RT NO. DOT-TSC-NHTSA-79-21 HS 803-657

JJ

AUTOMOTIVE MANUFACTURERS' COST/REVENUE, FINANCIAL AND RISK ANALYSIS: PROJECTED IMPACT OF AUTOMOBILE MANUFACTURING ON THE PLASTICS INDUSTRY

Robert Kaiser

H.H. Aerospace Design Company Inc.
Civil Air Terminal
Bedford MA 01370

AUGUST 1979

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

Prepared for

Transportation Systems Center

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No. HS-803-657	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
AUTOMOTIVE MANUFACTURERS' COST/REVENUE,
FINANCIAL AND RISK ANALYSIS: PROJECTED IMPACT OF
AUTOMOBILE MANUFACTURING ON THE PLASTICS INDUSTRY

5. Report Date
August 1979

6. Performing Organization Code

7. Author's)
Robert Kaiser

8. Performing Organization Report No.
DOT-TSC-NHTSA-79-21

9. Performing Organization Name and Address
H.H. Aerospace Company, Inc.*
Civil Air Terminal
Bedford, MA 01736

10. Work Unit No. (TRAIS)
HS 927/R9404

11. Contract or Grant No.
DOT-TSC-1333

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration
Office of Research and Development
Washington DC 20590

13. Type of Report and Period Covered
Final Report
June 1977 to July 1978

14. Sponsoring Agency Code

15. Supplementary Notes
*Under contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Kendall Square, Cambridge MA 02142

16. Abstract

This report provides background information on current and future uses of plastics in passenger automobiles and an assessment of the impact of changes in the characteristics of the average U.S. automobile, particularly on the producers of plastic resins.

Total U.S. plastics consumption has increased at an annual rate of 6.5 percent from 1969 through 1977. Plastics consumption by passenger car manufacturers has increased at an annual rate of 8.4 percent over the same period.

While there are over twenty generic types of plastics used in automobiles, the most important, in terms of tonnage, are polyurethane, polypropylene and its copolymers, polyvinyl chloride, thermosetting polyester resins, and ABS (acrylic-butadiene-styrene) resins.

The plastics content of the average car will probably increase from about 80 kgs in 1976 to as much as 250 kgs in 1990. Much of the growth will be as a result of new applications of plastic resins in exterior and functional parts, with thermosetting polyester resins, polyurethane and polypropylene accounting for 20 percent of the projected increase.

Major increases in manufacturing capacity will be required for some areas, requiring a total capital investment of about $1.7 billion (1978 basis) including investment for manufature of basic petro-chemicals, intermediates and monomer manufacture.

17. Key Words
Plastics Industry,
Cost/revenue Analysis,
Risk Analysis,
Automotive plastics

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	185	

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

This report is part of a study to update the historical and projected cost/revenue analysis of the U.S. domestic automobile manufacturers. It includes the evaluation of the historical and projected financial data to assess the corporate financial position of each manufacturer and the assessment of the extraordinary risks imposed on the manufacturers by Automotive Fuel Economy Standards. In particular, this report includes the effect of changes in the characteristics of the average U.S. automobile on the plastics industry.

The work reported here was completed under the direction of the TSC Program Manager, Joseph Blair. Mr. Blair's guidance, assistance, and cooperation are much appreciated.

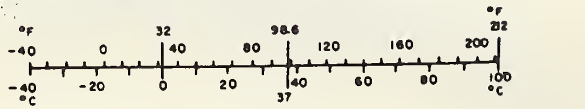
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

APPENDICES

CONTENTS (Continued)

APPENDICES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

SUMMARY

This report provides background information on the current and future uses of plastics in passenger automobiles and an assessment of the impact of changes in the characteristics of an average U.S. automobile, particularly on the producers of plastic resins.

Total U.S. plastics consumption, which was 14.8 million metric tons in 1977, has increased at an annual rate of 6.5 percent since 1969. Plastics consumed by passenger car manufacturers increased from 387,000 metric tons in 1969 to 797,000 tons in 1977, which corresponds to an average compounded annual growth rate of 8.4 percent. Automotive plastics accounted for 5.4 percent of total consumption in 1977. Total plastic resin sales were estimated to be $14 billion in 1977. Plastic sales for M.Y. 1977 automobiles were estimated to be $720 million or 5.1 percent of the total.

While there are over twenty generic types of plastics used in automobiles, over 97 percent of the usage is divided between sixteen major types for which consumption statistics were found. In 1977, the most important plastics for the automotive industry in terms tonnage were: polyurethane, polypropylene and its copolymers, polyvinyl chloride, thermosetting polyester resins and ABS (acrylic-butadiene-styrene) resins. The automotive consumption of any of the other resins was less than 50,000 metric tons in 1977.

The general consensus is that the plastics content of an average automobile will increase from about 80 kg in 1976 to 90 to 100 kg in 1980, up to 120 to 160 kg by 1985, and possibly as much as 250 kg by 1990. Much of the growth will be as a result of new applications of plastic resins in exterior and functional parts. Thermosetting polyester resins will exhibit the greatest growth (on a weight basis), followed by polyurethanes and polypropylene. These three resins will account for 70 percent of the projected increase in automotive plastics consumption over the next decade. On a proportionate basis, the engineering thermoplastics, notably thermoplastic polyesters, and high density polyethylene will

will exhibit high growth rates.

The current manufacturing capacity for the various automotive plastics and their key precursors was examined, and the required additional capacity needed to satisfy the 1988 M.Y. passenger automobile requirements was estimated (See Table 10). Major increases in manufacturing capacity will be required for unsaturated polyester resin polyurethane precursor and polypropylene. These additional facilities will require total capital investment of about $1.7 billion (1978 basis) including the investments needed for the manufacture of the basic petrochemicals and other basic chemicals, intermediates and monomers.

Assuming a 10 percent processing penalty to transform petroleum into petrochemicals, based on an automobile production of 8.5 million vehicles per year, a projected equivalent petroleum consumption of 133 gallons per 1988 automobile will be contained in the plastic used on the car, as compared to 48 gallons for a 1977 automobile.

1. INTRODUCTION

1.1 SCOPE OF STUDY

The purpose of this report is to provide background information on the current and future use of plastics in the automotive industry. The report assesses the impact of changes in the characteristics of an average U.S. automobile on the petrochemical materials industry, particularly the producers of plastic resins.

In this report, the major plastics used in automobiles at present are identified, and the relative importance of the automobile market in the total consumption for each of these plastics is specified. Published forecasts of plastics usage by type are reviewed and scoped in terms of the historic performance of the material. The impact of the future automotive market on the plastic resin manufacturers is assessed, in terms of additional capacity requirements and additional resource demands, such as additional capital investment and raw material and intermediate consumption.

The main body of this report is a summary document which considers the overall use of plastic resins in automobiles. The report also contains a series of appendices which describe, in more detail, each of the major resins which are used in automobile applications. The information presented includes a description of the general characteristics of the resin, typical applications, specific automotive applications, current price of a representative grade of material, current and projected supply capacity (by manufacturer and location to the extent possible), demand data, including total U.S. consumption, consumption by the U.S. transportation industry and by the U.S. automobile industry, historic supply and demand patterns and growth rates, and synthesis and manufacturing information. A representative manufacturing process used in the commercial production of the polymeric resin is described. Key raw material requirements for the resin, its monomers, and other key intermediates are identified and quantified in terms of the consumption of the various basic chemicals which are the building blocks from which the various plastic resins are derived. These materials include the following petrochemicals: methane, ethylene, acetylene, propylene, butadiene, and BTX (benzene, toluene and xylenes) as well as cellulose, sulfuric acid and chlorine. For the major plastic resins, capital investments and utility consumption are presented for the polymerization step.

1.2 DEFINITIONS

A plastic can be defined as a material derived from an organic polymeric resin that is formed into a finished product by the application of pressure and/or heat. A typical plastic will contain, in addition to resin that identifies it generically, a series of additives such as colorants and antioxidants, as well as fillers and reinforcements which modify the properties of the contained resin in order to have an optimum formulation for the particular application envisioned.

The plastics industry can be most conveniently divided into the following major groups:

a. The manufacture of monomers from basic petrochemicals and intermediates. In some instances, such as ethylene and propylene used in the manufacture of polyethylene and polypropylene, the basic petrochemicals are also the monomers.

b. The manufacture of the polymeric resins from the required monomer (s).

c. The manufacture of a specific plastic formulation which entails the addition of additives such as plasticizers, reinforcements, antioxidants, fillers, blowing agents, colorants, flame retardants, etc. to the polymeric resin.

d. The formation of a specific plastic object by operations such as molding, extruding, laminating, etc., which usually entail the application of heat and pressure. In some instances, a post-forming machining operation may be performed.

This report specifically focuses on the manufacture of the polymeric resins and their monomers. It does not cover the manufacture of additives, operations of plastic compounders, or plastic processors. Some information on these aspects of the plastics industry are discussed in periodic reviews published in journals such as Modern Plastics[1] and the Society of the Plastics Industry.[2]

1.3 SOURCES OF COMMERCIAL DATA ON THE PLASTICS INDUSTRY

Sales statistics for the major plastics resins are compiled on a standing basis by Ernst and Ernst, a large accounting firm, for the Society of the Plastics Industry, New York, N.Y. Nathanson recently described[3] the operations of the SPI Committee on Resins Statistics which makes available the following documents: Monthly Plastics Resin Reports, Annual Engineering and Specialty Resin Survey, Annual Major Market Survey, Annual Dollar Sales, and Annual Capacity Survey (Thermoplastic Resins Only). This information forms the basis of the annual yearbook of the Plastics Industry[2] published by the SPI. A shortcoming of the survey is that the final information for a given year is published only in July of the following year. This means that the SPI information for 1977 is not included in this present report.

A major trade magazine is Modern Plastics, which is published by McGraw Hill Book Publishing Co. of New York, N.Y. One of the features of the magazine is an industry review which is published in each January issue. This review publishes statistics on the consumption of the major plastics resins and identifies their consumption by major markets by cataloging the information both by plastic type and by market. Plant capacity data are also published for selected resins.

Final statistics on plastics consumption for the year prior to the previous year are published, as are preliminary statistics for the prior year, and projections for the forthcoming year. Since 1971, the final statistics published are those compiled by Ernst & Ernst for the SPI. Estimates for the prior year are based on SPI statistics for the first three quarters of the year, and are updated by a telephone survey by members of the magazine staff.

The telephone survey is also the basis of the projections for the forthcoming year.

Modern Plastics also periodically publishes (on an irregular basis) status reports on specific resin materials. Historical and projected markets for the resin, current and projected manufacturing capacity, and raw material availability and profitability are discussed.

Articles that discuss plastics consumption by specific markets, such as transportation, appear periodically in all the journals and magazines that cater to the plastics industry. In the United States, in addition to Modern Plastics, these include Plastics Engineering (published by the Society of Plastics Engineers), Plastics World (Cahner Publications, Boston, Mass.), and Plastics Technology, among others (A detailed list of trade publications is available from the SPI). In the past year, the American Chemical Society and American Chemical Marketing Association have sponsored symposia on the marketing of plastics to the transportation industry.

Periodic status reports on specific chemicals, published in the Chemical Marketing Reporter (New York, NY), provide extensive commercial data on many of plastic resin monomers and intermediates. Information of a similar nature that focuses on the petrochemical industry, is also published on a less regular basis in Chemical and Engineering News (published by the American Chemical Society, Washington, D.C.), and in Hydrocarbon Processing Magazine published by Gulf Publishing Co., Inc., as well as in other chemical engineering journals. Hydrocarbon Processing also publishes a quarterly plant construction survey of the petroleum and petrochemical industries. This survey lists new processing plants under construction, and usually identifies the owner, the contractor, the location, the products being made, and the status of the project. It may also contain information on the process being used, the licensee, plant capacity, and required capital investment. A similar survey is compiled by European Chemical News, a magazine published in London.

2. AUTOMOTIVE USE OF PLASTICS

2.1 PLASTICS CONSUMPTION DATA

As shown in Table 1 and Figure 1, plastics consumption in the United States has risen from 7.2 million metric tons in 1968 to 14.8 million tons in 1977 which corresponds to an average compounded growth rate of 7.4 percent per year over that period. Plastics consumed in the manufacture of U.S. passenger automobiles increased from 387,000 metric tons in 1969 (no data were available for 1968) to 797,000 metric tons in 1977, which corresponds to an average compounded rate of growth of 8.4 percent over that period. For direct comparsion, total plastics consumption increased at an annual rate of 6.5 percent between 1969 and 1977. Prior to 1975, automotive plastics consumption ranged between 4.5 percent and 4.9 percent of total consumption. There was a significant jump in relative consumption in 1975 to 5.4 percent, and this level has been maintained since then.

2.2 PLASTICS IN AUTOMOBILES

The major plastics consumed in the manufacture of automobiles in the United States are listed in Table 2. The amounts of these materials consumed in the manufacture of 1977 model year passenger cars are compared to the total U.S. consumption during calendar year 1977. In 1977, the most important plastics for the automotive industry were, in decreasing order: polyurethane, polypropylene and its copolymers, polyvinyl chloride, thermosetting polyester resins and ABS (acrylic-butadiene-styrene) resins. The consumption of the other resins was less than 50,000 metric tons per year.

In terms of market share, the relative order of importance was as follows: thermoplastic polyester, polyacetal, polyurethane, nylon, ABS and unsaturated polyester resins. For these resins, passenger vehicles represented at least 15 percent of the total market. Passenger vehicles consume an extraordinarily high fraction of the output of thermoplastic polyesters which is a

TABLE 1. COMPARISON OF AUTOMOTIVE USE OF PLASTICS TO TOTAL U.S. PLASTICS CONSUMPTION (1968 - 1977)

YEAR	A) TOTAL PLASTICS SALES	B) PLASTICS CONSUMPTION BY U.S. PASSENGER AUTOMOBILES	RATIO $\frac{B}{A}$x100
	10^3 METRIC TONS/YEAR		PERCENT
1968	7264		
1969	8412	387	4.6
1970	8898	420	4.7
1971	9030	439	4.9
1972	11597	522	4.5
1973	13152	623	4.7
1974	12932	577	4.5
1975	10672	578	5.4
1976	13234	728	5.5
1977	14791	797	5.4
Average Annual Growth Rate			
1968-1977	7.4%		
1969-1977	6.5%	8.4%	

Source: Reference 1, Annual Industry Review in January Issue.

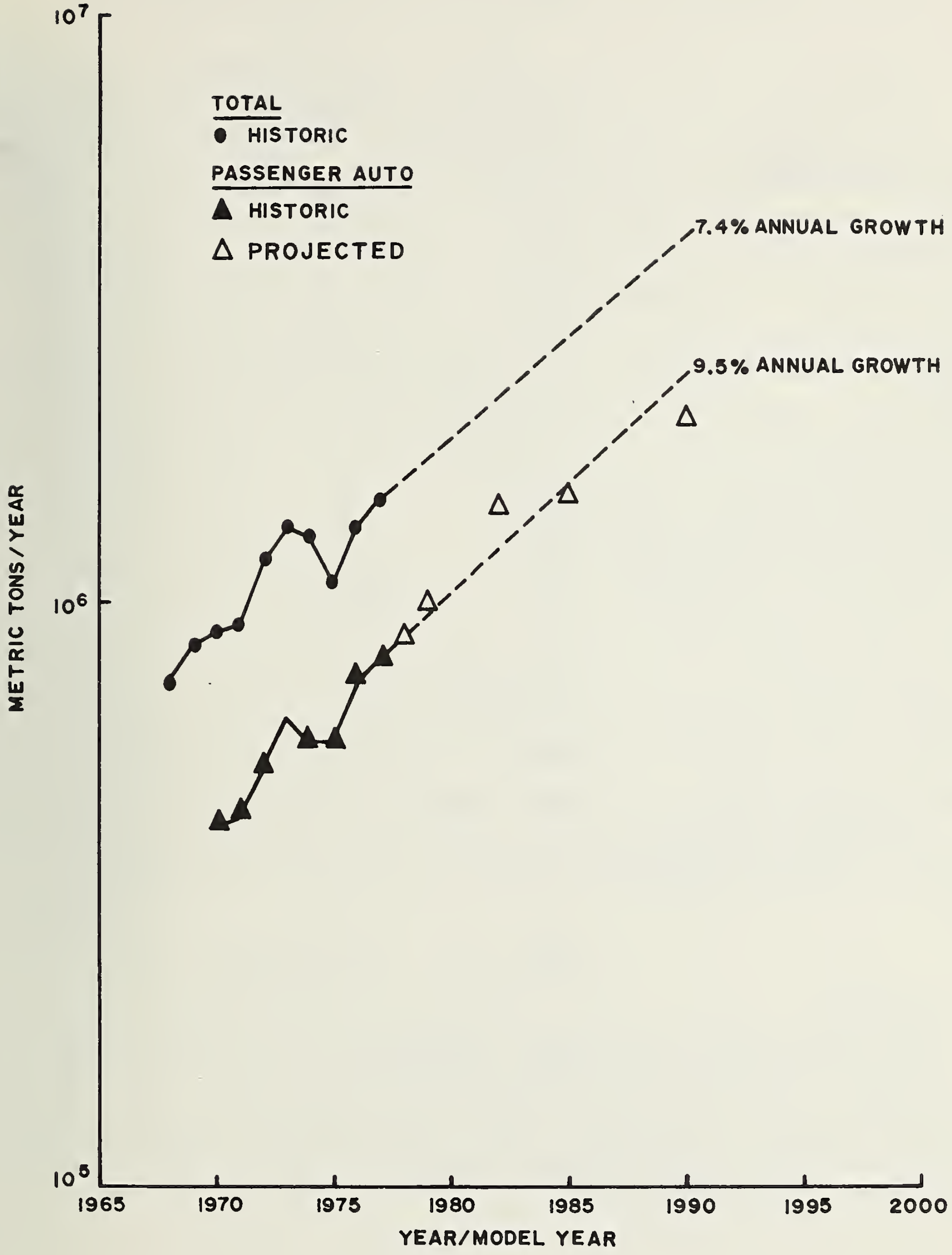


FIGURE 1. TOTAL PLASTICS CONSUMPTION & PASSENGER AUTO CONSUMPTION

TABLE 2. CONSUMPTION OF PLASTICS MATERIALS 1977 U.S. TOTAL and 1977 MODEL YEAR PASSENGER AUTOMOBILES

Materials	1977 Total U.S. Consumption 1000 Metric Tons	1977 Model Year Passenger Car Consumption 1000 Metric Tons	% Passenger Cars / Total U.S. Consumption
ABS	468	70	15.0
Acrylic	240	20	8.3
Cellulosics	67	7	10.4
Nylon	110	20	18.2
Phenolic, Total (Molding Powder)	638 (158)	22 (22)	3.4 (13.9)
Polyacetal	42	10	23.8
Polycarbonate	57	3	5.3
Polyethylene, High Density	1620	24	1.5
Polyethylene, Low Density	2939	1(a)	0.1
Polypropylene and Copolymers	1247	140	11.2
Polystyrene, (Molding Powder)	2010 (711)	2 (2)	0.1 (0.3)
Polyurethane(b)	811	182	22.4
Polyvinyl Chloride(c)	2380	135	5.7
Polyester, thermoset, (RP = polyester/glass)	477 (700)	72(a) (135)	15.0 (19.3)
SAN (Styrene-acrilonitrile)	50	4	8.0
Polyester, thermoplastic	21	9	42.9
Other	1614	15	0.9
	14791	736 (797)	5.0

a) Estimated.
b) Padding and Upholstery Foams, elastometric and microcellular bumper materials, rigid foams and TPU's.
c) Upholstery Materials, extruded flexibles and semi-rigid compounds.
d) Noryl phenylene oxide based resin, polysulfone, thermoplastic elastomers and rubbers, fluoroplastics, alkyds, epoxy, urea and melamine, silicones, etc.

Source: Reference 1, Plastics Industry Reviews January 1977 and January 1978 (other than for estimates) relatively new family of high performance engineering plastics.

The combined passenter vehicle consumption of the plastic resins grouped in the other category represents approximately 0.9 percent of the total consumption by passenger automobiles, or about 3 lbs/vehicle. Epoxy resins and Noryl phenyleneoxide based resins are the most important of this group. Approximately 8,500 tons of epoxy resins went into automotive body primary paints (Modern Plastics January 1977). This corresponds to about 2 lbs/car. Epoxy resins are also used in reinforced plastics for aerospace uses and may find greater use in the automotive industry if rapid curing, low cost formulations are developed. Noryl phenylene oxide resin is an engineering plastic manufactured by the General Electric Co. that has been used, on a limited basis, in automotive applications such as dashboards, grilles and trim and wheel covers; and as such, it is a potential competitor for ABS. It is, however, more expensive. Current automotive sales are estimated to be of the order of 1000 tons/year to 2000 tons/year. Since Noryl is a proprietary product manufactured by only one manufacturer, there is little specific published market information available. Growth rates and patterns of this resin are expected to be similar to that of other engineering thermoplastics (nylon, polycarbonate polyacetal and thermoplastic polyester). These miscellaneous resins will not be discussed further in this report.

2.3 VALUE OF THE AUTOMOTIVE MARKET TO THE PLASTICS INDUSTRY

Representative prices, as of January 1, 1978, of plastic resins used in passenger automobiles are presented in Table 3. These prices were multiplied by the consumption values presented in Table 2 to obtain the gross sales values presented in Table 4. As a first approximation, plastic resin sales in 1977 were nearly $14 billion dollars. Plastic sales for passenger automobiles were $720 million or 5.1 percent of the total. Polyurethanes sales represented nearly 22 percent of total automotive plastics sales. Sales of the following for plastics resins: polyurethane, polypropylene, polyvinylchloride, and ABS accounted for nearly 60 percent

TABLE 3. PRICE OF PLASTIC RESINS USED IN PASSENGER AUTOMOBILES AS OF JANUARY 1, 1978

	Price, ¢/lb (a)
ABS	
Medium Impact	57
High Impact	61
Acrylic Molding Powder	56
Cellulosics	
Acetate	83
Butyrate	86
Propionate	85
Nylon 6	116
Nylon 6/6	116
Nylon 11	207
Phenolic Molding Compound	47
Polyacetal	94
Polycarbonate	109
Polyester, unsaturated (thermoset)	36
Polyester, Thermoplastic (PBT)	98
Polyethylene High Density, GP Blow Molding	31 3/4
Polyethylene, Low Density, Injection Molding	31 1/2
Polypropylene	
G-P Homopolymer	30
Medium and High Impact Copolymers	33-35 1/2
Polystyrene, High Impact	29
Polyurethane	
Polymeric MDI	58
Polymeric TDI	54
Flexible Slabstock Polyol	35
Thermoplastic PUR	135
Polyvinyl Chloride	
Homopolymer, dispersion	39
Homopolymer, suspension	27
Styrene-Acrylonitrile (SAN)	40

(a) Prevailing list price in largest bulk quantity. General Purpose (GP) resin unless otherwise specified.

