL EXTENDED)	100,000	30	24
	25,000	11	28
NR (DELIVERED TO USA)	100,000	55	18
	25,000	14	18
RAW RUBBERS (INCLUDING RAW MATERIAL INVESTMENTS)*			
SBR (COLD OIL MASTERBATCH)	100,000	41	17
	25,000	13	20
SBR (COLD NON-OIL EXTENDED)	100,000	51	20
	25,000	16	23½
BR	100,000	61	22
	25,000	19	26
IR	100,000	61	24
	25,000	19	28
NR (DELIVERED TO USA)	100,000	55	18
	25,000	14	18

*BUT EXCLUDING PETROLEUM REFINERY INVESTMENTS.

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TABLE V

ALTERNATIVE PROCESS TECHNOLOGIES FOR SYNTHETIC RUBBER PRODUCTION

SBR - Emulsion - Cumene Hydroperoxide Catalyst
Solution - Butyl Lithium Catalyst

BR - Solution - Aluminum Alkyl - Titanium Tetrochloride Catalyst
Solution - Butyl Lithium Catalyst

IR - Solution - Al Alkyl - $TiCl_4$ Catalyst

Butadiene

- Butane Dehydrogenation
- Normal Butylene Dehydrogenation
- Ethyl Alcohol Condensation
- Naphtha or Gas Oil Pyrolysis

Styrene

- Benzene-Ethylene Alkylation

Isoprene

- Amylene Dehydrogenation
- Propylene Dimer Cracking
- Isobutylene-Formaldehyde Condensation
- Acetone-Acetylene Condensation

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FIGURE III A
RESOURCE BALANCE FOR COLD OIL MASTERBATCH SBR

(WEIGHT BASIS FOR LARGE PLANTS)

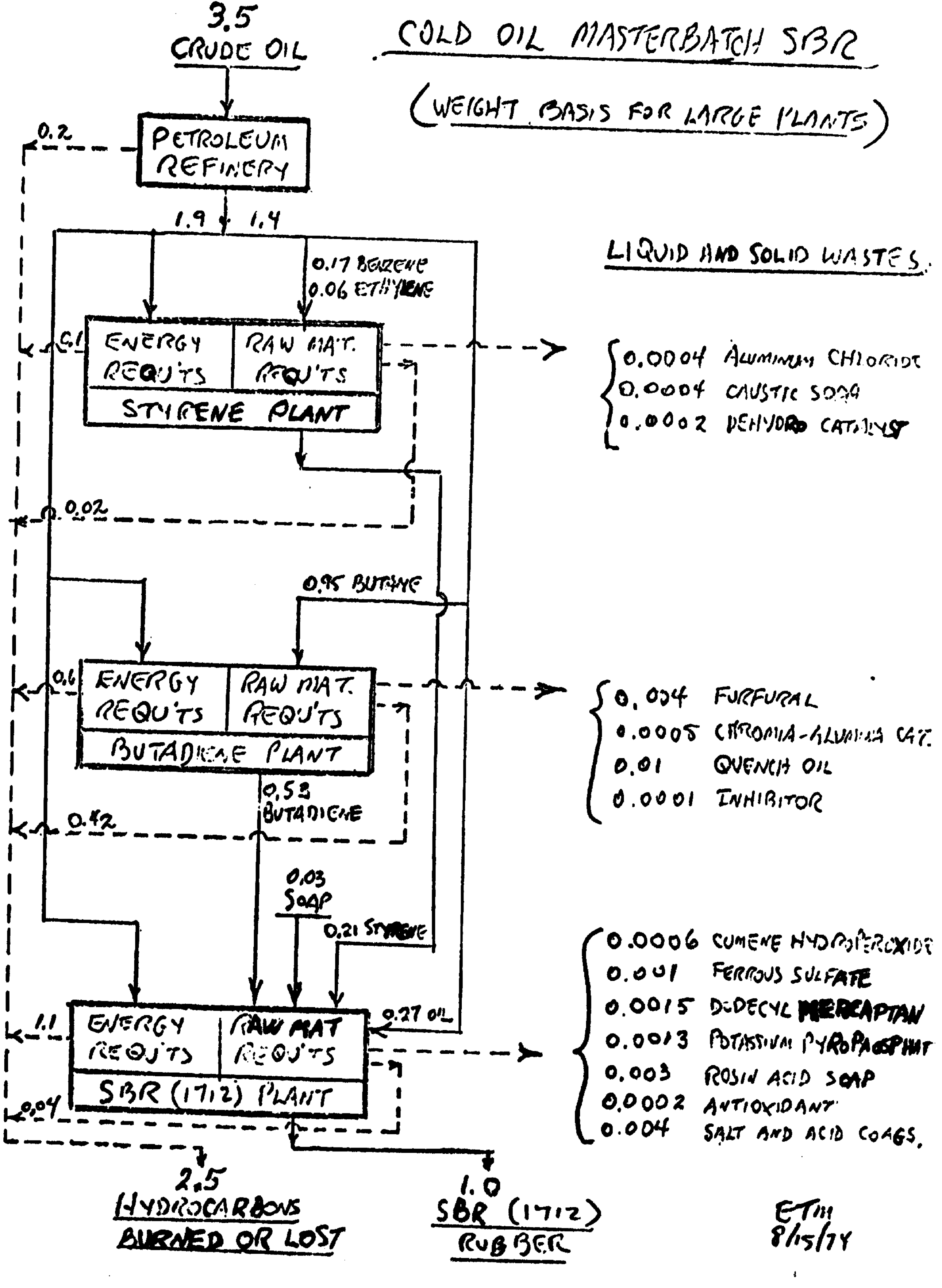

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FIGURE III B
RESOURCE BALANCE FOR COLD NON-PIGMENTED SBR (1500 TYPE)

(WEIGHT BASIS FOR LARGE PLANTS)