Sources: Reference 1, p. 55, January 1978

TABLE 4. ESTIMATED VALUE OF PLASTIC SALES IN 1977

	Unit Price ¢/lb	Value 1977 Total U.S. Consumption Million Dollars	Value 1977 Model Year Automobile Consumption Million Dollars
ABS	59	609.	91.0
Acrylic	56	296.	24.6
Cellulosics	85	126.	13.1
Nylon	116	281.	51.2
Phenolic (Molding Powder)*	47	661.	22.8
Polyacetal	94	87.	14.5
Polycarbonate	109	14.	9.6
Polyethylene HD	32	1143.	4.6
Polyethylene LD	32	2073	0.7
Polypropylene & Its Copolymers	35	962.	107.7
Polystyrene (Molding Powder)*	29	1285. (455)	1.3 (1.3)
Polyurethane**	43	769.	170.6
Polyvinyl Chloride	33	1731	95.2
Polyester Unsaturated	36	379	56.8
Polyester Thermoplastic	98	45	19.5
SAN	40	19	1.5
Other	100***	3500	33.0
Total		13980	717.4 ≃ 720

*Molding Powder Value assumed for different grades
**Assumes 60% polyol @ 35¢/lb and 40% isocyanate @ 56¢/lb
***Assumed Value

of plastic sales. The addition of nylon and unsaturated polyester to these four increases the sales fraction to 74 percent, or $572 million. Automotive sales of these six resins were all in excess of $50 million in 1977. The value of the passenger automobile market for all the other plastic resins was less than $25 million for any resin.

2.4 PROJECTED FUTURE USE OF PLASTICS IN AVERAGE PASSENGER AUTOMOBILES

The weight reduction programs that will be undertaken by the major U.S. automobile manufacturers will create new applications for plastic materials. The technical literature has been replete with articles on the manufacture of a specific part by a specific plastic, highlighting potential weight savings and cost benefits. A number of articles on the increased use of plastics in automobiles have appeared in the trade press, which discuss the projected increased automotive consumption of specific plastics.[2,4,5,6] The general consensus is that the plastics content of an average automobile will increase from about 80 kg (177 lbs) in 1976 to 90 kg (200 lbs) to 100 kg (220 lbs) in 1980, up to about 120 kg (260 lbs) to 160 kg (350 lbs) by 1985, and possibly up to as much as 250 kg (550 lbs) by 1990.

Some key results of a proprietary study prepared last year by Predicasts Inc. on the automotive markets for plastics were published in a review article in Plastics World.[4] These results have appeared or have been quoted in a number of subsequent articles and discussions on the topic,[7,8] thereby conferring better than average credibility to these results.

Projected applications of plastics in a typical car, published in the above mentioned review, are outlined in Table 5. Interior applications, which are currently the major consumers of plastics, would increase by 50 percent by 1990 as compared to 1976. Exterior applications are projected to increase by 450 percent, and functional applications by 350 percent. Overall plastics consumption would increase from 169 lbs (77 kg) in 1976 to 477 lbs (217 kg) in 1990, a nearly threefold increase. This

TABLE 5. PROJECTED AUTOMOTIVE USES OF PLASTIC MATERIALS

A. Interior applications for plastics, lb/car

	All Mat'ls	Plastics			
	1976	1976	1980	1985	1990
Seats and Padding	112	28	36	46	57
Instrument and door panels	22	12	14	15	16
Steering parts	15	5	5	6	6
Liners	8	8	8	-	-
Upholstery	9	6	6	6	6
Other*	94	22	26	28	29
TOTAL	260	81	95	108	121

*Visors, padding, trim moldings, instruments, lighting, armrests, handles, carpets, radio, housings, etc.

B. Exterior applications for plastics, lb/car

	All Mat'ls	Plastics			
	1976	1976	1980	1985	1990
Bumper system	220	3	16	27	36
Hood, roof, doors, trunk lid, fenders	496	neg.	2	47	84
Fender liners, extensions	25	6	14	18	19
Front end panels	35	8	13	15	17
Glazing	82	1	1	1	1
Grille, trim, lenses	26	15	17	18	19
Roof, vinyl	5	3	2	2	2
Other*	155	12	16	26	38
TOTAL	1044	48	80	154	216

*Retainers, underbody panels, scoops, spoilers, louvers, wheel covers, rocker panels, lamp housings, etc.

C. Mechanical, electrical, under-hood applications, lb/car

	All mat'ls	Plastics			
	1976	1976	1980	1985	1990
Engine, transmission, drive train	926	1	2	4	15
Steering, suspension, braking, fuel, exhaust, emission and cooling systems	516	9	16	30	41
Air comfort	80	14	16	17	18
Electrical, ignition	88	13	16	20	21
Frame and structural parts	245	neg.	2	8	19
Other*	538	3	5	10	28
TOTAL	2391	40	57	89	140

*Wheels, hubs, windshield wiper system, tires, fluids, lubricants, adhesives, sealants, paints, fastners etc.

D. Overall Vehicle, lb/car

	All mat'ls 1976	1976	1980	1985	1990
Grand Total	3695	169	232	351	477

Source: Plastics World, May 1977, p. 40

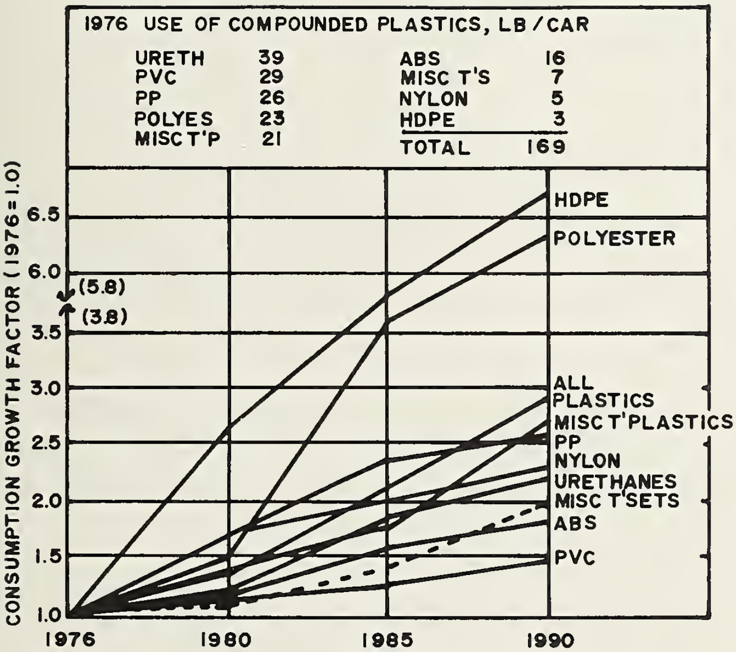
corresponds to an annual growth rate in plastics consumption per vehicle of 7.2 percent.

This specific growth rate is slightly lower than the growth rate of overall plastics consumption by the passenger automobile manufacturers in the 1969 to 1977 period. Projected consumptions for 1980 to 1990, based on the above plastics consumption per vehicle and an assumed automobile production level of 8.5 million automobiles per year (the same as in 1976), are also presented in Figure 1.

The projected consumption levels of specific plastics by the producers of passenger automobiles during the same time frame, presented in the review, are shown in Figure 2. This figure has been published elsewhere.[4] According to this prediction, the specific consumption of high density polyethylene and polyester resins will increase approximately 6.5 fold, which corresponds to an average compound rate of growth of 13 percent per year. The average growth rates of other plastics through 1990 are much more modest, ranging from an average of 2.5 percent per year for PVC to 6.4 percent for polypropylene. These growth rates are in accord with the historical growth rates of the automotive market for these plastics, as discussed in the appendices.

The data presented in Figure 2 are used to calculate the difference in weight of these various plastics in an average 1976 and an average 1990 passenger automobile. These data, shown in Table 6, indicate that thermosetting polyester resins will be the plastic resins most severely impacted. The average weight of polyester resins on an automobile will increase by 127 lbs. This is more than 40 percent of the projected weight increase of all plastics in an average automobile. The content of polyurethanes is expected to increase by 46 lbs, and that of polypropylene by 44 lbs. On a weight basis, these three resins will account for 70 percent of the total projected plastics increase.

The Plastics World projections are compared in Table 7 with other prognostications and data. The Modern Plastics references relates to the data for 1977 and projections for 1978 published in



1976 USE OF COMPOUNDED PLASTICS, LB/CAR

URETH	39	ABS	16
PVC	29	MISC T'S	7
PP	26	NYLON	5
POLYES	23	HDPE	3
MISC T'P	21	TOTAL	169

DATA IN GRAPH AND TABLES EXCERPTED FROM "*PLASTICS IN AUTOMOBILES: OEM & AFTERMARKET*," MAY, 1977, PREPARED AND PUBLISHED BY PREDICASTS, INC., CLEVELAND, OHIO.

SOURCE:
REFERENCE 4, MAY 1977, P. 41

FIGURE 2. GROWTH PROJECTIONS FOR AUTOMOTIVE PLASTICS 1976-1990

TABLE 6. INCREASE IN AVERAGE WEIGHT OF VARIOUS PLASTICS PER AUTOMOBILE BETWEEN 1976 - 1990

	Projected weight/car in 1990, lbs	1976 weight/car lbs	Δ, lbs
Polyurethanes	85	39	46
Polyvinylchloride	42	29	13
Polypropylene	70	26	44
Polyester	150	23	127
ABS	28	16	12
Nylon	11	5	6
High Density Polyethylene	20	3	17
Miscl. Thermoplastics	58	21	37
Miscl. Thermosets	14	7	7
Total	477	169	308

Source of Data: Reference 4, May 1977, p. 41.

TABLE 7. PUBLISHED PROJECTIONS OF PLASTICS CONSUMPTION IN AUTOMOBILES

	1976	1977	1978	1980	1985	1990
	Average Automotive Consumption (lbs/vehicle)					
<u>Total</u>						
Modern Plastics (1/78)		192	200			
Plastics World (5/77)	169			220	370	490
SPI 1977 YB.		165		191		
<u>ABS/SAN</u>						
Modern Plastics (1/78)						
Plastics World (5/77)	16			19	25	28
SPI 1977 YB						
<u>Polypropylene</u>						
Modern Plastics (1/78)		33	36			
Plastics World (5/77)	26			44	60	68
SPI 1977 YB		28		35		
<u>Polyurethane</u>						
Modern Plastics (1/78)		43	45			
Plastics World (5/77)	39			52	75	85
SPI 1977 YB		30		40		
<u>Polyvinyl Chloride</u>						
Modern Plastics (1/78)		31	31			
Plastics World (5/77)	29			33	36	42
SPI 1977 YB		20		17		
<u>Thermoset Polyester</u>						
Modern Plastics (1/78)		32	36			
Plastics World (5/77)	23			35	38	145
SPI 1977 YB		40		52		

Modern Plastics, based on the 1977 model year vehicle production of 9.1 million passenger automobiles. The SPI 1977 YB reference relates to the section on automotive plastics published in the 1977 SPI Yearbook. There appears to be generally good agreement for the near term between the figures derived from Modern Plastics and Plastics World. The figures that appeared in the SPI document tend to be lower.

2.5 PROJECTED DEMAND FOR AUTOMOTIVE PLASTICS IN 1988

The projected 1988 demand for each of the automotive plastics listed in Table 2 are estimated from the slopes of the historic trend lines, and published predictions are factored in where applicable. These projections are based on the histographs presented in the appendices of this report. Projected total consumption, and automotive consumption of the various automobile plastics in 1988, are presented in Table 8 and are compared with 1977 consumption. Ten year projections are volatile exercises in prediction since a small variation in compounded growth rate results in a large error in the absolute value of projected demand. That is, an assumed average growth rate of 5 percent per year results in a 63 percent increase in 10 years, whereas, a growth rate of 8 percent per year results in a 2.2 fold increase in demand over the same period.

The projected growth rates for total consumption of engineering thermoplastics (except polycarbonate) are lower than the 1981 projections published recently by Nathanson.[9] The polypropylene projections of about 10 percent growth are more conservative than Stover's estimates of 12 to 13 percent growth through 1981.[10] The projected consumption of unsaturated polyester agrees with projections published by Business Communications Co. (BCC), but the calculated growth rates do not.[11] The projected growth rate of 15.6 percent for PBT thermoplastic polyesters is more conservative than Nathanson's and BCC's estimates of 22 to 25 percent per year. It is hard to predict whether the rapid growth of PBT resins can be maintained.

TABLE 8. PROJECTED 1988 DEMAND FOR AUTOMOTIVE PLASTICS

Plastic	Total U.S. Consumption			U.S. Automobile Consumption		
	1977	1988	Effective Growth Rate %	1977	1988	Effective Growth Rate %
	10^3 Metric Tons/year			10^3 Metric Tons/year		
ABS	468	1000	6.5	70	125	5.0
Acrylic	240	400	4.3	20	70	11.0
Cellulosic	67	54	(1.8)	7	6	(1.3)
Nylon	110	310	9.0	20	60	9.6
Phenolic M.P.	158	260	4.2	22	20-40	0-5
Polyacetal	42	75	5.0	10	15	6.6
Polycarbonate	57	210	11.5	3	10	7.9
Polyethylene H.D.	1620	5000	9.8	24	80	10.6
Polyethylene L.D.	2939	7000	7.5	1	1	0
Polypropylene	1247	4000	10.2	140	400	9.1
Polystyrene	2010	3000	3.4	2	1	(5.6)
Polyurethane	811	1800	6.9	182	400	6.8
Polyvinyl chloride	2380	4900	6.2	135	260	5.6
Unsaturated Polyester	477	1100	7.2	72	350	14.1
Thermoplastic Polyester	21	120	18.6	9	49	15.2
SAN	50	100	5.9	4	5	1.9
Total Plastics*	14791	35000	7.4	736	2200	9.5

*includes others

Based on the data presented in Table 8, total consumption of automotive plastics in 1988 will increase by approximately 20 million metric tons, or about 2.3 times the 1977 demand. Use of these plastics in passenger automobiles will increase by 1.5 milion metric tons, or approximately three times the 1977 demand.

In terms of the projected automobile market, thermosetting and thermoplastic polyesters will have the highest growth rates (14 to 15 percent per year) followed by acrylics, high density polyethylene, nylon and polypropylene (9 to 11 percent). There will be a loss in demand, or a slight increase at best, for cellulosics, phenol, low density polyethylene, polystyrene and SAN.

Highest increases in automotive demand on a tonnage basis will be for unsaturated polyester, polypropylene and polyurethane resins. The automotive demand for each of these three materials will increase by more than 200,000 metric tons/year. The demand for PVC will increase by 130,000 tons per year, and by more than 70,000 tons a year for high density polyethylene. These resins will account for 66 percent of the increased plastics consumption by passenger car manufacturers.

2.6 RESIN MANUFACTURING CAPACITY REQUIREMENTS NEEDED TO MEET 1988 DEMAND

Current nominal operating capacities of U.S. manufacturing facilities for the major plastic resins are listed in Table 9. More details are presented in the appendices. This nominal or nameplate capacity is typically 10 to 20 percent higher than the effective plant capacity, a number which takes into account down time for maintenance and repairs. A measure of current overcapacity is obtained by subtracting 1977 consumption from the effective capacity in place on January 1, 1978. These figures are also presented in Table 9.

Table 10 presents projected increases in manufacturing capacity that would be required to meet the forecasted 1988 demand for the various automotive plastics of interest. The total projected increase in demand is multiplied by 1.25, and any current over

TABLE 9. COMPARISON OF PROJECTED INCREASES IN TOTAL AND PASSENGER CAR PLASTICS CONSUMPTION AND CURRENT OVER-CAPACITY OF AUTOMOTIVE PLASTICS (10^3 METRIC TONS/YEAR)

	Capacity Nominal	(1/178) Effective (80% Nominal)	Current Consumption (1977)	Current Over-Capacity	Projected Auto Use Increase 1977-1988	Projected Increase in Total Use 1977-1988
ABS	655	524	468	56	55	530
Acrylic	500	400	240	160	50	160
Cellulosic			67		(1)	(13)
Nylon	150	120	110	10	40	200
Phenolic M.P.	210	168	158	10	0-20	100
Polyacetal			42		8	33
Polycarbonate			57		6	150
Polyethylene L.D.	3600	2880	2939	-	-	4100
Polyethylene H.D.	2165	1732	1620	112	74	3400
Polypropylene	1717	1373	1247	126	260	2800
Polystyrene			2010		(1)	1000
Polyurethane			811		220	1000
Polyurethane Precursors						
Polyol	835	668	590	78	140	590
TDI	383	306	280	16	120	430
MDI	242	194	190	4	30	290
Polyvinyl Chloride	3195	2556	2380	176	130	2500
Unsat'd Polyester	900	720	477	243	280	620
Thermoplastic Polyester			21		31	100
SAN	140	112	50	62	1	50

TABLE 10. PROJECTED EXPANDED PLASTICS MANUFACTURING CAPACITY REQUIREMENTS NEEDED TO SUPPORT 1988 DEMAND FOR AUTOMOTIVE PLASTICS

Plastic	Total Demand Projected Increase	Auto Use Projected Increase	Gross Required Additional Capacity[1]	Current Overcapacity	Net Additional Capacity Required	Additional Capacity Allocated Automotive Needs[2]
	10^3 Metric Tons/Year					
ABS	530	55	663	56	607	63
Acrylic	160	50	200	50	150	47
Cellulosic	(13)	(1)	-	No Data	0	0
Nylon	200	40	250	10	240	48
Phenolic MP	100	0-20	125	10	115	0
Polyacetal	33	8	41	No Data	41	11
Polycarbonate	150	6	188	No Data	188	8
Polyethylene L.D.	4100	-	5100	-	5100	0
Polyethylene H.D.	3400	74	4260	112	4150	90
Polypropylene	2800	260	3500	126	3374	315
Polystyrene	1000	(1)	1250	500	750	0
Polyurethane Precursors						
Polyol	590	140	738	78	660	157
TDI	430	120	538	16	522	146
MDI	290	30	364	4	360	37
Polyvinyl Chloride	2500	130	3125	176	2949	153
Unsat'd Polyester	620	280	775	243	532	240
Thermoplastic Polyester	100	31	125	No Data	125	39
SAN	50	1	62	62	0	0

[1] Assuming 1.25 x Total Demand Increase

[2] Assuming Proportional Distribution to Auto Demand

capacity is subtracted. The ratio of projected increase in automotive demand to total demand is used to allocate additional plant capacity needed to support plastic made for passenger vehicles. These numbers are presented in the last column of Table 10.

2.7 PETROCHEMICAL RAW MATERIALS AND INTERMEDIATES

The polymeric resins of present interest are manufactured from intermediate chemicals derived mainly from petroleum or natural gas. In the appendices, synthesis flow diagrams are given for each of the automotive plastics which show a relationship between plastics output and intermediate and raw material requirements. Ultimately, all the polymers are derived from a limited number of basic petrochemicals, in addition to chlorine and sulfuric acid. Cellulosics also require cellulose derived from vegetable origin (wood or cotton). The basic petrochemicals are methane, which is purified natural gas, ethylene, propylene, butadiene, and key aromatics: benzene, toluene and xylene. The unit weights of the key precursor raw materials needed per unit weight of plastic produced for each of the automotive plastics of interest are given in Table 11. Depending on the products, from 0.5 lb to 3 lbs of basic hydrocarbons are needed per pound of polymer produced, with an additional 0.6 lb to 3.8 lbs of other chemicals required for five of the polymers. By-product acetone is formed for resins requiring phenol as an intermediate, and byproduct styrene may be formed for resins requiring propylene oxide, assuming this chemical is made by partial oxidation.

The current supply-demand situation for the primary petrochemical feedstocks, and chlorine and sulfuric acid is shown in Table 12. No data are given for methane or cellulose. As can be seen from this table, major expansions are planned in ethylene, propylene and benzene capacity to meet increasing demand mainly from the plastics industry. Most of the increased butadiene supply will come as a byproduct of ethylene and propylene manufacture, rather than from increased butane cracking (primary production). Toluene supply will depend, in part, on the petroleum industry's needs to upgrade the octane rating of the gasoline pool at the

TABLE 11: UNIT WEIGHT OF PRECURSOR RAW MATERIAL CONSUMED PER UNIT WEIGHT OF PLASTICS PRODUCED FOR THE VARIOUS AUTOMOTIVE PLASTICS

Material	C_1	C_2	C_3	C_4	BTX	Total HC	CE	CL	H_2SO_4	Total Other	By Product
ABS	0.14	0.15	0.46	0.35	0.35	1.45					
Acrylic	0.23			1.18		1.41					
Cellulosic		0.52				0.52	0.61			0.61	
Nylon	0.71				1.09	1.80					
Phenolic	0.31		0.45		0.78	1.54					0.51 Acetone
Polyacetal	0.82					0.82					
Polycarbonate	0.02		0.45		0.78	1.25		0.96		0.96	0.23 Acetone
Polyethylene H.D.		1.10				1.10					
Polyethylene L.D.		1.10				1.10					
Polypropylene			1.10			1.10					
Polystyrene		0.39			0.90	1.29					
Polyurethane											
TDI	0.52				0.68	1.20		2.99	0.77	3.76	
MDI	0.27		0.48		0.85	1.60		2.08		2.08	0.50 Acetone
Polyol		0.70	0.70		1.70	3.10					1.80 Styrene
Polyvinyl Chloride		0.50				0.50		0.60		0.60	
SAN	0.20	0.19	0.60		0.50	1.49					
Thermoplastic Polyester	0.05	0.25*			0.66	0.96					
Unsat'd Polyester		0.13	0.16		0.73	1.02					

Legend: CE = Cellulose CL = Chlorine HC = Hydrocarbons H_2SO_4 = Sulfuric Acid C_1 = Methane
C_2 = Ethylene or acetylene,* C_3 = Propylene C_4 = Butylene BTX = Benzene, Toluene, Xylene

TABLE 12. SUPPLY - DEMAND DATA OF PRIMARY CHEMICAL AND PETROCHEMICAL FEEDSTOCKS USED IN RESIN MANUFACTURE

Feedstock	Intermediates/Resins	Uses	Capacity 10^3 Metric Tons/Yr			Demand 10^3 Metric Tons/Yr		References
			1/1/78		Future	1977	Future	
Ethylene	Polyethylene	42%						
	PVC	12%	13,650		17,800 (1980)	11,190	15,100 (1980)	Chem. Eng. Prog., Jul 1977,p.6
	Polystyrene	8%					21,200 (1885)	C & E News, Nov 7, 1977, p. 11
	Ethylene oxide (Polyesters, polyurethanes)	21%						
Propylene	Polypropylene	22%	8,200		11,000 (1980)	5,700	7,100 (1980)	C & E News, Mar 27, 1979,p.115
	Acrylonitrile (ABS/SAN)	15%					11,500 (1985)	Hydrocarbon Proc., Nov 1976, pp. 12-13
	Propylene oxide (polyurethanes, polyesters)	17%						Chem. Eng. Prog., July 1977, p. 10
	Cumene (phenolics)	10%						C & E News, Nov. 7, 1977, p.12
Butadiene	ABS	11%	580	coproduct	1,860 (1985)	1,450	2,040 (1981)	Chem. Eng. Prog., Jul, 1977, p. 36
	Rubber	70%	670 200	primary imported	450 (1985) 450 (1985)		2,410 (1985)	C & E News, Nov. 7, 1977,p.14
Benzene	Styrene-(polystyrene, ABS, SAN, polyesters)	48%	5,700		8,200 (1981)	5,100	7,800 (1985)	Chem. Eng. Prog., Aug 1977, p. 14 C & E News, Nov 7, 1977, p.16
	Phenol - (phenolics)	19%						
	Cyclohexane (nylons)	15%						
	Aniline (MDI urethane)	4%						
	Maleic Anhydride (polyester)	3%						
Toluene	Gasoline	37%						Chem Eng.Prog. Aug 1977, p.10
	Benzene (see above)	25%	4,000		Total	3,700		
	TDI	3%			Chem.	2,300	2,790 (1980), 2,900 (1985)	
O-xylene	Phthalic anhydride (polyesters)	100%	655			428	633 (1982)	Chem. Mktg. Rptr, Apr 17, 1978 p. 9
P-xylene	Dimethyl terephthalate (thermoplastic polyester)	100%	1,730		2,030 (1979)	1,370	1,500 (1978)	C & E News, Nov. 7, 1977, p.21
Chlorine	Plastics (mainly PVC)	20%	11,300		12,500 (1979)	9,700	10,000 (1978)	C & E News, Feb 6, 1978, p. 9
Sulfuric Acid	Chemical Mfg.	5%	50,000			31,300	32,400 (1978)	C & E News, Mar 27, 1978, p.11

time. The calculated increased demand in these materials due to increased automotive use is presented in Table 13.