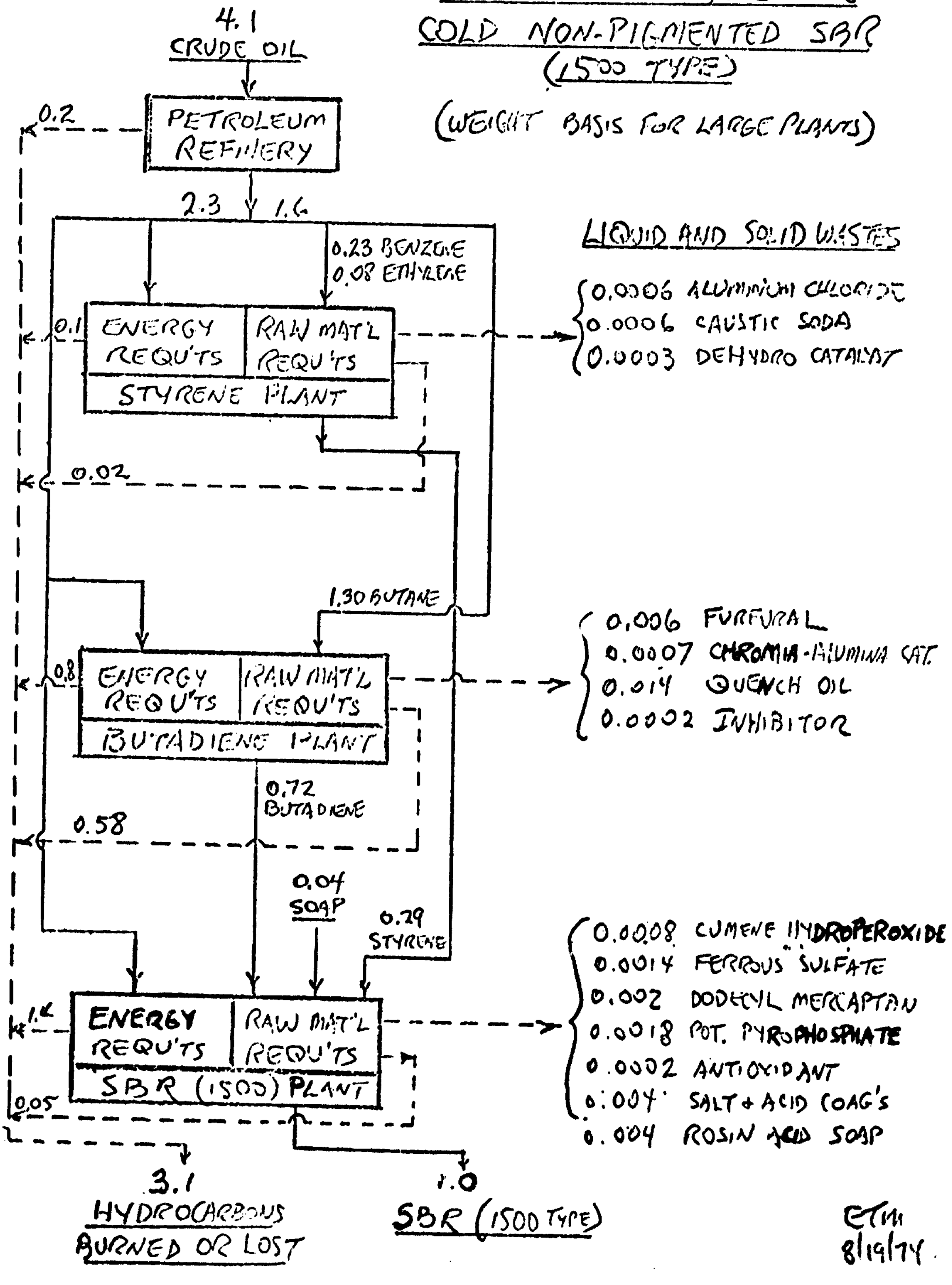

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FIGURE III C

RESOURCE BALANCE FOR BR PRODUCTION

(ON WEIGHT BASIS FOR LARGE PLANTS)