In 1988, plastics used in passenger vehicles would require about 2.8 million tons of basic hydrocarbon petrochemicals (not including 0.5 million ton organic by-products), about 1.1 million tons of chlorine, 0.2 million tons of sulfuric acid and 4000 tons of cellulose. As compared to 1977 use, the hydrocarbon consumption would be 62 percent higher, consumption of chlorine and sulfuric would be approximately twice as high, while cellulose consumption would decrease.

Assuming a 10 percent processing penalty to transform petroleum into the petrochemicals, and an automobile production of 8.5 million vehicles, a projected equivalent petroleum consumption of 133 gallons per 1988 automobile will be contained in the plastics used on the car. The equivalent number for 1977 passenger automobiles is 48 gallons per automobile.

The supply-demand situation for most of the key petrochemical intermediates is summarized in Table 14. Among these products, there is current excess capacity (assuming 80 percent effective capacity) for maleic anhydride, styrene, ethylbenzene, propylene oxide, propylene glycol, ethylene glycol, formaldehyde, cyclohexane and caprolactam. However, the current capacity of any of these intermediates is not sufficient to meet the additional 1988 demand engendered by the growth of the plastics industry, and additional manufacturing facilities will be required. If required, the additional demand, and commensurate additional manufacturing capacity required for each of these intermediates, can be calculated from the synthesis diagrams given in the appendices and the data presented in Table 14.

2.8 CAPITAL INVESTMENT REQUIREMENTS

In order to be able to support the increase in plastics demand projected for 1988, significant plant expansions will be required by the manufacturers of polymeric resins, as outlined in Table 10, and by the manufacturers of the various basic and

TABLE 13: RAW MATERIAL REQUIREMENTS FOR PROJECTED PLASTICS UTILIZATION IN M.Y. 1988 PASSENGER AUTOMOBILES

Plastic	Annual Consumption 10^3MT/YR			Projected 1988 Raw Material Consumption, 10^3MT/YR					Projected Increase in Raw Materials Consumption 1988 vs 1977, 10^3MT/YR				
	1988	1977	Delta	HC	CE	CL	H_2SO_4	Credits	HC	CE	CL	H_2SO_4	Credits
ABS	125	70	55	180					80				
Acrylic	70	20	50	99					71				
Cellulosic	6	7	(1)	3	4				(1)	(1)			
Nylon	60	20	40	108					72				
Phenolic	22	22		34				11 (acetone)					
Polyacetal	15	10	5	12					62				
Polycarbonate	10	3	7	13		10		2 (acetone)	9		7		2
Polyethylene HD	80	24	56	88					62				
Polyethylene LD	1	1	-	1					-				
Polypropylene	400	140	260	440					286				
Polystyrene	1	2	(1)	1					(1)				
Polyurethane													
TDI	260	140	120	312		777	200		144		359	92	
MDI	65	35	30	104		135		32 (acetone)	48		62		25
Polyol	304	164	140	868				504 (styrene)	570				331
Polyvinyl chloride	260	135	125	130		156			63		75		
SAN	5	4	1	7					1				
Thermoplastic Polyester	49	9	40	47					38				
Unsat'd Polyester	350	72	278	357					284				
Total				2,805	4	1,078	200	549	1,732	(1)	503	92	348

Petroleum Equivalent including 10% processing penalty $3085 = 27.0 \times 10^6$ BBl/yr $1905 = 16.7 \times 10^6$ BBl/yr

Legend: CE = Cellulose CL = Chlorine HC = Hydrocarbons H_2SO_4 = Sulfuric Acid

TABLE 14: SUPPLY-DEMAND DATA FOR SELECTED PETROCHEMICAL INTERMEDIATES USED IN RESIN MANUFACTURE

			Design Capacity 10^3 Tons/Yr		Demand	10^3 MT/YR	
Intermediate	Resins	Uses	1977	Future	1977	Future	References
Phthalic Anhydride	Polyesters, thermoset (plasticizer)	20% 53%	550	704 (1980)	454	570 (1981) 726 (1985)	C & E News, Oct 31, 1977,pp.8 9 Chem Mkt Rptr, Feb 7, 1977,p.9
Maleic Anhydride	Uns. Polyesters	58%	238		125	164 (1978)	Chem Mkt Rprtr, Feb 13; 1978,p.9
Styrene	ABS & SAN Polystyrene Polymers Uns. Polyesters	12% 60% 8%	3986	4580 (1980)	3000	3650 (1981)	C & E News, Aug. 15, 1977, p.10 Chem Mkt Rptr, May 9,1977,p.137 Hydrocarbon Processing, July 1977, p. 137 Chem Eng. Prog. Nov 1977, p. 35
Ethyl Benzene	Styrene	100%	5083		3098	3954 (1982)	Chem Mkt Rptr, Mar 27, 1978,p.9
Propylene Oxide	Polyurethane Foams Unsat'd Polyesters	58% 20%	1180		860		C & E News, Aug 15, 1977
Propylene Glycol	Polyesters	45%	379		256	332 (1981)	Chem Mkt Rptr, May 2, 1977, p.9
Ethylene Glycol	Polyesters (including) (textiles)	50%	2600	3000 (1979)	1580	1730 (1978)	C & E News, Dec 5, 1977, p. 12
Acrylonitrile	ABS/SAN	20%	935	1090 (1980)	755	969 (1980)	Chem Eng Prog, Nov. 1977, p. 42
Formaldehyde (37% basis)	Phenolic Resins Polyacetal 1-4 butanediol	25% 9% small	4090	4135 (1978)	2763	3526 (1982)	Chem Mkt Rptr, Jan 23, 1978,p.9
Phenol	Phenolic Resins Caprolactam (nylon)	40% 15%	1343	1760 (1981)	1095	1360 (1982)	Chem Mktg Rptr, Feb 6, 1978,p.9
Cyclohexane	Nylons	81%	1300		1020	1190 (1980)	Chem Eng Prog, Sept.1977, p. 25 Chem Mktg Rptr, Jan 24, 1977, p. 9 C & E News, Dec 5, 1977, p. 15
Caprolactam	Nylon 6	100%	508		386	431 (1981)	Chem Mktg Rptr, Dec 19, 1977, p. 9
Adipic Acid	Nylon 6-6 Polyurethane	90% 4%	842		838	926 (1982)	Chem Mktg Rptr, Feb 20, 1978, p. 9
Bisphenol A	Epoxy Polycarbonate	47% 40%	236	381 (1979)	209	318 (1981)	Chem Mktg Rptr, Sept. 18. 1977, p. 9

intermediate compounds necessary to the manufacture of these resins. As listed in Table 15, approximately seventy-five different compounds are involved in the manufacture of the key automotive plastics. Any projections of the capital investments required to support the additional plastics consumption by the passenger automobile manufacturer, have to take into account the capital investments needed to enlarge the manufacturing facilities needed to make the intermediate chemicals as well as the investments needed for the enlargement of the polymeric resin plants.

There are a number of different ways of estimating the cost of constructing a chemical plant. For purposes of this study, summary cost data published in the literature and adjusted for capacity and inflation were deemed sufficiently accurate. While it is feasible to project for 1988 the need for an additional 530,000 metric tons of unsaturated polyester capacity, and assign 240,000 metric tons of that total to the passenger automobile market, it is not possible to specify the exact number of plants that will be built, or their locations or capacities. These will all influence the required capital investment. The capital investment per annual ton of product usually decreases with increasing capacity. The relative capital investments needed for two similar chemical plants of different capacities can be expressed by the following equation:

$$\frac{CA}{CB} = \frac{A}{B}^{m}$$

where

CA = cost in dollars of a plant of capacity A

CB = cost in dollars of a plant of capacity B

m = exponent.

Depending on the process, m may vary from 0.5 to 1.0. For most chemical processes $m \approx 0.65 - 0.70$.

With inflation, plant costs have risen rapidly over the past decade. The effect of time on building costs is given by several indices, which are used to determine the costs in year A if they

TABLE 15. LIST OF PRODUCTS UTILIZED OR FORMED IN MANUFACTURE OF AUTOMOTIVE PLASTICS (Sheet 1 of 2)

A

ABS polymer
Acetaldehyde
Acetic acid
Acetone
Acetone cyanohydrin
Acetylene
Acrylic Resins
Acrylonitrile
Adipic acid
Adiponitrile
Ammonia
Aniline

B

Benzene
Bisphenol A
Butadiene
1,4 Butanediol
Butyric acid

C

Caprolactam
Carbon monoxide
Cellulose
Cellulosic resins
Chlorine
Cumene
Cyclohexane

D

1,4 Dihydro-2-butyne
Dimethyl Terephthalate
Dinitrotoluene
Diphenyl methyl dianiline (DPMDA)

E

Ethylbenzene
Ethylene
Ethylene glycol

F

Formaldehyde

G

H

Hexamethylene diamine
Hydrogen
Hydrogen Cyanide

I

Isobutene

JKL

—

M

Maleic Anhydride
MDI
Methacrylic acid
Methane

TABLE 15. LIST OF PRODUCTS UTILIZED OR FORMED IN MANUFACTURE OF AUTOMOTIVE PLASTICS (Sheet 2 of 2)

Methanol
Methyl Methacrylate

N

Nitric Acid
Nylon 6
Nylon 6-6

O

—

P

Phenol
Phenolic Resins
Phosgene
Phthalic Anhydride
Polyacetal Resins
Polycarbonate Resins
Polyester, Unsaturated
Polyester, Thermoplastic (PBT)
Polyetherglycol
Polyethylene, low density
Polyethylene, high density
Polypropylene
Polystyrene
Polyvinyl chloride
Propionic acid
Propylene
Propylene glycol
Propylene oxide

QR

—

S

SAN Resins
Styrene
Sulfuric Acid

T

Terephthalic Acid
Toluene
Toluene Diamine
Toluene Diisocyanate

U

—

V

Vinyl acetate monomer
Vinyl chloride monomer

W

—

X

O - xylene
P - xylene

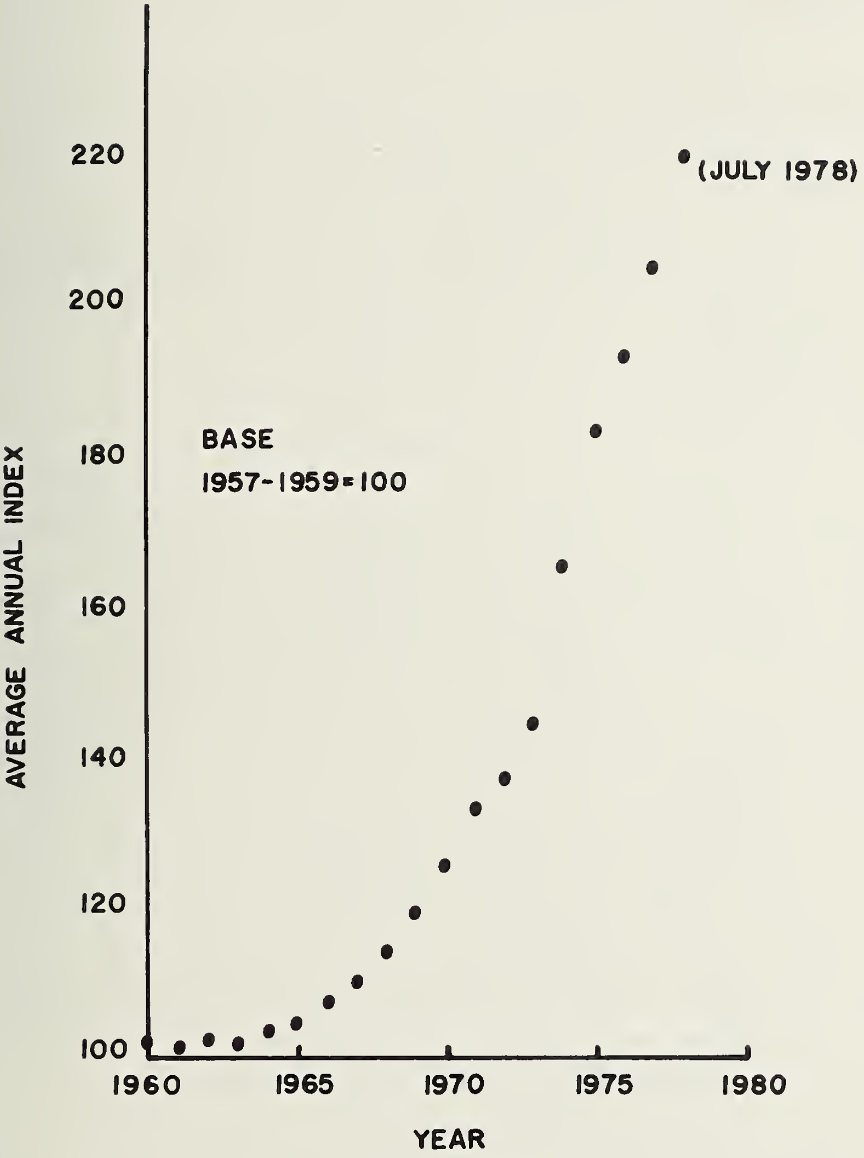
are known in year B, as per the following equation:

$$\text{Cost in Year A} = \frac{\text{Index in Year A}}{\text{Index in Year B}} \text{ (Cost in Year B)}$$

The Chemical Engineering Plant Cost Index (published in Chemical Engineering Magazine) and the Nelson Refinery Construction Index are the two indices most useful for estimating plant costs. The Chemical Engineering Index, which is used here, is reproduced in Figure 3. Costs were adjusted to January 1978, which had an index of 210.8.

There are a number of published sources of the capital investments required for various chemical plants: Guthrie,[12] and Heselbarth[13] collected investment data on numerous chemical plants in the late 1960's. Hahn also presented various capital cost estimates for a number of petro-chemical plants of the same era.[14] More recent data can be obtained from professional articles (for example, Stobaugh[15] on propylene oxide, Gans[16] on aniline manufacture, or Vora et al.[17] on dimethyl terephthalate manufacture). The plant construction reviews, published by trade magazines such as Hydrocarbon Processing and European Chemical News, are valuable additional sources. These magazines track petroleum, petrochemical and chemical plant construction on a world wide basis. The particulars include the ownership, location and scheduled completion date of facility and product and coproducts to be manufactured. Data on plant capacity, process, licensor, engineer contractor and capital investment may also be given.

More data were found for the manufacture of the major plastics such as high and low density polyethylene, polypropylene, polystyrene including styrene monomer, and polyvinyl chloride (including vinyl monomer) than for the other petrochemicals of interest. The capital investments required to build representative manufacturing plants of different capacities for these polymers are presented in Table 16. In the case of polystyrene and PVC, the cost of the intermediate monomer manufacturing facility is included. The data presented in Table 16 were plotted from a smoothed trend line obtained from a log-log plot of capital



(Source: Chemical Engineering Magazine)

FIGURE 3. CHEMICAL ENGINEERING PLANT COST INDEX

investment versus plant capacity. The data are considered ± 20 percent estimates at best. The results support the rule of thumb estimate that the capital investment required to produce a commodity chemical from a base petrochemical is approximately equal to value of the annual production of the plant. The unit price (on a metric ton basis) of the various plastics are also presented in Table 16.

For the other plastic resins, on which the data are more limited, it also appears that the capital investment of the various facilities needed to transform the basic raw materials listed in Table 12 into the various polymers of automotive interest, is approximately equal to the annual value of the amount of polymer produced. For example, consider the manufacture of unsaturated polyester according to the scheme outlined in Figure 4. In Table 17, estimated capital investments for the process steps necessary are given and allocated to the investment needed to make the polyester resin on a pro rata basis. For this assortment of representative facilities (which do not have matched capacities), the total capital investment per ton of polyester production is approximately $685. This figure is within 20 percent of the present selling price of the resin. It is to be noted that the cost of the polymerization facilities alone account for about one third of the total integrated investment.

Based on the above, a first measure of the capital investment in additional manufacturing facilities needed to support the growth of plastics used in automobiles would be the product of the additional plant capacity required for each plastic by the unit value of the material. The additional required capacity that will be needed by 1988 for each plastic resin is given in the last column of Table 10. The unit price of these materials is given in Table 3. The projected capital investment, for each resin, is the product of these two numbers in compatible units, and is given in Table 18. The estimate includes the prorated investment for facilities for the various intermediate products that would be required, starting from the raw materials listed in Table 12. The capital investment figure does not include the cost of making the

TABLE 16. CAPITAL INVESTMENT FOR VARIOUS POLYMER MANUFACTURING PLANTS

	Nominal Plant Capacity 10^3 Metric Tons/Yr	Capital Investment $/Annual Ton	Product Value $/Metric Ton
Polyethylene, LD (from ethylene)	60	760	700
	100	600	
	150	500	
Polyethylene, HD (from ethylene)	40	1000	
	80	700	700
	150	450	
Polypropylene (from propylene)	30	1100	
	60	800	770
	100	600	
Polystyrene (from benzene & ethylene)	60	970	
	100	810	640
	200	610	
PVC (from ethylene & chlorine)	40	750	
	100	640	730
	200	360	

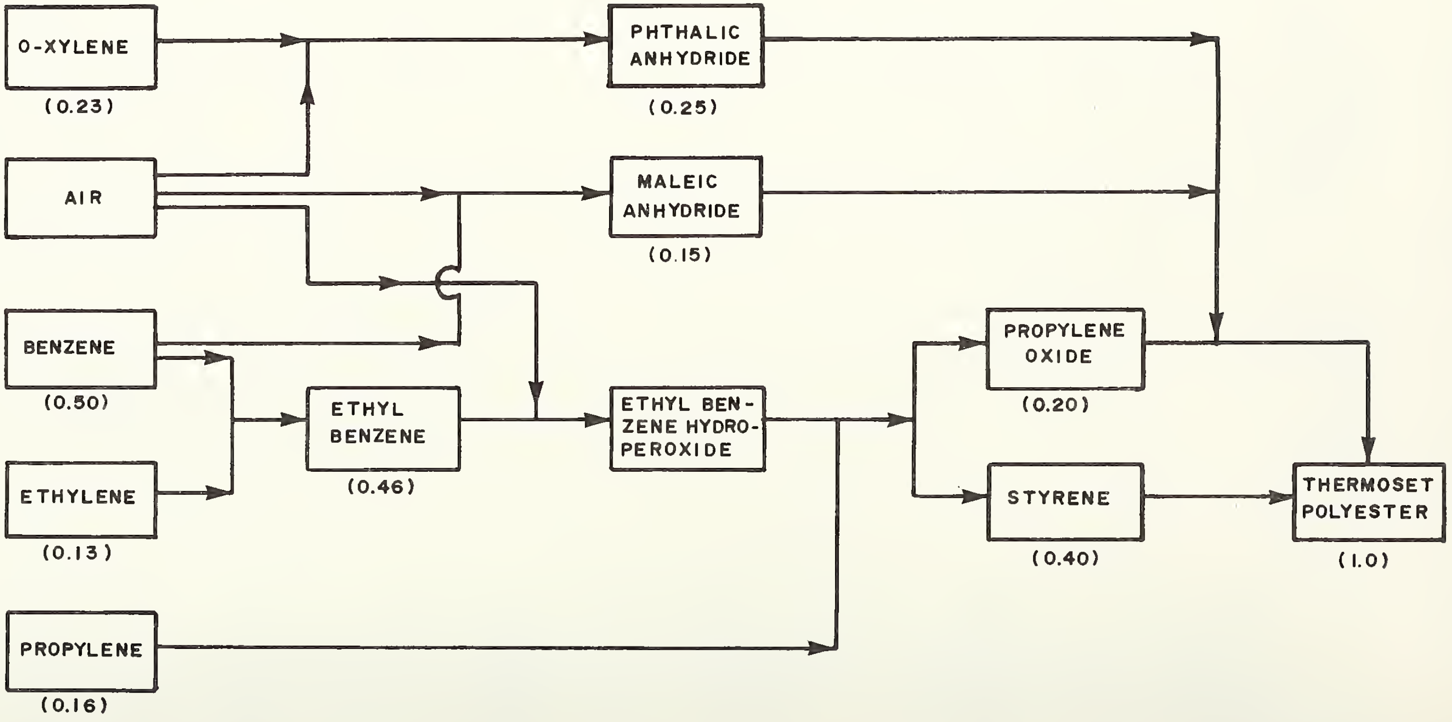


FIGURE 4. SYNTHESIS OF THERMOSETTING POLYESTER RESIN

TABLE 17. ESTIMATED CAPITAL INVESTMENT REQUIRED TO MANUFACTURE UNSATURATED POLYESTER RESINS FROM BASIC PETROCHEMICALS

Chemical	Production Capacity 10^3 Metric Tons/Year	Capital Investment $/Metric Ton	Chemical Needed per Ton of Polyester Resin Tons	Capital Investment Allocated to Polyester Manufacture $/Ton Polyester
Ethyl Benzene	320	120	0.46	55
Propylene oxide	140	430	0.20	115
Styrene	280	propylene oxide coproduct	0.40	-
Maleic Anhydride	45	760	0.15	115
Phthalic Anhydride	40	600	0.25	150
Polyester Resin	40	250	1.0	250
		Total		685

Current Price of Unsaturated Polyester Resin: 36¢/lb = $790 Metric Ton.

TABLE 18. ESTIMATED CAPITAL INVESTMENT NEEDED TO CONSTRUCT ADDITIONAL MANUFACTURING FACILITIES TO SUPPORT INCREASE IN PLASTICS USE IN 1988 M.Y. AUTOMOBILES, (NOT INCLUDING BASIC CHEMICAL PLANTS)

Plastic	Additional Capacity Needed for 1988 MY Automobiles 10^3 Metric Tons/Year	Unit Price ¢/lb	Unit Price $/Metric Ton	Estimated Capital Investment Million$(1978)
ABS	63	59	1300	82
Acrylic	47	56	1230	58
Cellulosic	0	85	1870	0
Nylon	48	116	2560	123
Phenolic MP	0	47	1030	0
Polyacetal	11	94	2070	23
Polycarbonate	8	109	2400	19
Polyethylene L.D.	0	32	700	0
Polyethylene H.D.	90	32	700	63
Polypropylene	315	30	660	208
Polystyrene	0	29	640	0
Polyurethane Precursors				
Polyol	157	35	770	121
TDI	146	54	1190	174
MDI	37	58	1280	47
Polyvinyl Chloride	153	27	595	91
Thermoplastic Polyester	39	98	2160	84
Unsaturated Polyester	240	36	790	190
SAN	0	40	880	0
Total				1283

basic materials listed in Table 12 from petroleum products, sulfur and chlorine.

The various hydrocarbons are all coproducts of a basic petrochemical complex, formed by the pyrolysis of a heavier hydrocarbon. Depending on the feedstock, a 1 billion pound/year ethylene plant would now cost approximately $100/annual metric ton of feedstock to $200 annual metric ton of feedstock, and could co-produce from 25 to 400 percent co-products on an ethylene weight basis.[18] While it is realized that the ratios of products in any given plant would not match the mix of hydrocarbons desired to make the various automotive plastics, it is assumed that it would not be unreasonable to allocate a capital investment factor of $180 annual ton for each additional metric ton of hydrocarbon products that would be required to make plastics for automobiles in 1988. The above figure includes a 25 percent allowance for plant downtime. In Table 13, it is estimated that an additional 1.73 million metric tons a year would be required to support the manufacture of automotive plastics. The capital investment needed for new facilities that would transform raw petroleum into the various basic petrochemicals listed in Table 12 for the 1988 automobile market, is estimated to be ($180) (1.73×10^6) = $311 million.

Additional capital investments would be needed for chlorine and sulfuric acid plants. Based on Table 13, additional chlorine capacity of (503) (1.25) = 630,000 metric tons per year would be needed. Based on Guthrie's estimates,[12] additional chlorine capacity would now cost about $125/annual metric ton. Capital investment for these new sulfuric acid facilities is thus estimated to be $11 million.

The total capital investment for new plants and facilities needed to support the expanded use of plastics in passenger cars in 1988 as compared to 1977, is the sum of the following:

	Million Dollars
New Basic Petrochemical Facilities	311
New Chlorine Plants	79
New Sulfuric Acid Plants	11
New Petrochemical Intermediate and Polymer Plants	1283
	1684

or approximately $1.7 billion dollars (1978 basis). This corresponds to an average annual investment of $153 million per year over the eleven years between 1977 and 1988. If the basic chemical plants are not included, the average annual investment for new polymer and polymer precursor facilities would be $117 million.

Selected financial data for the chemical and petroleum industries for the last three years are given in Table 19. Corresponding ratios of total assets, net plant and equipment, and capital expenditures to net sales are given in Table 20. Capital expenditure data for Industrial Chemicals and Synthetics, which best describes the synthetic plastics industry, are not available as a separate category, but are included in the Chemical and Allied Products category. The average ratio of capital expenditures to net sales for this group decreased from 7.1% in 1975 to 6.0% in 1977. Examination of the ratios of total assets to net sales, and of net plant and equipment to net sales for the various industry groups listed in Table 20, indicates that the capitalization of the industrial chemicals and synthetics segment of chemical and allied products industry is more akin to the petroleum and coals products industry than to the chemical and allied products industry as a whole. The ratio of capital expenditures to net sales for petroleum and coal products ranged form 9.8% in 1976 to 7.2% in 1977.

Based on the above historical record, it would be expected that future capital investments in the plastics industry would range from 6% to 10% on net sales per year. Based on projected 1980 demand, as outlined in Table 8, and current unit prices, given in Table 3, the projected values of U.S. plastics sales in 1988 are $29.6 billion for the industry as a whole, and $2.1 billion for plastics in passenger automobiles, as shown in Table 21. In comparison, 1977 total U.S. plastics sales were $13.980 billion, while passenger automobile plastics sales were $0.720 billion. The averages of the 1977 and projected 1988 values of plastics sales are $21.8 billion for the U.S. total market, and $1.4 billion of the U.S. passenger automobile market. (The above dollar values

TABLE 19 SELECTED FINANCIAL DATA FOR THE CHEMICAL AND PETROLEUM INDUSTRIES

	1975	1976	1977
Chemical & Allied Products			
Net Sales, $\$10^9$	88.2	101.8	113.4
Total Assets, $\$10^9$	81.1	91.7	101.4
Net Plant & Equipment, $\$10^9$	31.8	36.1	40.5
Capital Expenditures, $\$10^9$	6.25	6.68	6.83
Industrial Chemicals & Synthetics*			
Net Sales, $\$10^9$	42.5	50.0	55.5
Total Assets, $\$10^9$	43.1	48.2	53.4
Net Plant & Equipment, $\$10^9$	19.6	22.3	25.4
Capital Expenditures, $\$10^9$	n.a.	n.a.	n.a.
Petroleum & Coal Products			
Net Sales, $\$10^9$	121.8	141.3	161.7
Total Assets, $\$10^9$	122.7	143.0	154.7
Net Plant & Equipment, $\$10^9$	56.4	65.8	74.8
Capital Expenditures, $\$10^9$	10.51	13.87	11.62

*Included in Chemicals and Allied Products Category above

Source: Reference 19

TABLE 20 SELECTED FINANCIAL RATIOS FOR THE CHEMICAL AND PETROLEUM INDUSTRIES

	1975	1976	1977
Chemical and Allied Products			
Total Assets to Net Sales	0.92	0.90	0.89
Net Plant & Equipment to Net Sales	0.36	0.35	0.36
Capital Expenditures to Net Sales	0.071	0.066	0.060
Industrial Chemicals & Synthetics*			
Total Assets to Net Sales	1.01	0.96	0.96
Net Plant & Equipment to Net Sales	0.46	0.45	0.46
Petroleum & Coal Products			
Total Assets to Net Sales	1.01	1.01	0.96
Net Plant & Equipment to Net Sales	0.46	0.47	0.46
Capital Expenditures to Net Sales	0.086	0.098	0.072

*Included in Chemicals and Allied Products Category Above

TABLE 21 ESTIMATED VALUE OF U.S. PLASTIC SALES IN 1988[a]

	Unit[b] Price ¢/lb	Projected Total U.S. Consumption Million Dollars	Projected Automobile Consumption Million Dollars
ABS	59	1301	163
Acrylic	56	493	86
Cellulosics	85	102	11
Nylon	116	792	154
Phenolic (Molding Powder)[c]	47	1088	41
Polyacetal	94	155	22
Polycarbonate	109	52	32
Polyethylene HD	32	3528	15
Polyethylene LD	32	4937	1
Polypropylene & Polymers	35	3086	308
Polystrene (Molding Powder)[c]	29	1918(679)	1
Polyurethane[d]	43	1707	375
Polyvinyl Chloride	33	3564	183
Polyester Unsaturated	36	874	276
Polyester Thermoplastic	98	257	106
SAN	40	38	2
Other	100	5700	300
Total		29592	2076

a) 1978 dollars
b) Unit Prices as of 1/1/78
c) Molding Powder Value assumed for different grades
d) Assumes 60% polyol at 35¢/lb and 40% isocynate at 56¢/lb
e) Estimated value

are all in constant 1978 dollars.)

Based on these average sales, and the historic ratios for capital investment, it is expected that the synthetic plastics industry will invest between \$1.3 billion and \$2.2 billion per year in plants and equipment over the coming decade. Capital investments related to automotive plastics sales would be expected to range between \$90 million and \$140 million per year. The projected average annual investment of \$117 million required for new polymer and polymer precursor plants for automotive plastics falls halfway between these two values.

3. REFERENCES

1) Modern Plastics, McGraw Hill, Inc., 1221 Avenue of the Americas, New York, NY.

2) Facts and Figures of the Plastics Industry, 1977 Edition, The Society of the Plastics Industry, Inc., 355 Lexington Avenue, New York, NY 10017.

3) B. Nathanson, "The SPI Committee on Resin Statistics," Section 7A, Proc. 33rd Annual Conference on Reinforced Plastics, Washington, DC, February 7-10, 1978.

4) "Detroit's Weighting Game the Smart Money is on Plastics," Plastics World, May 1977, pp. 38-44.

5) American Chemical Society, Division of Chemical Marketing and Economics, Symposium of the Impact of the Automobile on the U.S. Polymer Industry, 1977 Annual Meeting, Chicago, IL, September 1977.

6) Chemical Marketing Research Association, "Chemicals and Plastics Growth in the Automotive Industry in the '80's," Detroit, MI, February 8-9, 1978.

7) "Plastics Use to Gain in Lighter Autos," C & E News, September 12, 1977, pp. 15-16.

8) E.F.H. Pennekemp, "Symposium on Plastics in the Automobile," Annual Meeting of the Society of Plastics Engineers, Washington, DC, April 25, 1978.

9) "Outlook Bright for Engineering Thermoplastics," C & E News, May 16, 1977, pp. 16-17.

10) R.R. Stover, "Polypropylene," Chem. Eng. Progress, 73(7), 25-31, (1977).

11) "Energy Issues May Spur Polyester Resin Use," C & E News, January 30, 1978, p. 11.

12) K.M. Guthrie, "Process Plant Estimating Evaluation and Control," Craftsman Book Company of America, Solana Beach, CA (1974).

REFERENCES (Continued)

13) J.E. Haselbarth, "Up-dated Investment Costs for 60 Types of Chemical Plants," Chemical Engineering, December 4, 1967, p. 214.

14) A.V. Hahn, "The Petrochemical Industry, Market and Economics," McGraw Hill Book Company, New York, 1967.

15) R.B. Stobaugh et al., "Propylene Oxide: How, Where, Who-Future," Hydrocarbon Processing, January 1973, pp. 99-108.

16) M. Gans, "Which Route to Aniline?," Hydrocarbon Processing, November 1976, p. 145.

17) B.V. Vora et al., "The Technology and Economics of Polyester Intermediates," Chem. Eng. Progress 73 (8), pp. 74-80 (1977).

18) T.B. Baba and J.R. Kennedy, "Ethylene and Its Co-products, The New Economics," Chemical Engineering, January 5, 1976, pp. 116-128.

19) "Facts & Figures of the U.S. Chemical Industry," C & E News, 56 (24), June 12, 1978, p. 57.

APPENDIX A:

POLYETHYLENE

A.1. INTRODUCTION

Polyethylene is a thermoplastic material made by the polymerization of ethylene monomer. It is available in a wide variety of formulations and can be fabricated by all thermoplastic processes. Formulations are classified primarily by density (specific gravity) of the resin:

1) ASTM Type I, specific gravity 0.912 - 0.925, also known as low density, regular, conventional or high pressure polyethylene.

2) ASTM Type II, specific gravity 0.925 - 0.940, commonly referred to as intermediate-density or medium density polyethylene.

3) ASTM Type III, specific gravity 0.940 - 0.965, also known as high density linear, or low pressure polyethylene.

The modulus and tensile strength of the polymer increase with density. The automotive industry principally uses Type III, or high density polyethylene. Type I, or low density polyethylene, is used in the automobile industry mainly as packaging film. The present discussion focuses on high density polyethylene.

A.2. TYPICAL USES OF HIGH DENSITY POLYETHYLENE

General:

Bottles, Pails

Pipe, Crates

Automotive:

Exterior:	Bumper components
Under the Hood:	Washer bottles
	Radiator Overflow bottles
Other:	Gasoline tanks

A.3 CURRENT PRICE FOR HIGH DENSITY POLYETHYLENE

General Purpose Blow Molding	31 3/4¢/lb
Injection Molding	31 3/4¢/lb

A.4 SUPPLY

As of January 1, 1978, thirteen different firms operated 15 H.D. polyethylene plants in the United States as listed in Table A-1. Total plant capacity was 2.165 million metric tons. (Total polyethylene plant capacity, including low density polyethylene production facilities, amounted to 5.760 million tons). Plant capacity will be increased by 365,000 metric tons in 1978, and by 45,000 tons in 1979. By January 1, 1980, it is expected that total H.D. polyethylene capacity will reach 2.575 million metric tons. This number presumes that American Hoechst's new 100,000 ton/yr facility in Bayport, TX will only be operating in 1980.

A.5 DEMAND

Total sales of high density polyethylene were 1.620 million metric tons in 1977. Major uses of high density polyethylene were blow molded bottles which consumed 434,000 metric tons, or 26.8 percent, and extruded pipe, which consumed 184,000 metric tons, or 11.4 percent. It is estimated that MY 1977 passenger automobile will consume 24,000 tons or 1.5 percent of the total. In addition, it is estimated that passenger automobiles will consume less than 1000 tons of low density polyethylene. This is less than 0.1 percent of the 2.934 million tons of low density resin consumed in the United States in 1977. Detailed data are given in Table A-2 and Figure A-1.

TABLE A-1 HIGH DENSITY POLYETHYLENE U.S. MANUFACTURING COMPANY

		Capacity as of 1/1/78	1978 Additions	1979 Additions	Capacity as of 1/1/80	Note
		——10^3 Metric Tons/Yr——				
Allied Chemical Co.	Baton Rouge, LA	275			275	
Amoco Chemical Corp.	Alvin, TX	135			135	
ARLO/Polymers	Port Arthur, TX	70	80		150	
CHEMPLEX CO.	Clinton, IO	85		45	130	
DOW CHEMICAL U.S.A.	Plaquemine, LA Freeport, TX	275			275	
DuPont, E.I. de Nemours & Co.	Orange, TX Victoria, TX	205			205	
Gulf Oil Chemicals	Orange, TX	90	110		200	
Hercules, Inc.	Parlin, NJ	10			10	
(American) Hoechst Inc.	Bayport, TX					100 in 1980
Monsanto Company	Texas City, TX	80			80	
National Petrochemicals Inc.	Deer Park, TX	230			230	
Phillips Petroleum Co., Inc.	Pasadena, TX	250	155		405	
Soltex Polymers	Deer Park, TX	275			275	
Union Carbide Corp.	Sea Drift, TX	185	20		205	
Total		2165	365	45	2575	

TABLE A-2. STATUS POLYETHYLENE (HIGH DENSITY) RESINS

Year	Total Capacity At Year Start	Total Consumption	Transportation Consumption	Automobile Consumption
		10^3 Metric Tons/Year		
1967	476	444		
1968	590	556		
1969	681	642	18	
1970		738	22	20
1971		864	20	18
1972		1085	23	20
1973		1248	26	23
1974		1217	23	20
1975	1252	1048	21	18
1976	1435, 1589[1]	1421	23	20
1977	1865, 1777[2]	1620	27 (est.)	24[2]
1978	2165			
1979	2530			
1980	2575			
1981				
1982		2500-3000[3]		

Source: Modern Plastics, Annual Industry Review in January issue unless otherwise indicated.

1) SPI 1976 Yearbook

2) SPI 1977 Yearbook

3) Modern Plastics, June 1977, p. 98.

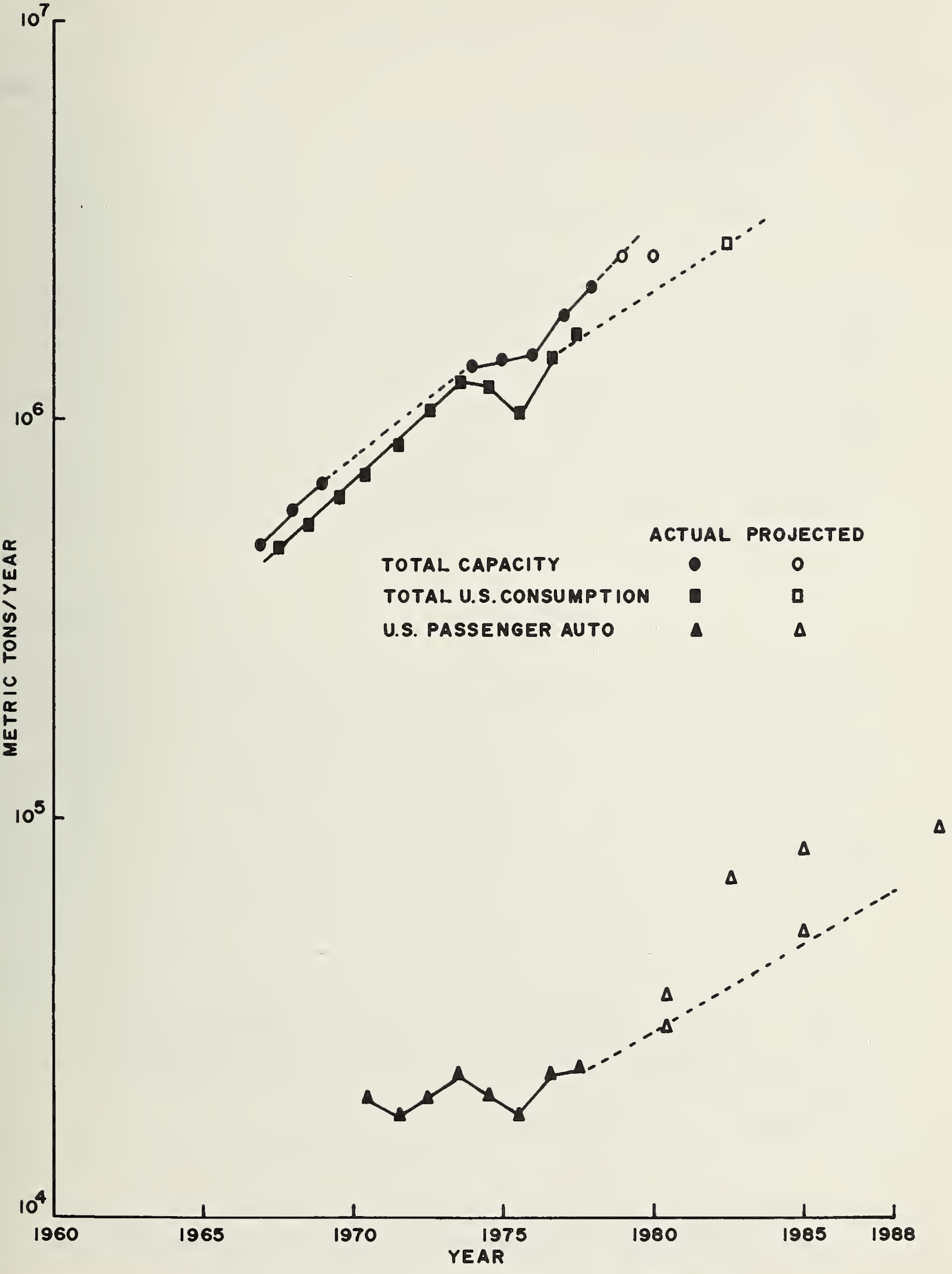


FIGURE A-1. HIGH DENSITY POLYETHYLENE

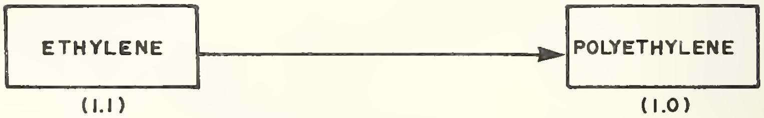


FIGURE A-2. SYNTHESIS L.D. OR H.D. POLYETHYLENE

A.6 PROJECTED GROWTH FOR HIGH DENSITY POLYETHYLENE

The compounded annual growth for H.D. Polyethylene was as follows:

Period	Total	Transportation	Automobiles
1968-1977	11.3%	NO DATA	NO DATA
1973-1977	5.4%	0.8%	0.9%
1976-1977	14.0%	17%	20%

High density polyethylene is expected to grow at an annual rate of 8 to 10 percent through 1982. Automobile use of high density polyethylene will increase more rapidly, possibly as much as 10 percent a year through 1985, if high polyethylene becomes a prevalent material of construction for automotive fuel tanks. However, even with this growth rate, automotive uses will represent less than 2 percent of the projected consumption of high density polyethylene.

A.7 MANUFACTURING

High density polyethylene is made by the polymerization of ethylene (see Figure A-2), dissolved in the presence of a catalyst. The catalysts used vary widely, but the most commonly used are metal alkyls in combination with metal halides (Ziegler type catalysts) or activated metal oxides (Phillips Petroleum Process). Polymerization normally occurs at less than 30 bars and at temperatures of from 60°C to 100°C. The product, as withdrawn from the reactor, is suspended in the solvent. The catalyst is added in such small amounts that there is no need to remove it from the product. Due to the almost complete conversion of ethylene, ethylene recycle or a monomer recovery system is not required. Most of the hydrocarbon diluent is removed from the polymer by drying in a closed circuit nitrogen drier. The polymer, in the form of a powder, is usually mixed with selected additives and extruded into pellets which are then sold.

The capital investment for a high density polyethylene plant is estimated to range from about $1000/annual ton for a 40,000 metric ton/year facility to $450/annual ton for a 150,000 metric ton/year facility. Process requirements per ton of polymer produced are:

Ethylene and Comonomers, ton	1.03 - 1.20
Hydrogen, Kg	1
Hydrocarbon diluent, Kg	10-20
Catalyst, $	2-10
Steam, tons	0.3 - 0.4
Cooling water, m^3	120
Inert Atmosphere (nitrogen), Nm^3	50
Electricity Kwh	60-300

A synthesis diagram is given in Figure A-2.

REFERENCES FOR APPENDIX A:

1) "HDPE, Status Report," Modern Plastics, July 1974, p. 52-53.

2) "Polyethylene Process," Phillips Petroleum Co., Hydrocarbon Processing, November 1977, p. 216.

3) "Polyethylene Process," Hoeschst, A.G., Hydrocarbon Processing, November 1977, p. 208.

4) "Polyethylene Process," Naphthachimie, Hydrocarbon Processing, November 1977, p. 209.

APPENDIX B:

POLYPROPYLENE

B.1 INTRODUCTION

As a result of the discovery of stereospecific catalysts in the 1950's, it became possible to produce a commercially useful polymer from propylene. In 1957, Hercules Incorporated started the first commercial polypropylene plant in the United States. Polypropylenes are very versatile thermoplastic polymers that offer an excellent balance of physical and chemical properties. The density of polypropylenes is among the lowest of all plastic materials, ranging from 0.900 to 0.915. Polypropylenes also have exceptionally long life under flexing.

B.2 TYPICAL USES OF POLYPROPLYENE

General:

- Carpet backing
- Dishwasher tub & door liners
- Pipe and fittings
- Caps and closures
- Packing film
- Process tanks

Automotive:

Interior	Trim, glove box
Exterior	Fender apron, lamp housing
	Front end retainer
Under the hood	Battery case
	Battery tray
	Fan shroud
	Fan

B.3 CURRENT PRICE FOR POLYPROPYLENE

General Purpose Homopolymer:	30¢/lb
Medium Impact Copolymer	33-35½¢/lb
High Impact Copolymer	35-35½¢/lb

B.4 SUPPLY

As of January 1, 1978, nine different firms operated thirteen polypropylene plants in the United States. Total plant capacity was 1.664 million metric tons. Plant capacity will be increased by 435,000 metric tons in 1978 and 375,000 metric tons in 1979. By January 1, 1980, it is expected that twelve manufacturers will be operating seventeen plants with a total production capacity of 2.744 million metric tons. More detailed data are given in Tables B-1 and B-2, and in Figure B-1.

B.5 DEMAND

Total U.S. sales of polypropylene and its copolymers were 1.247 million metric tons in 1977. Major uses of polypropylene included fibers and filaments (27 percent), packaging (17 percent) and transportation equipment (14 percent). Model year 1977 passenger cars consumed 140 million metric tons, or 11 percent of the total. The data are summarized in Table B-1 and Figure B-1.

B.6 PROJECT GROWTH FOR POLYPROPYLENE

Compounded annual growth for polypropylene was as follows:

Period	Total	Transportation	Automobiles
1968-1977	12.7%	15.4%	NO DATA
1973-1977	4.3%	7.8%	8.0%
1976-1977	5.9%	9.7%	10.2%

Growth rates of 10 to 13 percent over the next five years have been projected for polypropylene. New automotive uses of polypropylene, such as for seat shells and instrument panels, will support this growth in this sector. Average polypropylene consumption per automobile is expected to increase from about 28 lbs. per vehicle in 1977 to about 40 lbs. in 1980, 60 lbs. in 1985 and 70 lbs. in 1990. This corresponds to about a 10 percent annual growth rate in the automotive sector through 1985. Model year 1985 passenger automobiles should consume approximately 200 million tons of polypropylene.