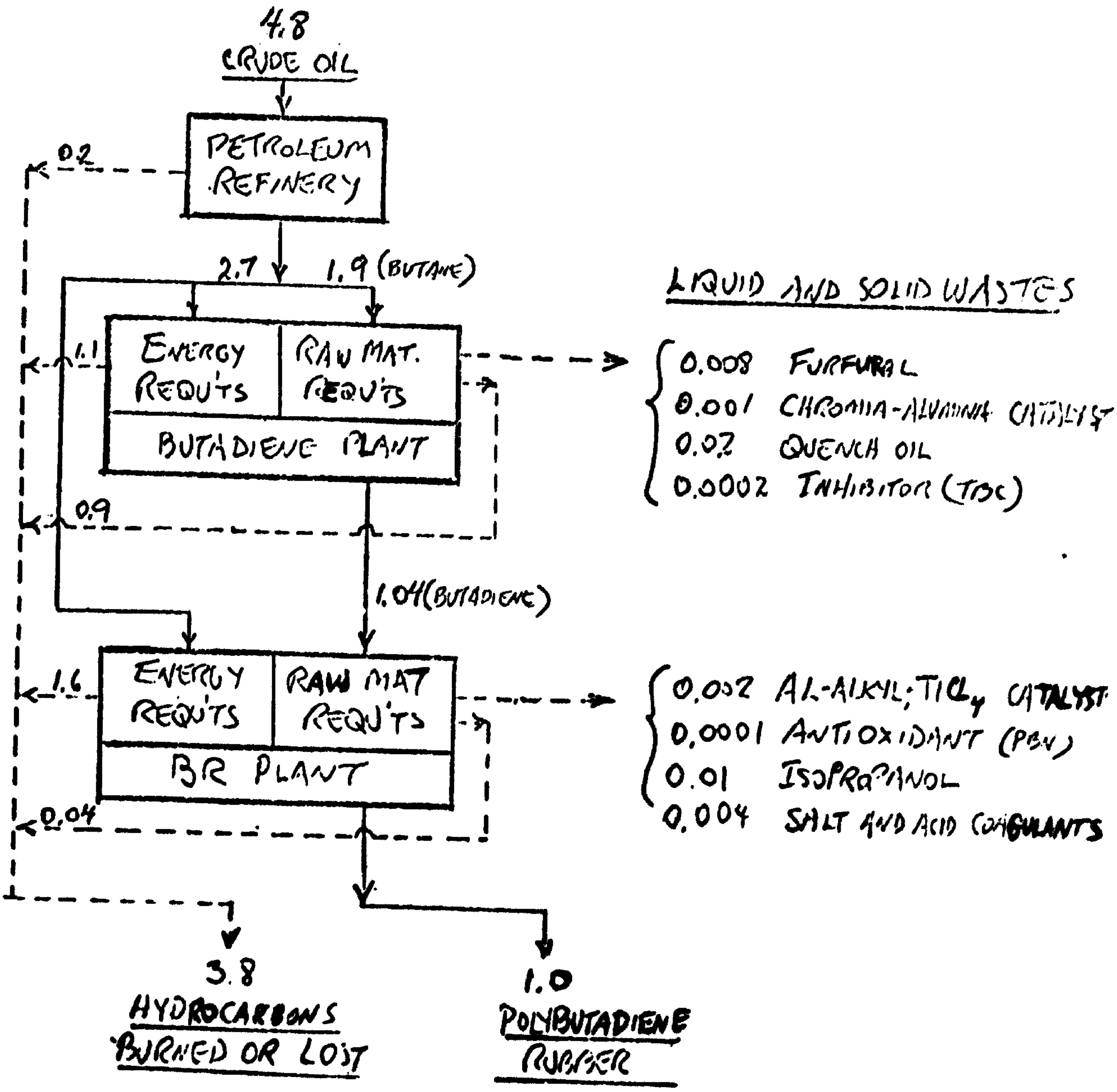

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FIGURE III D
RESOURCE BALANCE FOR IR PRODUCTION

(WEIGHT BASIS FOR LARGE PLANTS)