TABLE B-1. POLYPROPYLENE - U.S. MANUFACTURING CAPACITY

Manufacturer	Location	Capacity as of 1/1/78	1978 Additions	1979 Additions	Projected Capacity 1/1/80
		———10^3 Metric Tons/Year———			
Amoco Chemicals	Chocolate Bayou, TX	120		110	230
"	New Castle, DE	130			130
ARCO Polymers	La Porte, TX	125	55		180
Eastman Chemical Products	Longview, TX	65			65
EXXON Chemical Products	Baytown, TX	230	20		250
Gulf Oil	Cedar Bayou, TX		180		180
Hercules Inc.	Bayport, TX	182			182
" "	Lake Charles, LA	340		55	395
Northern Petrochemicals, Inc.	Morris, IL		90		90
Novamont Corp.	Neal, WV	75			75
" "	La Porte, TX			120	120
Phillips Petroleum Co.	Pasadena, TX	65	20		85
Rexene Polyolfins Co.	Bayport, TX	70			70
" "	Odessa, TX	60			60
Shell Chemical Co.	Narco, LA	66			66
" "	Woodbury, NJ	136			136
Soltex Polymers	Deer Park, TX			90	90
Total		1664	435	375	2474

TABLE B-2. STATUS- POLYPROPYLENE RESINS

Year	Total Capacity At Year Start	Total Consumption		Transportation Consumption		Automobile Consumption
		1000 Metric Tons/Year				
1967	254	291		25		
1968	340	376		35		
1969	450	476		45		
1970	540	447		54		49.9
1971		590		62		56.7
1972		766	744[1]	83		77.3
1973		1012,	1010[1]	101	144[1]	95.5
1974	1130	1001	998[1]	95	130[1]	90
1975	1236	861	863[1]	96	114[1]	90
1976	1357	1178	1151[1]	134	156[1]	127
1977	1445	1247		147		140
1978	1864	1500[2],	1348[3]			155
1979	2100	1700[2]				
1980	2474	1700[2]				165[1]
1981		2100[2]				
1982		1974[3]				

Sources: Modern plastics Annual Industry Review in January issue unless otherwise indicated.

1 SPI 1977 Year Book
2 Modern Plastics November 1977, p. 44
3 Chemical Marketing Reporter, May 15, 1978, p. 9.

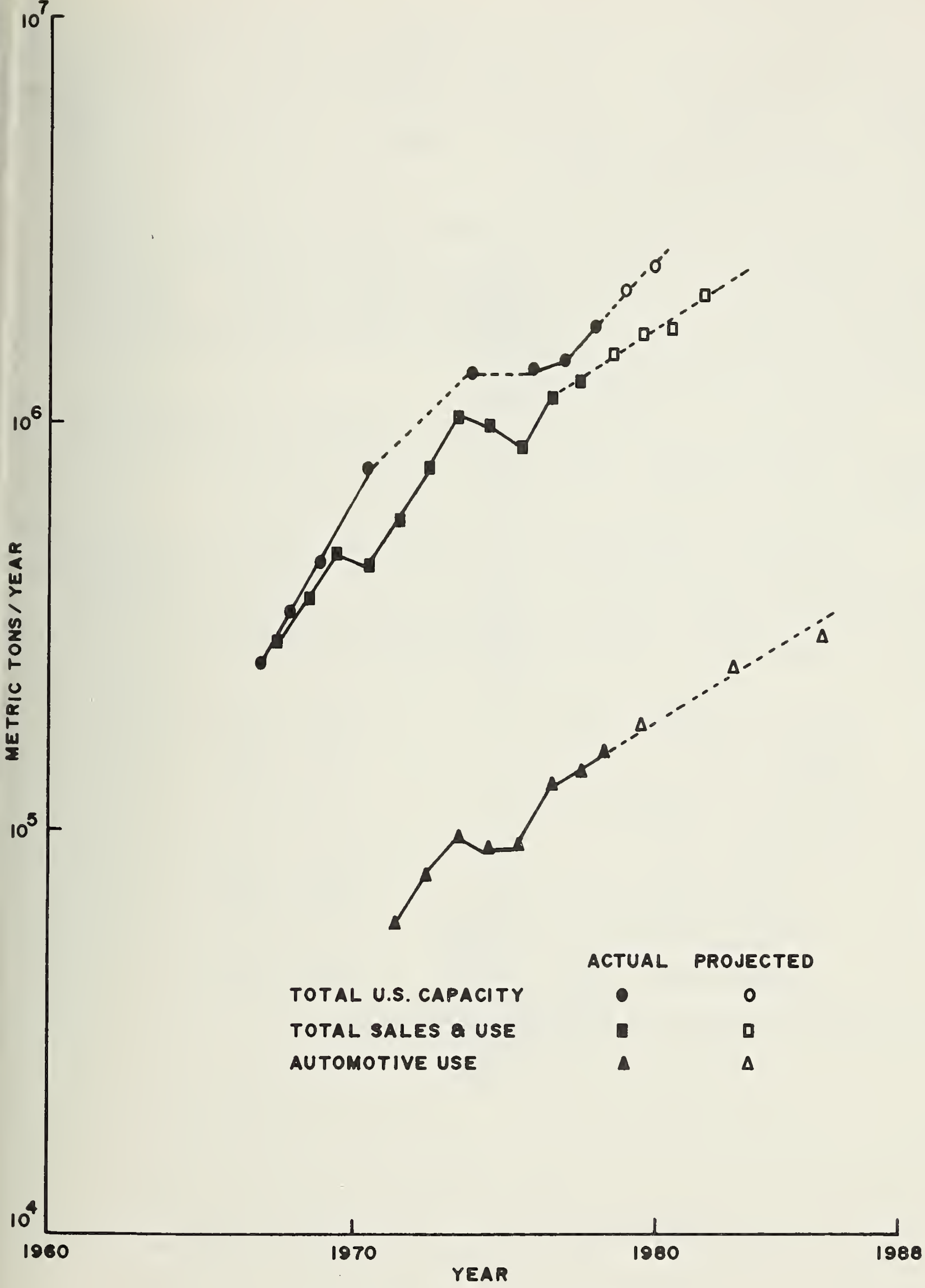


FIGURE B-1. POLYPROPYLENE

B-7 MANUFACTURING

Polypropylene is produced by polymerization of propylene monomer in the presence of a Ziegler type catalyst. Propylene monomer is obtained by purifying the crude C_3 fraction obtained from cracked petroleum products to remove propane and water which adversely affect the catalysts.

Propylene, ethylene as co-monomer (when desired to improve impact properties), and the catalyst system are fed into a polymerization reactor containing a hydrocarbon solvent. Typically, polymerization occurs at temperatures between 50° and 80°C and at pressures of 5 to 15 atmospheres.

The polymer is transferred to a centrifuge to separate the solvent. The polymer is then dried, stabilized and extruded into pellets. The solvent is recovered by distillation.

The capital investment for a polypropylene plant is estimated to range from $1100/annual ton for a 30,000 metric ton/year facility to $600/annual ton for a 100,000 metric ton/year facility. Process requirements per ton of polymer produced are:

Propylene Monomer, tons	1.05 - 1.12
Solvent, Kg	40 - 60
Catalyst & Chemicals, $	40 - 60
Utilities	
Steam, tons	3.3 - 4.0
Cooling water, m^3	250 - 250
Process water, m^3	2
Electricity, Kwh	200 - 900

A synthesis diagram is given in Figure B-2.

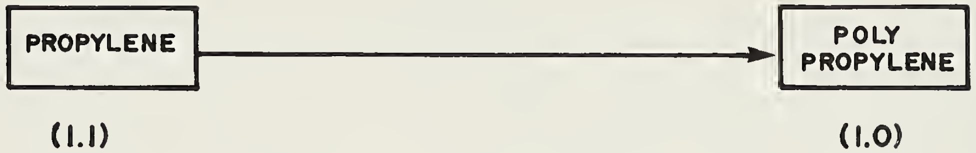


FIGURE B-2. SYNTHESIS OF POLYPROPYLENE

REFERENCES FOR APPENDIX B

1) "Polypropylene - Supply Status Report," Modern Plastics, September, 1974, p. 78-79.

2) "No End in Sight for PP Growth," Chemical Marketing Reporter, May 15, 1978, p. 46.

3) "Polypropylene, Chemical Profile," Chemical Marketing Reporter, May 15, 1978, p. 9, 15.

4) "Polypropylene Process," Mitsui Petrochemical Industries Ltd. Monteedison S.P.A., Hydrocarbon Processing, November 1977, p. 214.

5) "Polypropylene Process," Phillips Petroleum Co. Hydrocarbon Processing, November 1977, p. 215.

6) "Polypropylene Process," Hoechst AG, Hydrocarbon Processing, November 1977, p. 196.

7) "Polypropylene (FWH) Process," Friedrich Uhde AG, Hydrocarbon Processing, November 1971, p. 201.

APPENDIX C:

POLYSTYRENE

C.1 INTRODUCTION

Free radical polymerization of styrene results in the formation of polystyrene resin. The homopolymer is characterized by its rigidity, sparking clarity and ease of processibility; however, the crystal polymer tends to be brittle. Other limitations include poor weatherability and flammability. Mechanical properties of this material can be altered by the addition of modifying agents such as rubber (for impact strength), methyl styrene (for heat resistance), methyl methacrylate (for light stability) and acrylonitrile (for chemical resistance). Most polystyrene is processed by injection molding, but other standard thermoplastic processes can also be used. Polystyrene can also be easily fabricated into a cellular structure or foam which has excellent heat insulation and flotation properties.

C.2 TYPICAL USES OF POLYSTYRENE

General:
- Appliances
- Foamed Cups
- Margarine Tubs
- Shutters

Automotive:

Interior: Ashtray Door Base
Instrument Panel
Steering Column Cover Base

C.3. CURRENT PRICE FOR POLYSTYRENE RESINS, JANUARY 1, 1978

Crystal grade	28¢/lb
High impact grade	29¢/lb

C.4. SUPPLY

As of January 1, 1978, as shown in Table C-1, there were fifteen manufacturers of polystyrene in the United States with a total annual plant capacity of 2.480 million metric tons. Only a 5000 ton/year expansion is being planned over the next two years.

C.5 DEMAND

Total sales of polystyrene and styrene copolymers (other than ABS and SAN) were 2.010 million metric tons in 1977. The market was divided as follows: solid polystyrene 1.255 million tons, foamed polystyrene 337,000 metric tons, and other styrene 418,000 metric tons. Packaging was the single major use of solid polystyrene with 227,000 metric tons. Only 5,000 tons of polystyrene were used in transportation equipment. Historical data are given in Table C-2 and Figure C-1.

C.6 PROJECTED GROWTH FOR POLYSTYRENE

Compounded annual growth for polystyrene was as follows:

Period	Total	Transportation	Automobiles
1968-1977	6.8%	Data not sufficiently accurate	
1973-1977	1.4%		
1976-1977	13.9%		

Over the past decade, polystyrene consumption grew at a rate of 6.8 percent per year. The 1976-1977 change reflects an overcoming of the sharp decline in consumption that occurred in 1975. Polystyrene growth should increase with the economy at a rate of 6 percent per year. Automotive usage of polystyrene has been declining slowly because of the inroads of competing plastics that exhibit better physical properties such as ABS and SAN which are modified polystyrene resins.

C.7 MANUFACTURING

Styrene can be polymerized into commercial grade polystyrene by either suspension, continuous, or press polymerization. The

TABLE C-1. POLYSTYRENE U.S. MANUFACTURING CAPACITY

Supplier	Location	Capacity as of 1/1/78	Expansion 1978	Expansion 1979	Capacity as of 1/1/80
		10^3 Metric Tons/Yr			
A & E Plastik Pak		25			25
Amoco Chemicals Corp.	Willow Springs, IL	180			180
ARCO/Polymers		215			215
BASF/Wyandotte Corp.		50	5		55
Cosden Oil & Chemical Corp.		275			275
Dow Chemical USA	Joliet, IL	455			455
Gulf Oil Chemical Co.	Marietta, OH	100			100
Hammon Plastics	Owensboro, KY Worcester, MA	75			75
(American) Hoechst Corp.		280			280
Huntsman Chemical and Oil Corp.	Salt Lake City, UT	15			15
Monsanto Company	Addyston, OH Decatur, AL Springfield, MA	370			370
Polysar Group		135			135
Rexene Styrenes Co.*		60			60
Shell Chemicals Co.	Marietta, OH	135			135
USS Chemicals		100			100
Total		2480	5	0	2485

*Purchased by Mobil Chemical Co. April 1978.

TABLE C-2. STATUS POLYSTYRENE RESINS (NOT INCLUDING ABS AND SAN)

Year	Plant Capacity At Year Start	Total	U.S. Consumption Transportation	Automobiles
	10^3 Metric Tons/Yr			
1967		953		
1968		1041		
1969		1228		
1970		1273	6.4	6.4
1971		1410	7.2	6.8
1972	1637*	1708	4.6	4.1
1973		1879	4.6	4.0
1974	2124*	1758	3.5	3.0
1975	2360	1549	2.5	2.0
1976	2595	1765	2.8,5	2.1
1977	2509	2010	5	?
1978	2480			
1979	2485			
1980	2485			

*June capacity

Sources: Modern Plastics Annual Industry Review in January issue except where indicated

*Modern Plastics June 1974, "Styrenics Status Report"

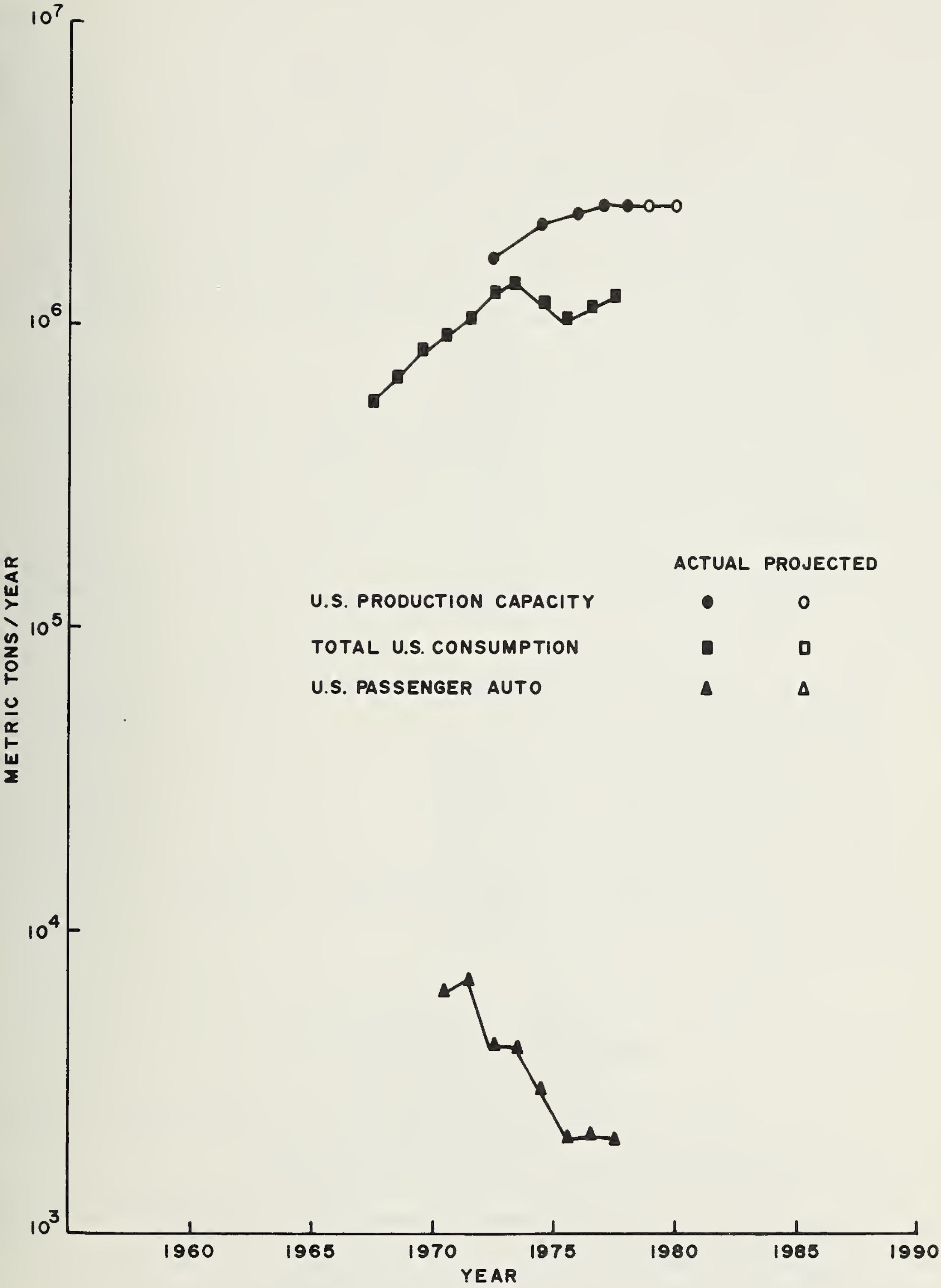


FIGURE C-1. POLYSTYRENE

capital investment for a continuous process plant is slightly higher than for an emulsion polymerization plant but the operating costs are lower. In a typical continuous process, styrene is fed continuously in a three stage stirred polymerization train, with typical conversions attaining 90 percent. The polymer solution is then pumped to a devolatilizer where residual unreacted styrene is vaporized, condensed, and recycled to the first stage reactor. The hot polystyrene melt flows from the bottom of the devolatilizer to an extruder and is pelletized, cooled, dried and screened. The resulting polystyrene pellets are conveyed to storage for subsequent packaging and sale.

The capital investment for a polystyrene polymerization plant is estimated to range from about $570/annual ton for a 50,000 metric ton/year plant to about $300/annual ton for a 300,000 metric ton/year plant. This investment does not include the manufacture of styrene (which is typically made from benzene and ethylene). Typical process requirements per ton of polymer produced are:

Styrene (plus polybutadiene and plasticizers, if any), tons	1.02
Electricity, kwH	150
Cooling water, m^3	35
Heat, Kcals (10^6Btu)	3.6×10^5 (1.43)

The key intermediate for polystyrene is styrene, as outlined in Figure C-2.

REFERENCES FOR APPENDIX C

1) R. B. Bishop, "Find Polystyrene Plant Costs," Hydrocarbon Processing, November 1972, pages 137-140.

2) "Polystyrene - ATO Chemie Process," Hydrocarbon Processing. November 1977, p. 216.

3) "Styrenics-Status Report," Modern Plastics, June 1974.

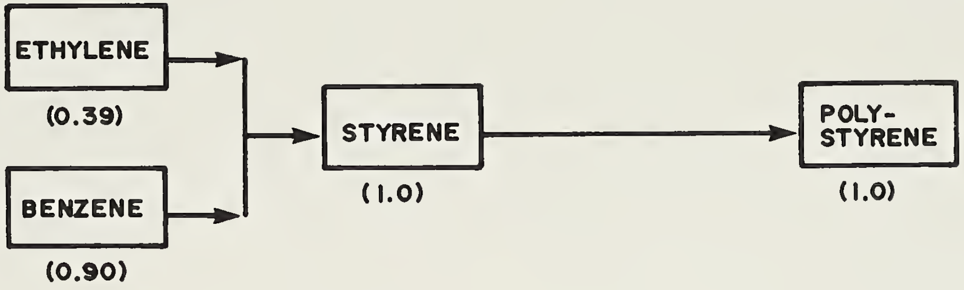


FIGURE C-2. SYNTHESIS OF POLYSTYRENE

APPENDIX D:

ACRYLONITRILE - BUTADIENE - STYRENE (ABS) RESINS

D.1 INTRODUCTION

These thermoplastics, commonly referred to as ABS plastics, were first introduced by U.S. Rubber in the late 1940's. They are manufactured by grafting styrene and acrylonitrile onto a diene-rubber backbone. The diene rubber used is usually polybutadiene. ABS resins offer a good balance of impact resistance, tensile strength, hardness and elastic modulus properties over a wide range of temperatures, - 40°F to + 225°F. (-40°C to + 107°C) . Physical properties are little affected by moisture which greatly contributes to the dimensional stability of ABS materials. ABS resins are chemically resistant and non-staining. They can be colormatched, compounded or alloyed with other plastics. Over seventy-five grades of ABS resins are available. ABS plastics can be processed into finished parts by almost any of the standard thermoplastic converting processes.

D.2 TYPICAL USES OF ABS RESINS

General:
- Business Machines (Housings)
- Luggage
- Piping
- Refrigerator Liners
- Telephone Housings

Automotive:
- Interior:
  - Instrument Panel
  - Instrument Panel Retainer
  - Ash Tray Door
  - Glove Box Door
- Exterior:
  - License Plate Housing
  - Grille
  - Wheelcovers

D.3 CURRENT PRICE FOR ABS RESIN (January 1, 1978)

Medium Impact Grade	57¢/lb
High Impact Grade	61¢/lb

D.4 SUPPLY

As of January 1, 1978, seven firms operated 12 plants producing ABS resins in the United States. Total plant capacity was 715,000 metric tons/year. Plant capacity will be increased by 75,000 tons in 1978, and 70,000 tons in 1979. Total capacity as of January 1, 1980, is projected to be 860,000 tons. Detailed data are given in Tables D-1 and D-2.

D.5 DEMAND

Total sales of ABS resins were 468,000 metric tons in 1977. Major identified uses were piping (26.5 percent), automotive (15.6 percent) and appliances (12.2 percent). Model year 1977 passenger automobiles consumed 70,000 metric tons, and 2,000 metric tons were used in other transportation equipment in 1977. Historical data are given in Table D-3 and Figure D-1.

D.6 PROJECTED GROWTH FOR ABS PLASTICS

Compounded annual growth for ABS resins was as follows:

Period	Total	Transportation	Automobiles
1968-1977	8.7%	8.4%	No Data
1973-1977	2.1%	1.1%	0.5%
1976-1977	11.4%	1.4%	-

ABS resins are expected to grow at the total rate of about 6 to 8 percent through 1981. Major new automotive applications are not foreseen for this material which will be more extensively used in interior components. The Predicast Study (Figure 2) projects a 4.0 percent annual rate of increase over the 1976 to 1990 period.

D.7 MANUFACTURING

ABS is manufactured in three polymerization steps, and

TABLE D-1. ABS RESIN U.S. MANUFACTURING CAPACITY

Producer	Location	Capacity as of 1/1/78	1978 Additions	1979 Additions	Capacity as of 1/1/80
Abtec	Louisville, KY	35	15		50
Borg-Warner	Ottawa, IL	105		70	105
" "	Washington, WV	135			135
Dow Chemical Co.	Gales Ferry, CN	30			30
" " "	Midland, MI	30			30
" " "	Torrance, CA	10			10
" " "	Hanging Rock, OH	70			70
Hammond Plastics	Worcester, MA	5			5
Monsanto	Addyston, OH	125	32		152
"	Muscatine, IO	55			55
"	Springfield, MA		13		13
Rexene*	Joliet, IL	25			25
Uniroyal	Baton Rouge, LA	90	15		105
Total		715	75	70	860

TABLE D-2. ESTIMATED SAN RESIN MANUFACTURING CAPACITY

Abtec	5
Dow Chemical	75
Monsanto	45
Union Carbide Corp.	15
Total	140

---

*Purchased by Mobil Chemical Co., April 1978

TABLE D-3. STATUS - ABS RESINS

Year	Total Capacity At Year Start	Total Consumption	Transportation Consumption	Automobile Consumption
	1000 Metric Tons/Year			
1967		156	25	
1968		204	32	
1969		230	41	
1970		228	29	29
1971	417[4]	300	41	41
1972	393[4]	357, 356[1]	59	59
1973	475[4]	422, 407[1]	68 70[1]	68
1974	555[4]	371, 345[1]	62 60[1]	62
1975	580	292, 267[1]	59 55[1]	58
1976	720, 637[1]	420	71 77[1]	70
1977	658, 638[2]	468	72	70
1978	715		74	72
1979	790			
1980	860			71[1]
1981		674[3], 740[2]	118	

Source: Modern Plastics, Annual Industry Review unless otherwise indicated.

*Includes SAN

1. SPI, 1977 Facts and Figures
2. Chemical Mkt Reporter, March 28, 1977
3. Modern Plastics, February 1977, page 16
4. Modern Plastics, June 1974.

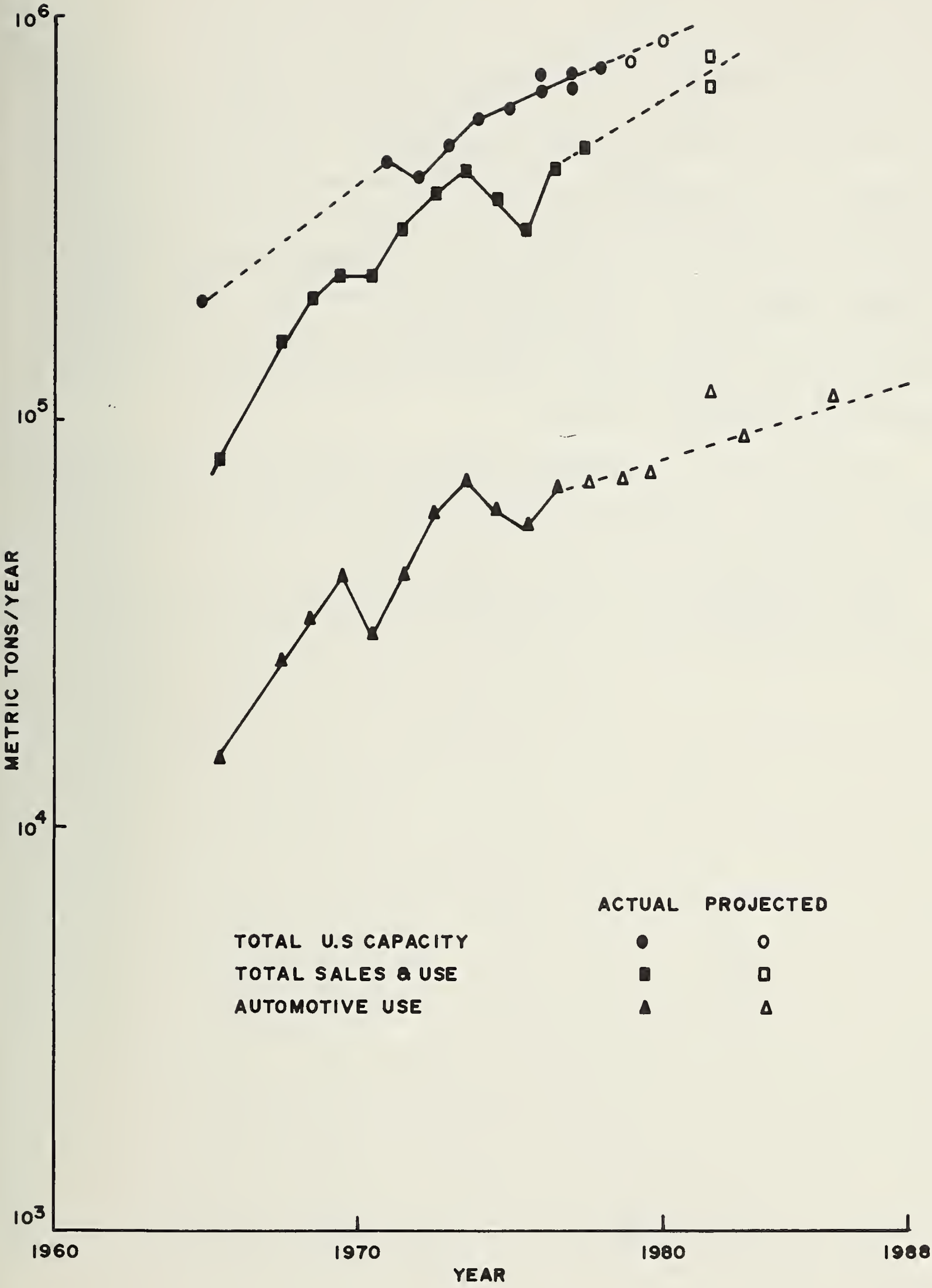


FIGURE D-1. ABS RESINS

peroxytype catalysts are used to initiate the reaction through the formation of free radicals. In the first step, polybutadiene is made by emulsion polymerization of butadiene in water. After residual butadiene is steam stripped from the latex, the polybutadiene rubber is further polymerized under a nitrogen atmosphere in the presence of styrene and acrylonitrile. The third polymerization step is the manufacture of SAN (styrene-acrylonitrile) resin by emulsion, suspension or mass polymerization. By blending the ABS graft phase with the SAN resin, and incorporating various antioxidants, lubricants, stabilizers and pigments, a wide range of ABS grades are made. The blended ABS-San latex is flocculated, washed and dried, and finally pelletized by extrusion to form a commercial granulated product.

No cost data were obtained for ABS manufacture. The manufacturing process is similar to, but more involved, than the manufacture of polystyrene discussed elsewhere.

Key intermediates for ABS production and styrene, acrylonitrile and butadiene, are outlined in Figure D-2.

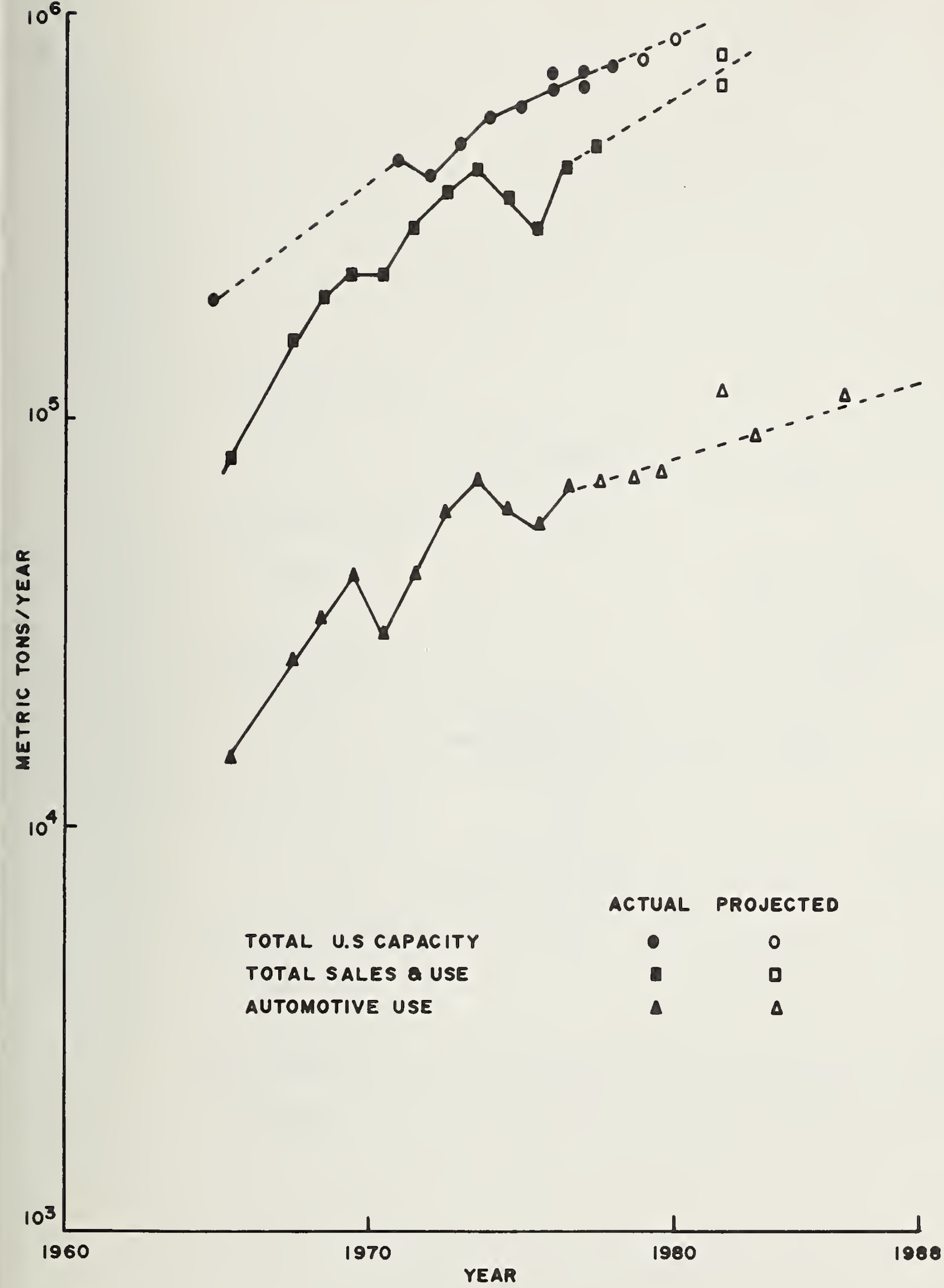


FIGURE D-1. ABS RESINS

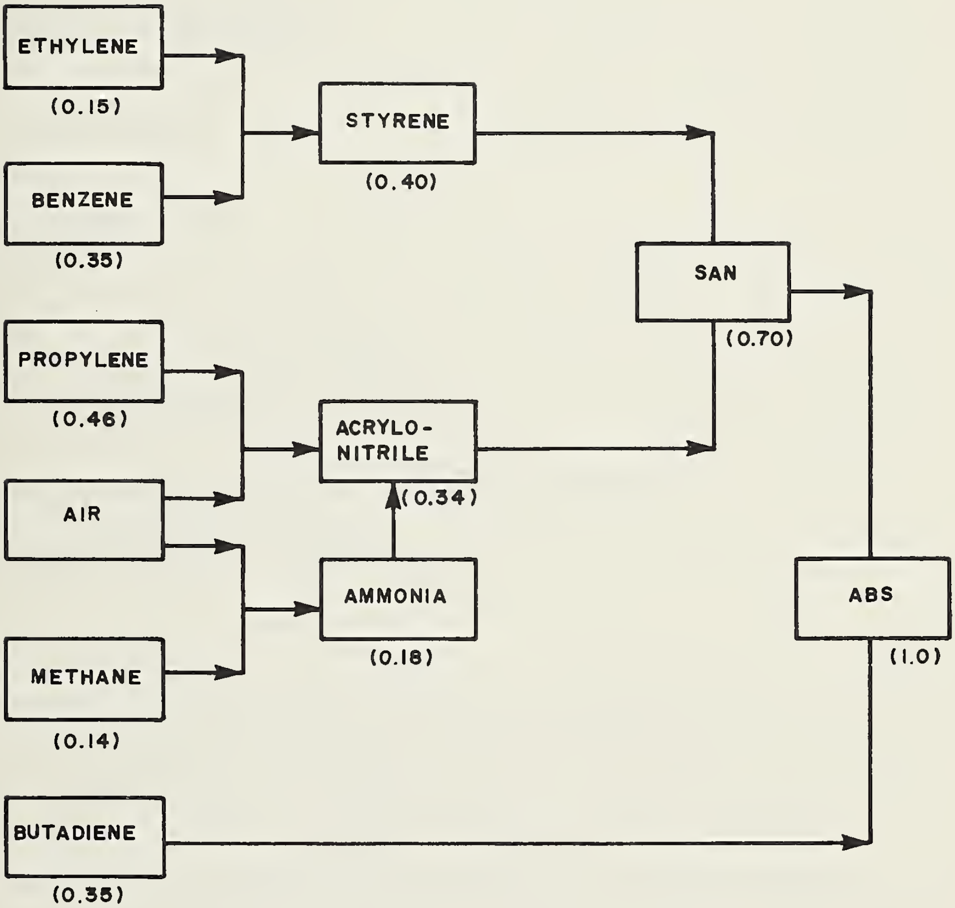


FIGURE D-2. SYNTHESIS OF ABS

APPENDIX E:

STYRENE-ACRYLONITRILE (SAN) RESINS

E.1 INTRODUCTION

In addition to their use as modifiers of styrenated polybutadiene in the manufacture of ABS resins, SAN resins are used in their own right, when transparent resins with better impact properties than polystyrene are needed.

E.2 TYPICAL USES OF SAN RESINS

General:
- Appliance knobs
- Lamps
- Bath accessories

Automotive:
- Interior: Ash tray door
  - Instrument panel
  - Console

E.3 CURRENT PRICE OF SAN RESINS (JANUARY 1, 1978)

General purpose grade 40¢/lb

E.4 SUPPLY

As of January 1, 1978, four firms manufactured SAN resins for merchant sale with total plant capacity of 140,000 metric tons/year, as shown in Table D-2. Three of these firms were also suppliers of ABS resins. These figures may not be too accurate because SAN capacity is considered proprietary by some manufacturers. Future supply will be closely associated with ABS supply.

E.5 DEMAND

Total sales of SAN resins were 50,000 metric tons in 1977. Compounding accounted for 32 percent of the total, housewares for

18 percent, and molded packaging for 10 percent. In January 1978, Modern Plastics listed automotive consumption as 3000 metric tons in 1977 and 2000 metric tons in 1976. In January 1977, 1976 consumption was given as 4,400 metric tons and 1975 consumption as 4,000 metric tons. This change in the figures reflects the uncertainty in the data, rather than a real drop in consumption. The data are summarized in Table E-1 and Figure E-1.

E.6 PROJECTED GROWTH FOR SAN PLASTICS

Compounded annual growth for SAN plastics was as follows:

Period	Total	Transportation	Automobiles
1968-1977	11.4%	Data not sufficiently accurate	
1973-1977	(-1.9%)		
1976-1977	6.4%		

Overall growth of SAN should be similar to that of ABS resins, discussed previously. No major change is forecast for automotive applications of this material.

E.7 MANUFACTURING

See ABS resins.

Key intermediates for SAN production are styrene and acrylonitrile, as outlined in Figure E-2.

TABLE E-1. STATUS - SAN RESINS

Year	Capacity at Year Start	U.S. Consumption Total	U.S. Consumption Transportation	U.S. Consumption Passenger Automobiles
		10^3 Metric Tons/Year		
1965				
1966				
1967		16	1.4	1.4
1968		17	1.4	1.4
1969		18	2.3	2.3
1970		20	2.7	2.7
1971		33	3.6	3.6
1972		46	4.6	4.6
1973		55	5.0	5.0
1974		54	4.5	4.5
1975		34	4.0	4.0
1976	140	47	4.4	4.4
1977	140	50	4	4
1978	140			

Source: Modern Plastics Annual Industry Review in January issue

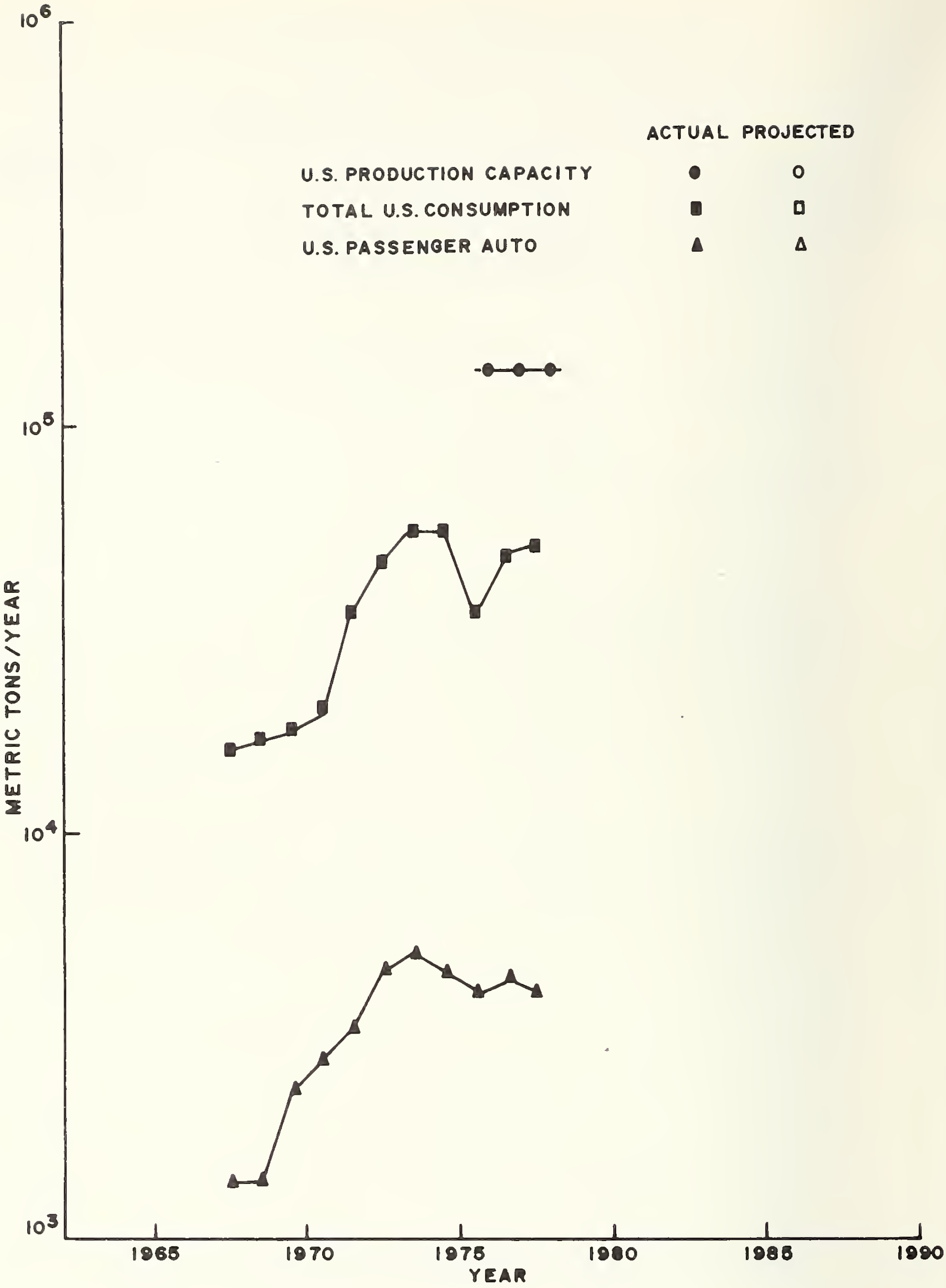


FIGURE E-1. STYRENE-ACRYLONITRILE (SAN)

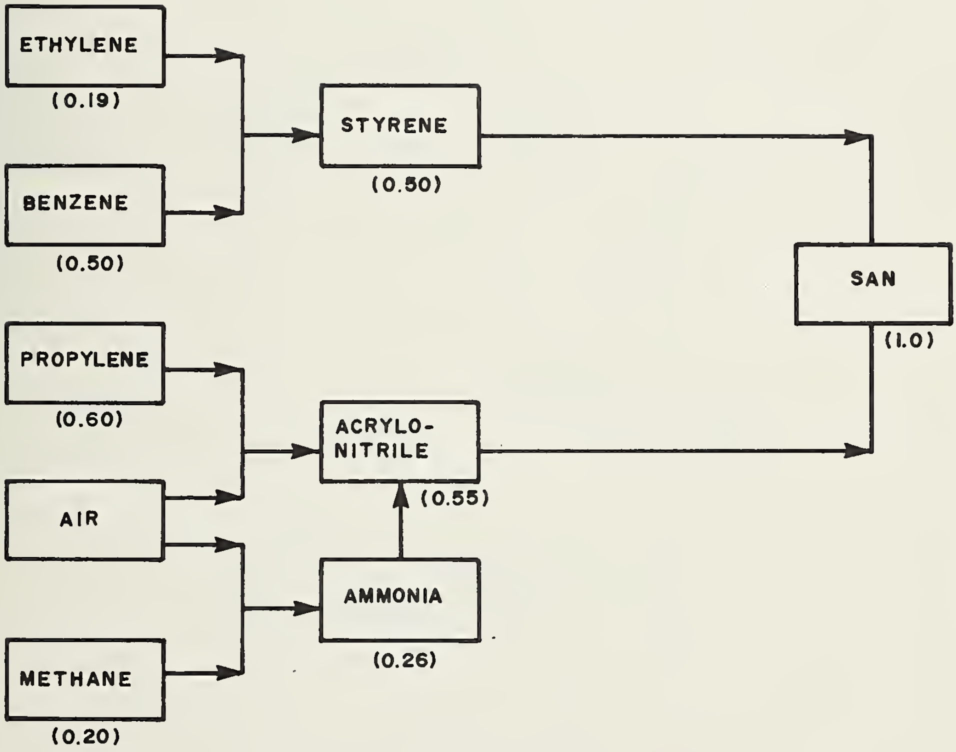


FIGURE E-2. SYNTHESIS OF SAN

APPENDIX F:

POLYVINYL CHLORIDE (PVC)

F.1 INTRODUCTION

Polyvinyl chloride (PVC) is one of the oldest and most commonly used thermoplastic materials. PVC is a material with a wide range of rigidity and flexibility. One of its basic advantages is the way it accepts compounding ingredients. A variety of plasticizers can be added to PVC to produce soft yielding materials to almost any desired degree of flexibility. Without plasticizers, it is a strong, rigid material that can be machined, heat formed, or welded by solvents or heat. It is tough, and has high resistance to acids, alcohol, alkalies, oils and many other hydrocarbons.

F.2 CURRENT PRICE FOR PVC (JANUARY 4, 1978)

Holopolymer, dispersion	39¢/lb
Homopolymer, suspension	27¢/lb

F.3 TYPICAL USES OF PVC

General:

- Bottles
- Flooring
- Phonograph Records
- Piping
- Wall Covering
- Wires and Cable Insulation

Automotive:

Interior: Crash Pad, Headrest Pad, Trim Glove Box, Upholstery, Carpet

Interior: Styled Roof

Under the Hood: Electrical Housing and Wiring

F.4 SUPPLY

As of January 1, 1978, twenty different firms operated 36 polyvinyl chloride plants in the continental United States. An additional firm operated a facility in Puerto Rico. Total plant capacity at the time was 3.075 million metric tons. Plant capacity will be increased by 277 metric tons in 1978 and 305 metric tons in 1979. Projected capacity will be 3.675 million metric tons by January 1, 1980. More detailed supply data are given in Tables F-1 and F-2, and in Figure F-1.

F.5 DEMAND

Total U.S. sales of polyvinyl chloride and its copolymers amounted to 2.380 million metric tons in 1977. The principal use of PVC (36 percent of the total) was in the manufacture of pipe, conduit and fittings. Model year 1977 passenger cars consumed 130,000 metric tons, metric tons, or 5.5 percent of the total. Other transportation uses in 1977 consumed an additional 15,000 metric tons. Data are summarized in Table F-2 and Figure F-1.