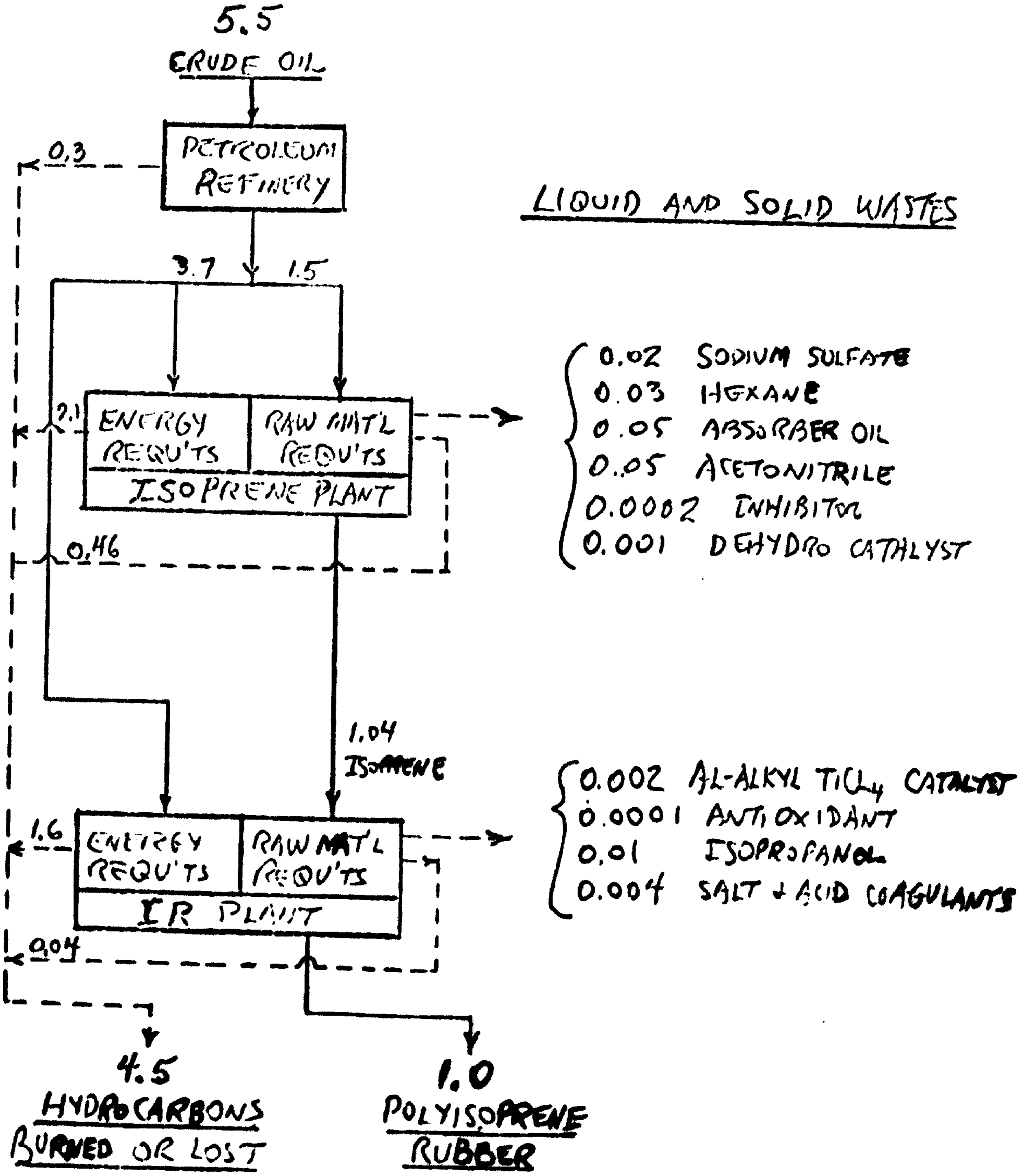

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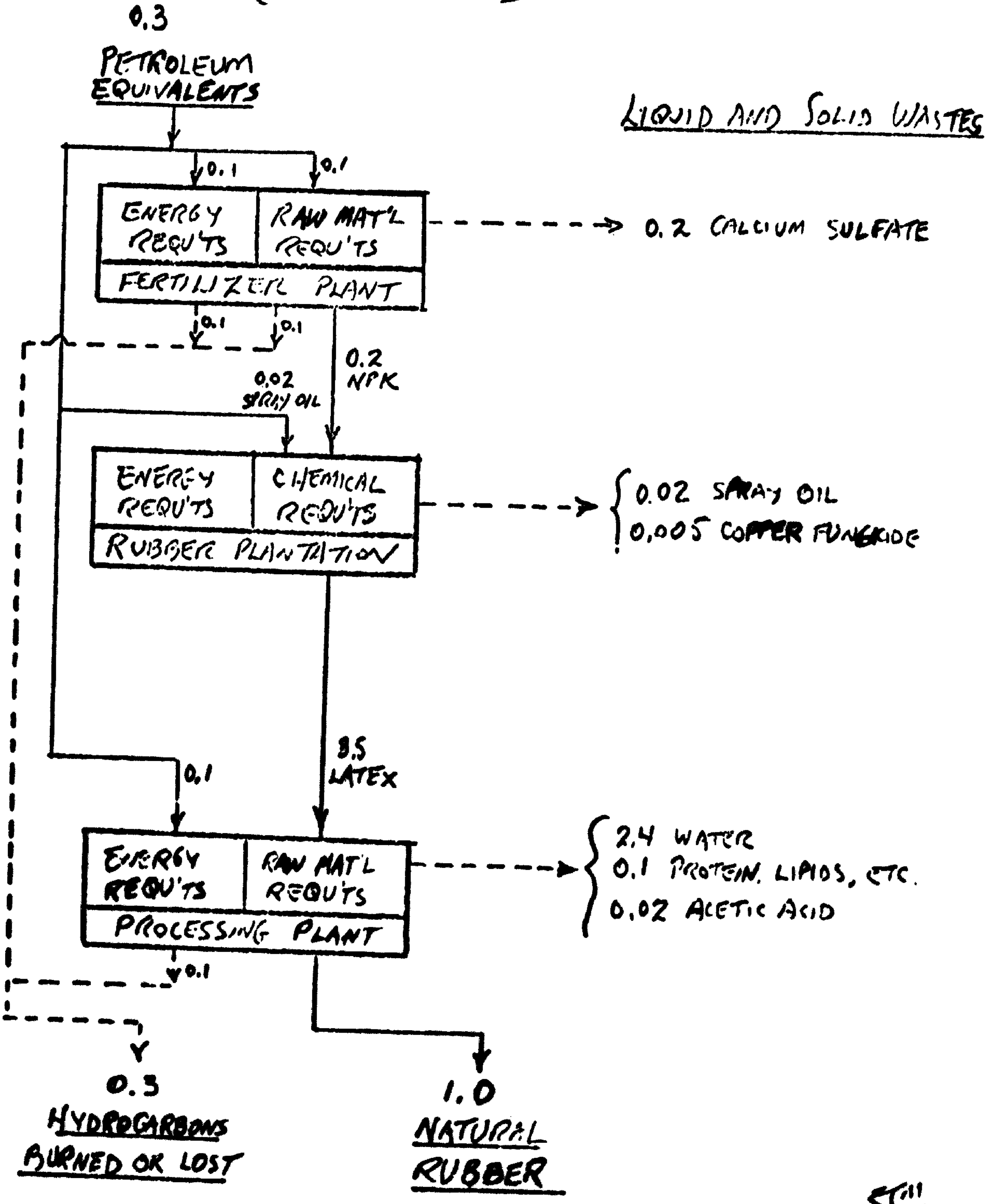
FIGURE III E
RESOURCE BALANCE FOR NATURAL RUBBER PRODUCTION