F.6 PROJECTED GROWTH FOR PVC

Compounded annual growth of PVC demand was as follows:

Period	Total	Transportation	Automobiles
1968-1977	8.1%	6.2	No Data
1973-1977	2.0%	2.5	1.9
1976-1977	13.2%	11.1	8.0

Based on an annual average growth rate of 8 percent, total U.S. consumption of PVC in 1982 should be about 3.5 million metric tons. Automotive growth should be less than the total. According to Figure 2 in Section 2, automobile growth rates range from 0 percent (through 1980) to 9.4 percent (through 1982). Based on an annual growth rate of 6 percent, total transportation usage should be about 200,000 metric tons in 1982.

According to Figure 2 in Section 2, the use of PVC in automobiles should increase at an average annual rate of 2.5 percent per

TABLE F-1. POLYVINYL CHLORIDE - U.S. MANUFACTURING CAPACITY

Manufacturer	Location	Capacity 5/30/77	1977 Additions	Capacity 1/1/78	1978 Additions	1979 Additions	Projected Capacity 1/1/80
		10^3 Metric Tons/Year					
Air Products	Calvert City, KY	55	41	96	40		204
" "	Pace, FL	68		68			
Atlantic Tubing & Rubber	Cranston, RI	23		23			23
Borden	Illiopolis, IL	155		155			237
"	Leominster, MA	82		82			
Certain-Teed	Lake Charles, LA	100		100		20	120
Conoco	Aberdeen, MD	180		180	75		255
"	Oklahoma City, OK						
Diamond Shamrock	Deer Park, TX	214		214			275
" "	Delaware City, DE	46		46		15	
Ethyl	Baton Rouge, LA	82		82			82
Firestone	Perryville, MD	132		132		90	295
"	Pottsdown, PA	73		73			
General Tire	Ashtabula, OH	57		57			57
" "	Point Pleasant, WV	25		25			25
Georgia Pacific	Plaquemine, LA	100		100		180	394
" "	Painesville, OH	114		114			
Goodrich	Henry, IL	86		86			478
"	Long Beach, CA	64		64			
"	Louisville, KY	155		155			
"	Pedricktown, NJ	55		55			
"	Avon Lake, OH	118		118			
Goodyear	Niagara Falls, NY	23		23	25		139
"	Plaquemine, LA	91		91			
Great American Chem.	Fitchburg, MA	36	9	45			45
Hooker	Burlington, NJ	82		82			82
Keysor Century	Saugus, CA	23		23			23
Pantasote	Passaic, NJ	27		27			54
"	Point Pleasant, WV	27		27			
Rico Chemical	Guayanilla, PR	73		73			73
Shintech	Freeport, TX	100		100	50		150
Stauffer	Delaware City, DE	123		123			191
"	Long Beach, CA	68		68			
Tenneco	Burlington, NJ	75		75			316
"	Flemington, NJ	41		41	80		
"	Pasadena, TX	120		120			
Union Carbide	Texas City, TX	136		136	7		143
TOTAL		3025	50	3075	277	305	3657

Source: Chemical Marketing Reporter, p. 1, May 30, 1977
Modern Plastics, p. 55, January 1978.

TABLE F-2. STATUS - POLYVINYL CHLORIDE RESINS

Year	Total Capacity at Year Start	Total Consumption	Transportation Consumption	Automobile Consumption
		1000 Metric Tons/Year		
1965	1320 (June)			
1967		983	72.6	
1968		1093	82.5	
1969		1248	68.0	
1970		1384	86.2	77.1
1971		1571	90.7	81.7
1972		1975	118.6	109.1
1973		2151	132.6	122.7
1974		2141	119.0	110.0
1975	2648	1700	109.0	100.0
1976	2995	2103	135.0	125.0
1977	3040,2745[1],3020[2]	2380	150.0	135.0
1978	3080, 3195[2]			
1979	3393[3], 3210[2]			
1980	3699[3]			
1981		3134[2]		

Source: Modern Plastics Annual Review unless otherwise noted

1 SPI 1977 Year Book

2 Chemical Marketing Reporter, May 30, 1977

3 Modern Plastics, December 1977

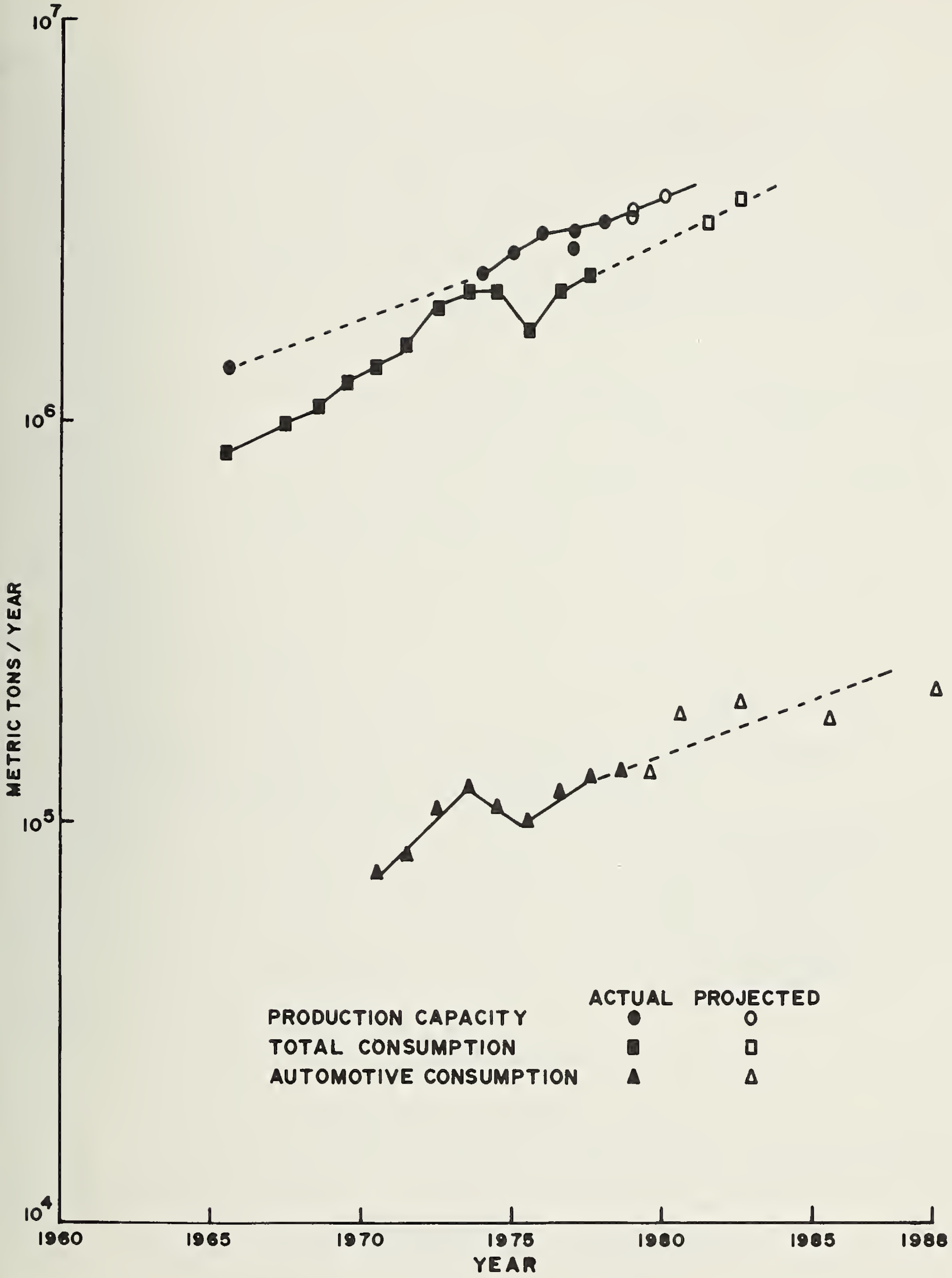


FIGURE F-1. POLYVINYL CHLORIDE POLYMERS

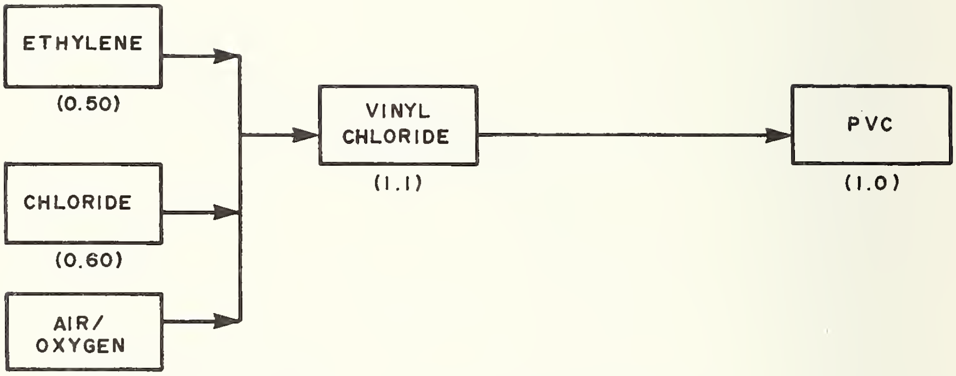


FIGURE F-2. SYNTHESIS OF POLYVINYL CHLORIDE year.

F.7 MANUFACTURING

PVC is manufactured by suspension, emulsion, bulk, and solution polymerization of vinyl chloride (VCM). Suspension polymerization accounts for about 80 percent of U.S. production. Suspension polymerization is a batch process wherein polymerization is performed in an aqueous medium which acts both as a dispersing and heat transfer agent. To meet OSHA requirements, the final resin has to have a low monomer content.

The capital investment for a PVC plant is estimated to range from $460/annual ton for a 40,000 metric ton/year facility to $220/annual ton for a 200,000 metric ton/year facility. Process requirements per ton of polymer produced are:

Vinyl Chloride Monomer (VCM), tons	1.05
Catalysts	$6
Utilities	
Steam, tons	0.4 - 1
Cooling Water, m^3	60 - 100
Process Water, m^3	3
Electricity, kwh	120 - 150

Since PVC is the major user of VCM, the manufacture is closely coordinated with the production of PVC. Most present day VCM plants use a so-called balanced oxychlorination process to convert chlorine and ethylene to VCM. The process involves the following steps.

1) Direct chlorination of ethylene with chlorine to form ethylene dichloride (EDC)

$$\underset{\text{ethylene}}{CH_2 = CH_2} + \underset{\text{chlorine}}{Cl_2} \rightarrow \underset{\text{EDC}}{CH_2Cl - CH_2Cl}$$

2) Cracking of EDC at elevated temperature to form VCM and hydrochloric acid (HCl)

$$\underset{\text{EDC}}{CH_2Cl - CH_2Cl} \xrightarrow{900\text{-}950^{\circ}F} \underset{\text{VCM}}{CH_2 = CHCl} + HCl$$

3) Separation VCM and HCl by distillation and purification of VCM.

4) Oxychlorination of ethylene with HCl in the presence of oxygen to form additional EDC

$$\underset{\text{ethylene}}{CH_2 = CH_2} + \underset{\text{hydrochloric acid}}{2HCl} + \underset{\text{oxygen}}{\tfrac{1}{2}\,O_2} \rightarrow \underset{\text{EDC}}{CH_2Cl - CH_2Cl} + \underset{\text{water}}{H_2O}$$

With oxychlorination, VCM is formed without having to export or dispose of a large quantity of by-product HCl, and it does not require more expensive acetylene as an alternate feed stock.

Capital investment for a VCM plant is estimated in range from about $340/annual ton for a 100,000 metric ton/year facility to $220/annual ton for a 400,000 metric ton/year facility. Process requirements per ton of VCM produced are estimated to be:

Chlorine	0.62 ton	Electric Power	130 - 200 Kwh
Ethylene	0.47 ton	Steam	1.0 - 1.5 ton
Oxygen	0.14 ton	Cooling Water	31 m^3
Fuel	1.2×10^6 Kcal		

A conceptual process diagram for the manufacture of PVC from ethylene and chlorine is given in Figure F-2.

REFERENCES FOR APPENDIX F

1) D.P. Keane, R.B. Stobaugh and P.L. Townsend, "Vinylchloride: how, where, who- future," Hydrocarbon Processing, February 1973, p. 99-110.

2) Vinyl Chloride - Mitsui Toatsu Chemicals, Inc., Hydrocarbon Processing, November 1971, p. 221.

3) B. Terwiesch, "Suspension-PVC in Large Reactors," Hydrocarbon Processing, November 1976, p. 117-121.

4) R.R. MacBridge, "PVC-Status Report," Modern Plastics, May 1974, pp. 44-46.

5) Polyvinyl Chloride - ATO Chemie, Hydrocarbon Processing, November 1977, p. 218.

6) Polyvinyl Chloride - Rhone Poulenc, Hydrocarbon Processing, November 1977, p. 220.

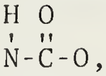
7) "Chemical Profile: PVC," Chemical Marketing Reporter, May 30, 1977, p. 9 and 35.

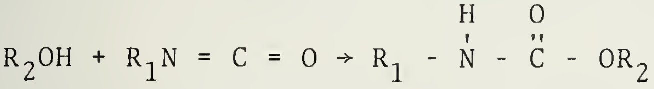
8) "Chemical Profile: Ethylene Dichloride," Chemical Marketing Reporter, May 16, 1977, p. 9.

APPENDIX G:

POLYURETHANES

G-1 INTRODUCTION

The polyurethanes are a conglomerate family of polymers in which formation of the urethane group,  $\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-O$, is an important step in the polymerization. The urethane group is usually the reaction product of an isocyanate, $-N=C=O$, with a hydroxyl, $-OH$, or other group that contains an active hydrogen that can react with the nitrogen in the isocyanate. A typical reaction is



$$R_2OH + R_1N = C = O \rightarrow R_1 - \overset{H}{\overset{|}{N}} - \overset{O}{\overset{\|}{C}} - OR_2$$

Alcohol Isocyanate Urethane

Polyurethanes are made by mixing bifunctional isocyanates with molecules that contain at least two active hydrogens, such polyols, diamines, amino alcohols, and water. Depending on the formulation and reaction procedure, the polyurethane produce can be obtained either as a rigid or flexible foam, a resilient elastomer, a structural plastic, a protective coating or an adhesive.

Polyurethane technology has grown rapidly since its inception in the late 1930's because it allows a user to make a desired product by mixing two liquids and pouring the reaction mixture into a suitable mold or container. Because of the extraordinary variety of formulations possible, polyurethane products can be produced to meet a broad spectrum of physical properties under controlled reaction conditions. With proper catalysts, a product can be made in less than a minute under essentially ambient conditions.

Polyurethanes are mainly used in the form of either flexible or rigid foam. Foam formulations contain isocyanates and polyols with suitable catalysts, surfactants for stabilization of the foam structure, and blowing agents which produce gas for expansion. The blowing agent may be a liquid with a low boiling point such as

Refrigerant 11, $CFCL_3$, or may be carbon dioxide, generated in situ by reaction of an isocyanate with water. Flexible foams are widely used as cushioning material for furniture, bedding, and transportation. They are also used as flexible insulation in apparel. Rigid polyurethane foams are currently the most efficient insulating material on the market for ambient and low temperature applications. Rigid foam also has superior buoyancy properties which is of value in marine applications. Higher density polyurethane foam is used in structural applications such as furniture, and as an energy absorbent in crash protection systems.

Solid polyurethane products, prepared under conditions where no gas generation occurs, also have found commercial use. Polyurethane elastomers and cast products are noted for their good abrasion resistance and low coefficient of friction. Polyurethanes are used in roller coatings and press pads, where they can outlast rubber by as much as tenfold. Other applications are gaskets, encapsulation, casting molds, timing belts, heels and soles.

Highly catalyzed polyurethane formulations that can react and form a solid product in less than 30 seconds are the basis of current RIM (Reaction Injection Molding) technology.

G-2 TYPICAL USES OF POLYURETHANES

	Flexible Foams	Rigid Foams	Solid Products
General:	Furniture cushioning	Insulation	Footwear
	Bedding	Refrigerators	Roller coatings
	Sleeping Bags	Housing	Gaskets
	Carpet Pads	Storage Tanks	
		Flotation Devices	
Automotive:	Seats	Air Conditioner Insulation	Fascia
	Crash Pad		Bumper Sight Shield
	Headrest Pad		

G-3 POLYURETHANE PRECURSORS

Isocyanates and polyols are the common raw materials used in the commercial preparation of polyurethane products. The most common polyurethane isocyanates are toluene diisocyanate (TDI) and 4,4' diphenyl methane diisocyanate (MDI). TDI is the principal isocyanate precursor. Polyether polyols are the primary polyols used commercially (85 percent of the market share), with the balance being mainly polyester polyols.

Refrigerant 11 ($CFCl_3$) is also an important raw material in the manufacture of rigid foams. Typical formulations contain 15 percent Refrigerant 11 as a blowing agent.

All other raw materials are used in trace quantities.

G-4 CURRENT PRICE OF POLYURETHANE AND PRECURSORS (1/1/78)

Polymeric MDI	58¢/lb
Polymeric TDI	54¢/lb
MDI	
TDI	
Flexible Slabstock Polyol	35¢/lb
Refrigerant 11	38¢/lb
Thermoplastic Polyurethane Resin	$1.35/lb

G-4 SUPPLY OF POLYURETHANE PRECURSORS

The polyurethane supply situation is best defined in terms of the availability of the key precursors, namely the isocyanates and the polyether polyols. U.S. manufacturing capacity of MDI and TDI is presented in Table G-1, and U.S. manufacturing capacity of polyether polyols is given in Table G-2. Currently, three manufacturers operate 4 MDI plants with a total capacity of 242,000 metric tons. A fourth manufacturer is currently not operating a 16,000 ton plant. A 23,000 ton expansion is planned for 1978. No data on 1979 expansions were obtained. By 1980, MDI capacity will be at least 250,000 metric tons (not including the currently inoperative facility). As far as TDI is concerned, eight manufacturers now operate nine facilities with a combined estimated capacity

TABLE G-1. POLYURETHANE PRECURSORS- ISOCYANATES: U.S. MANUFACTURING CAPACITY

Company	Location	Capacity as of 1/1/78	1978 Additions	1979 Additions	Capacity as of 1/1/80
		10^3 Metric Tons/Year			
MDI (4-4' DIPHENYL METHANE DIISOCYANATE)					
Jefferson Chemical	Port Neches, TX	16*			16*
Mobay	New Martinsville, WV	46			46
"	Baytown, TX	23	23		46
Rubicon	Geismar, LA	34			34
Upjohn	La Porte, TX	123			123
Total		242	23		265

*not in operation at present

Company	Location	Capacity as of 1/1/78	1978 Additions	1979 Additions	Capacity as of 1/1/80
TDI (TOLUENE DIISOCYANATE)					
Air Products	Pasadena, TX	-		57	57
Allied Chemical Co.	Moundsville, WV	38			38
ARCO	Channelview, TX	-		91	91
BASF Wyandotte	Geismar, LA	50			50
Dow Chemical Co.	Freeport, TX	45			45
E.I. Dupont de Nemours & Co.	Deepwater, NJ	45			45
Mobay	New Martinsville, WV	100		80	180
"	Baytown, TX				
Olin	Lake Charles, LA	60			60
Rubicon	Geismar, LA	20			20
Union Carbide	Institute, WV	25			25
Total		383		228	611

TABLE G-2. POLYURETHANE PRECURSORS-POLYOLS U.S. MANUFACTURING CAPACITY

Company	Capacity as of 1/1/77	1978 Additions	1979 Additions	Capacity as of 1/11/80
BASF Wyandotte	150			
Choate	45			
Dow Chemical	180			
Jefferson Chemical	45			
Mobay	45			
Olin	95			
Union Carbide	200			
Others	70			
Total	835			

of 403,000 metric tons. Over the next two years, capacity will increase by 228,000 metric tons to a projected total capacity of 631,000 metric tons by 1980, divided among ten manufacturers.

Over 90 percent of polyol capacity is distributed over the seven manufacturers listed in Table G-2. The balance of production is distributed over at least ten other firms. The data presented in Table G-2 is the most current compilation obtained.

G-6 DEMAND

Total consumption of polyurethanes in 1977 was 811,000 metric tons, based on data published in Modern Plastics. Of the total, 597,000 metric tons were consumed as flexible foam, 199,000 metric tons were consumed as rigid foam and 15,000 metric tons as thermoplastic polyurethane. No data were published explicitly for castable polyurethane consumption, which may be included in the polyurethane foam statistics. According to the SPI, in 1976, consumption of polyurethane products, other than foamed polyurethane and thermoplastic polyurethane, was about 77,000 metric tons. If castable and millable polyurethane are not included in the 811,000 metric tons, it is estimated that total polyurethane consumption in the U.S. in 1977 was about 900,000 metric tons. The major market for polyurethanes was the furniture and bedding industry, which consumed 347,000 metric tons, principally flexible foam. Transportation equipment consumed 204,000 metric tons, nearly 87 percent as flexible foam. Building insulation, which consumed 87,000 metric tons, was the third largest total user, and the largest user of rigid foam. Automotive use was estimated to be 182,000 metric tons for model year 1977, as shown in Table G-3 and Figure G-1.

The limited data obtained on precursor consumption are presented in Table G-4 and Figure G-2. No 1977 consumption data were obtained for the precursors. During the 1972 to 1976 period, since polyurethanes are the major use of isocyanate chemicals, total isocyanate consumption was closely correlated to total polyurethane consumption. During that period, an average of 0.58 lbs of TDI + MDI was consumed per pound of polyurethane. In any one

TABLE G-3. U.S. CONSUMPTION OF POLYURETHANES

Year	Flexible Foam Consumption	Rigid Foam Consumption	Other Consumption (Thermoplastic Polyurethane)	Total Consumption	Transportation Consumption	Automobile Consumption
			1000 Metric Tons/Year			
1967	165	57	No Data	222	64	No Data
1968	207	70	"	277	82	"
1969	261	95	"	356	97	"
1970	259	109	"	369	109	73
1971	306	108	"	414	137	86
1972	365	128	"	493	150	105
1973	434	159	"	593	176	136
1974	454	170	16	640	196	125
1975	457	153	13	623	172	155
1976	552	173	15	740	195	200
1977	597	199	15	811	204	182
1978					243	198
1980				900[1]	210[1]	189[1],250[2]
1985						360[2]
1990						400[2]

Source: Modern Plastics Magazine, Annual January Industry Review unless otherwise indicated

[1] Data from SPI, 1977 Edition Facts and Figures - Figures do not include non-foam polyurethane products which would increase values by 15 percent.

[2] C & E News, September 12, 1977, p. 15.