(WEIGHT BASIS)



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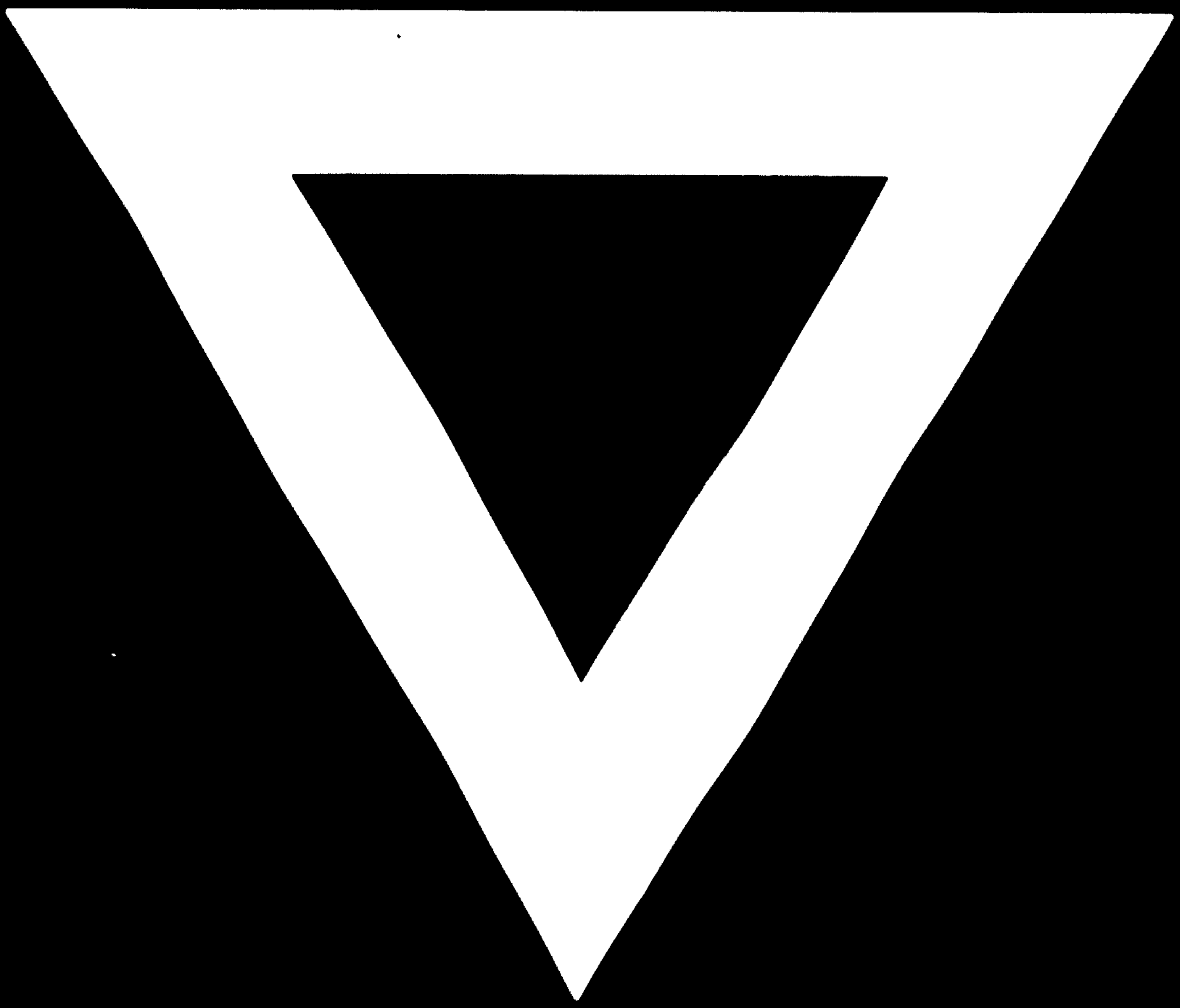

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