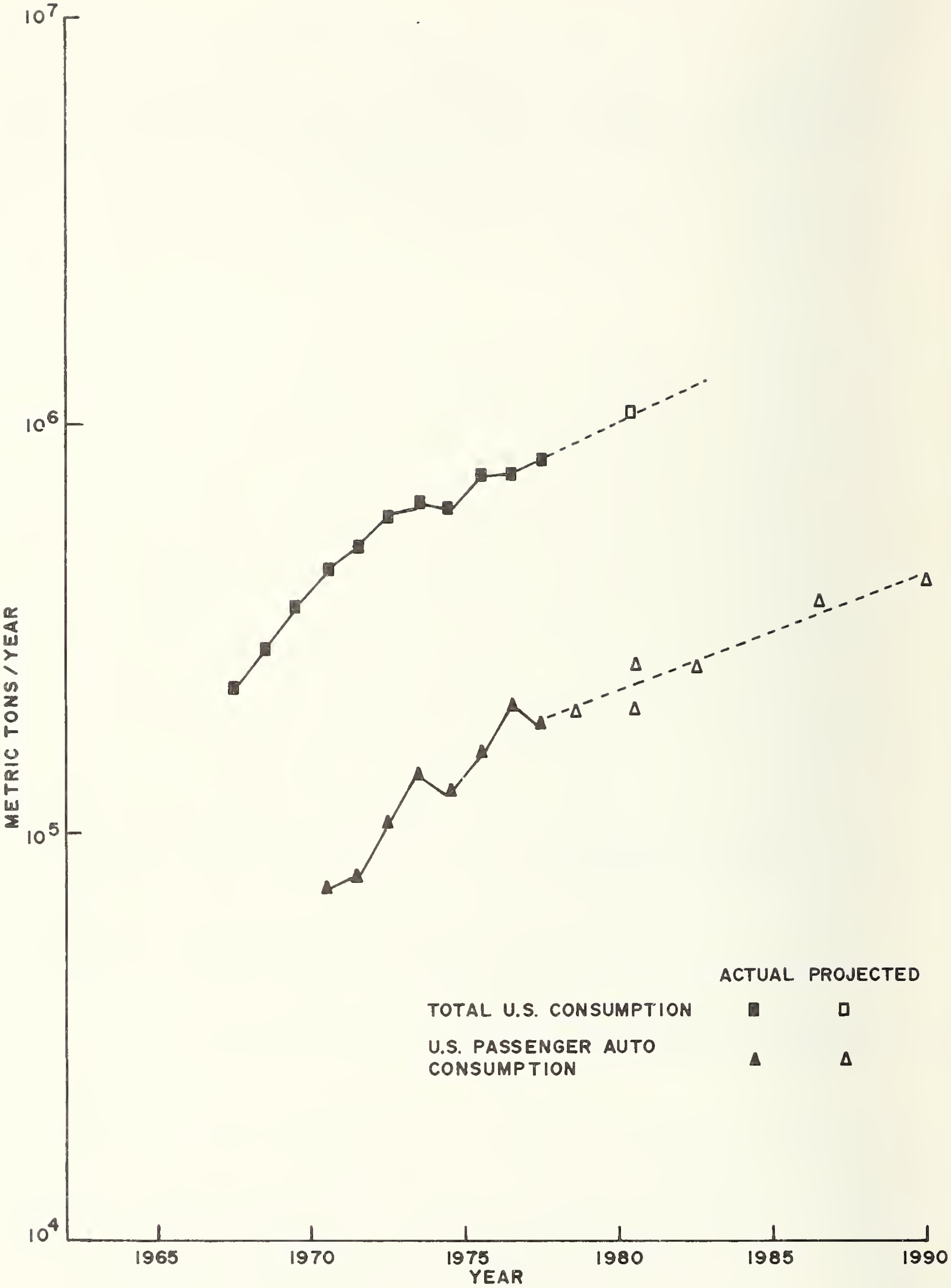


FIGURE G-1. POLYURETHANES

TABLE G-4. STATUS- POLYURETHANE PRECURSORS

	Polyether Polyol		TDI		MDI	
Year	Capacity	Consumption	Capacity	Consumption	Capacity	Consumption
	10^3 Metric Tons/Year					
1972		460(1)		89(1)		90(1)
1973		499(1)		215(1)		134(1)
1974		434(1)		217(1)		156(1)
1975	730(3)	395(1)	298(3)	198(3)	181(3)	143(1),136(2)
1976	730(3)	548(1)	298(3)	255(1)	181(3)	177(1),170(2)
1977	835(3)		383(3)		242(3)	
1978			383(4)		242(4)	
1979						
1980			611(4)		265(4)	250[2]

Source:

1) SPI, Facts & Figures of the Plastics Industry
2) Chemical Marketing Reporter, February 21, 1977, p. 9
3) Modern Plastics, Industry Review, January 1975
4) Estimate

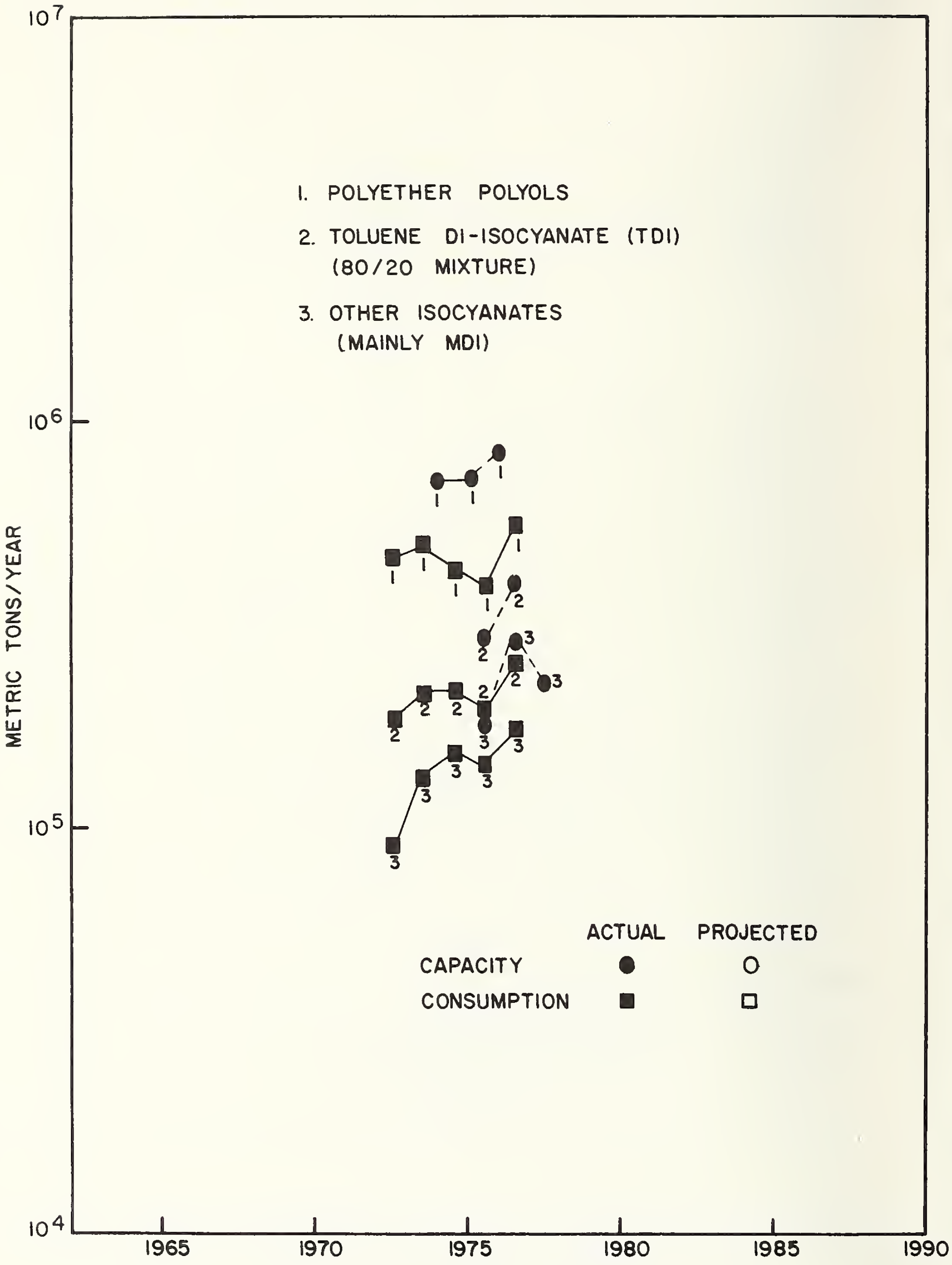


FIGURE G-2. POLYURETHANE PRECURSORS

year, the ratio ranged from 0.55lbs/lb to 0.59 lbs/lb. The TDI to MDI ratio was proportional to the ratio of flexible foam to rigid foam, or approximately 5 to 3. Assuming these ratios to be valid for 1977, it is estimated that in 1977, consumption of TDI was 290,000 metric tons, and that of MDI was 180,000 metric tons.

The correlation between polyurethane consumption and polyol consumption is not as distinct as the correlation between polyurethane consumption and isocyanate consumption. Between 1972 and 1975, apparent polyol consumption per unit weight polyurethane produced decreased from a value of 0.93 lb/lb in 1972 to 0.63 lb/lb in 1975. In 1976 a value of 0.74 lb/lb was noted. This variation reflects other uses for polyesters than polyurethanes, and the use of polyester polyols in lieu of the polyether polyols in polyurethane formulations. Assuming the 1976 ratio of 0.74 lb/lb to be valid for 1977, it is estimated that polyol consumption was 600 metric tons that year.

Exact data for 1977 TDI, MDI, and polyol consumption will be available upon public release later this year of the next semi-annual report of the SPI Committee on Resin Statistics.

G.7 PROJECTED GROWTH FOR POLYURETHANE

Compounded annual growth data for polyurethanes are presented in Table G-5 for the different classes of polyurethane materials. Over the past ten years, polyurethane consumption increased at the rate of approximately 11 percent per year. However, over the past five years, growth averaged only 6.5 percent. Transportation and automotive growth rates were less than the total growth rates, particularly in the last five years. Extensive use is already made of flexible foams in automotive applications so that further growth will depend on increased use of rigid foams to improve the crashworthiness of an automobile, for example, or in castable or microcellular polyurethanes, in various body components. It is doubtful that the 1968-1977 growth rate in transportation will be maintained over the next 10 years in view of the current extensive use of polyurethanes in automobiles, but an annual growth rate of

TABLE G-5. POLYURETHANES- GROWTH TRENDS

		Annual Growth Rate Percent		
	Period	Total	Transportation	Automobile
Total Polyurethane Consumption	1968-1977	11.3	9.5	No Data
	1973-1977	6.5	3.0	6.0
	1976-1977	9.6	4.6	(9.1)?
Flexible Polyurethane Foam	1968-1977	11.2	10.1	No Data
	1973-1977	6.6	2.7	"
	1976-1977	8.2	4.1	"
Rigid Polyurethane Foam	1968-1977	11.1	6.3	No Data
	1973-1977	4.6	3.5	"
	1976-1977	15.0	8.7	"

6 to 8 percent appears to be reasonable.

G.8 MANUFACTURING

The manufacture of polyurethane components involves the mixing of the various precursors in suitable equipment. This step is akin to the fabrication of components from other polymers by operations such as molding, pultrusion, etc. In this case, the product manufacturing concept applies to the manufacture of the various precursors of interest.

G.9 TDI MANUFACTURE

Toluene diisocyanate is made by nitrating toluene to dinitrotoluene (DNT), reducing the DNT to toluene diamine (TDA), and reacting TDA with phosgene made on site, to form toluene diisocyanate (TDI) which is purified to specifications.

Toluene is nitrated by mixed acids (sulfuric acid and nitric acid) in a continuous reactor to form crude DNT. After separation and purification, DNT is catalytically reduced to TDA by hydrogen in a liquid phase reactor at moderate pressure (5 ATM - 20 ATM). Crude TDA is then purified by distillation to obtain pure TDA. The pure TDA is then dissolved in o-dichlorobenzene (O-DCB), and caused to react with phosgene also dissolved in O-DCB, to form crude TDI. The phosgenation product is then subjected to a series of distillations to eliminate impurities, light ends, and heavy ends, and to adjust the ratio of ortho TDI to para TDI to the desired ratio of either 80/20 or 65/35.

Phosgene is normally produced on site by reacting carbon monoxide with chlorine over an activated charcoal catalyst.

As outlined in Figure G-3, consumption of raw materials per ton of TDI produced are estimated to be:

Toluene, ton	0.68
Methane, ton	0.52
Sulfuric Acid (100% basis), ton	0.77
Chlorine, ton	2.99

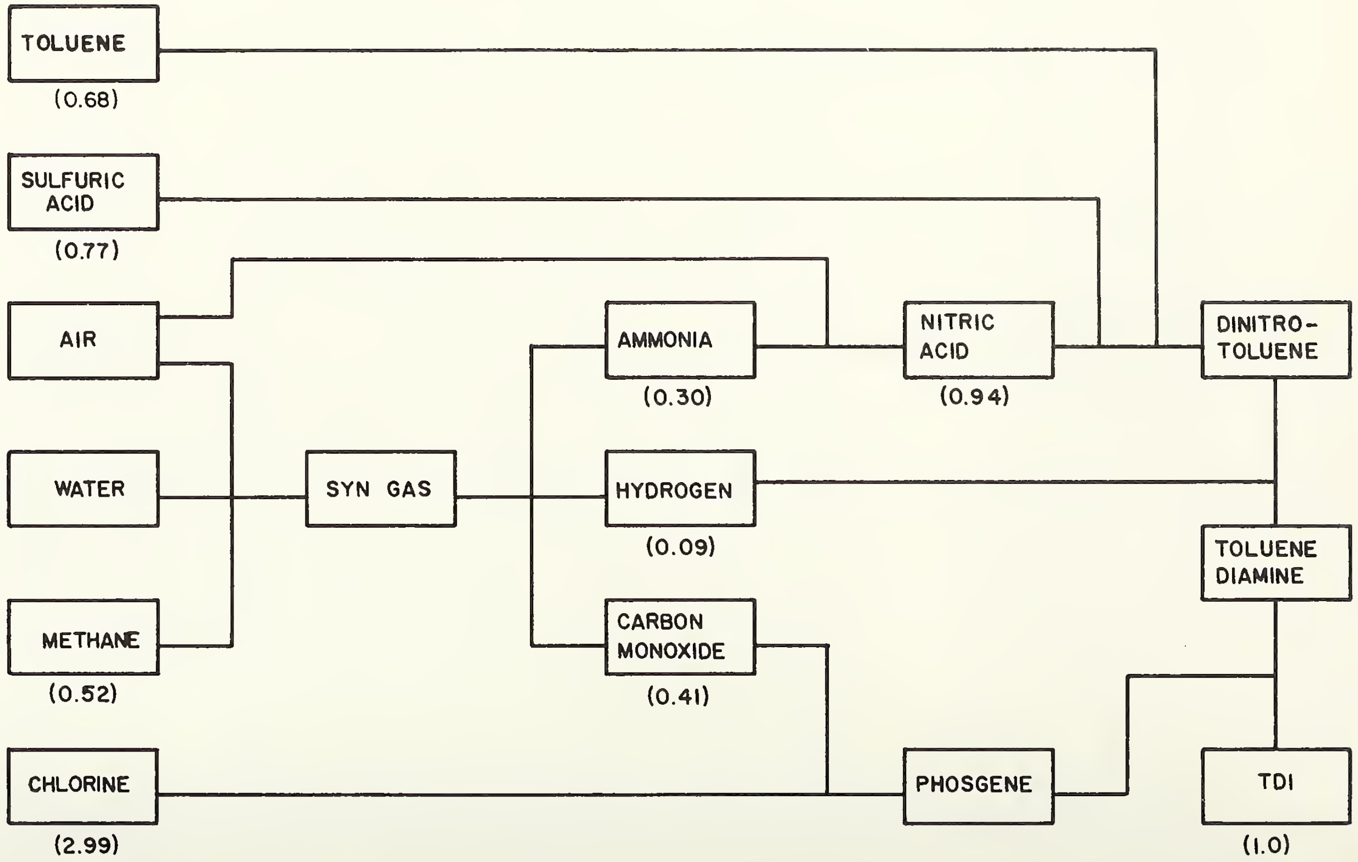
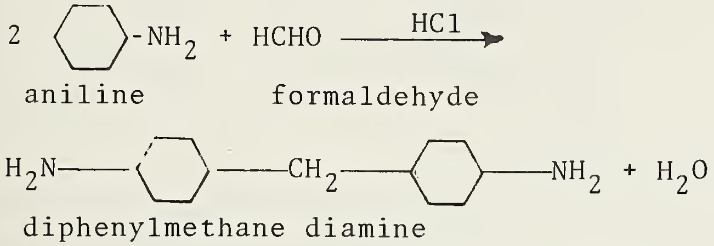


FIGURE G-3. SYNTHESIS OF TOLUENE DIISOCYANATE (TDI)
A POLYURETHANE PRECURSOR

G-10 MDI MANUFACTURE

The manufacture of MDI starts with the reaction of aniline with formaldehyde to form diphenylmethane diamine (DPMDA) and water:



MDI is then made by reacting diphenylmethane diamine with phosgene in an analogous manner to the formation of TDI from TDA as discussed above.

Aniline is classically made by first nitrating benzene with mixed acids to form nitrobenzene, which is then reduced to aniline by hydrogenation. An alternate process for the manufacture of aniline from benzene which uses phenol as an intermediate has been developed by Halcon International. In this process, aniline is formed directly by reacting phenol with ammonia in a vapor phase catalytic reactor.

There are number of processes available which synthesize phenol from benzene. One of the major processes involves reacting benzene with propylene to form cumene. Cumene is then oxidized to cumene hydroperoxide which decomposes into phenol and acetone. Phenol represents 69 percent and acetone 43 percent by weight of the cumene charged to the process.

Based on 1976 data publised by Gans, it is estimated that a 90,000 metric ton per year benzene to aniline battery limits plant would now cost approximately $41 MM to $45 MM, for either the nitrobenzene or phenol process. The capital investment needed to convert the aniline produced to MDI is estimated to be twice this amount. This results in a total capital investment of $80 MM to $90 MM for a 110,000 Ton/Year MDI plant, assuming an aniline to MDI yield of 80 percent. This corresponds to a capital investment of about $900 per annual ton. In comparison, a 30,000 Ton/Year plant would cost $41MM, or $1400 per annual ton.

As outlined in Figure G-4, raw material requirements per ton of MDI for a grass roots plant are estimated to be:

Benzene, Tons	0.85
Propylene, Tons	0.48
Methane, Tons	0.27
Chlorine, Tons	2.08

G-11 POLYETHER POLYOLS

The polyether polyols used as co-reactments in the synthesis of polyurethanes are prepared principally by the addition of 1, 2 propylene oxide to hydroxyl or amino in the presence of a strong base catalyst. Choice of the initiating molecules and of the amount of propylene oxide added controls both the functionality and molecular weight of the polyol. Since 1, 2 propylene oxide normally adds to leave terminal secondary hydroxyl groups, ethylene oxide is often added to form polyols capped with primary hydroxyls which react more readily with isocyanates. The principal raw material in the above synthesis is propylene oxide.

Propylene oxide is produced by two major processes, chlorohydrination of propylene, and a newer, direct oxidation process developed by Oxyrane. In the hydrochlorination process, propylene is reacted with hypochlorous acid to form propylene chlorohydrin, which is then decomposed by the addition of lime to yield propylene oxide and calcium chloride. The major disadvantages of this process are the costs of chloring consumed to make hydrochlorous acid and of disposing large amounts of waste brine solution.

In the direct oxidation process, propylene is reacted with a hydrocarbon peroxide to form propylene oxide and an olefin. The composition of the olefin depends on the choice of the hydrocarbon use to form the hydrocarbon peroxide. The Oxirane process is operated with either isobutene or ethyl benzene as the peroxidation feed stock. This results in the formation of either isobutylene or styrene as a coproduct. Oxyrane's facility in Channelview, Texas produces styrene as the coproduct. The major

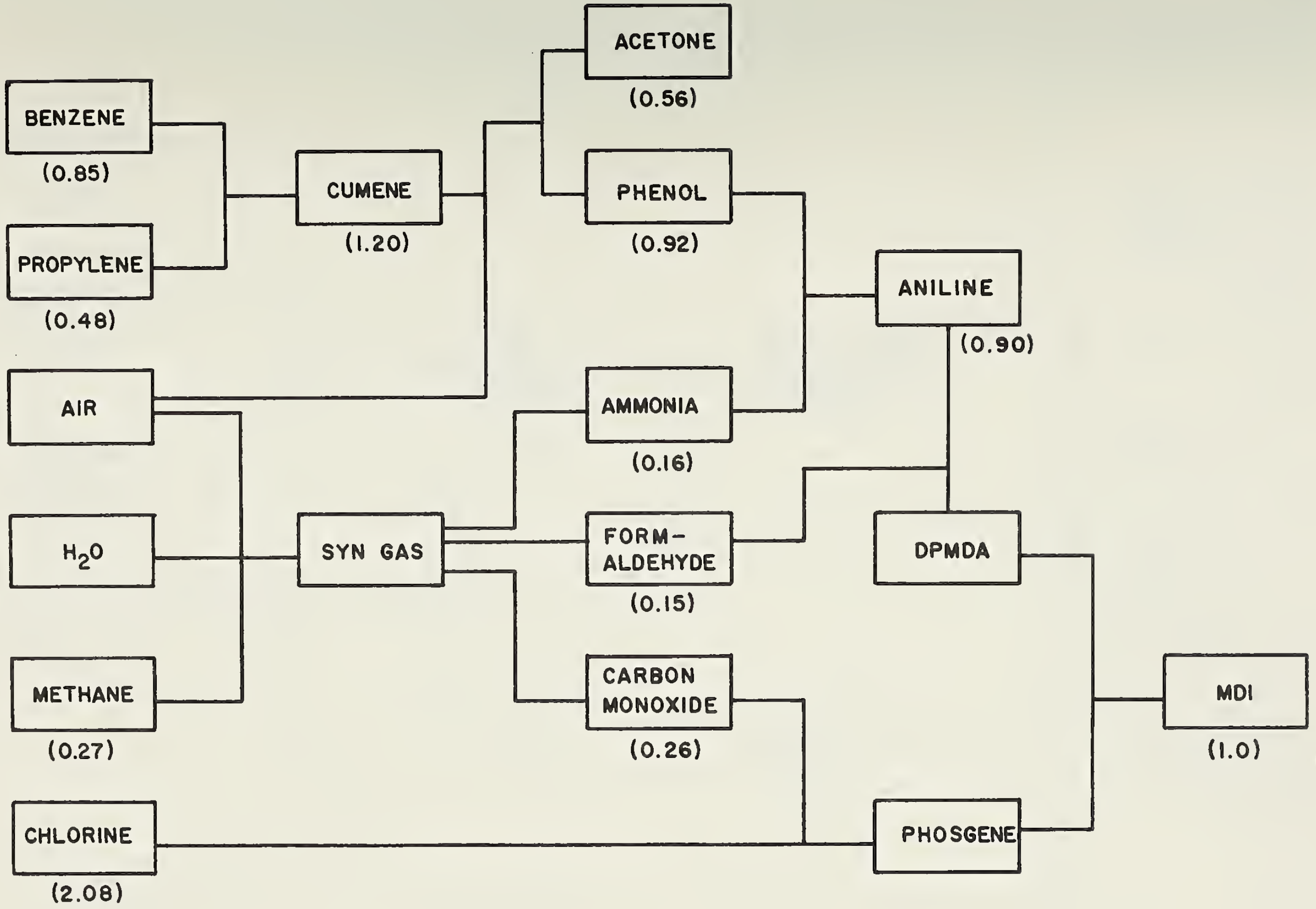


FIGURE G-4. SYNTHESIS OF DIPHENYL METHANE DIISOCYANATE (MDI)
A POLYURETHANE PRECURSOR

disadvantage of the direct oxidation process for propylene oxide is that propylene oxide production is only half the coproduct output, in this case styrene. The process depends on a good market for both propylene oxide and styrene.

As outlined in Figure G-5, the raw material consumption per ton of polyether glycol produced is esimated to be:

Benzene, tons	1.7
Ethylene, tons	0.7
Propylene, tons	0.7

Approximately 1.8 tons of styrene are coproduced.

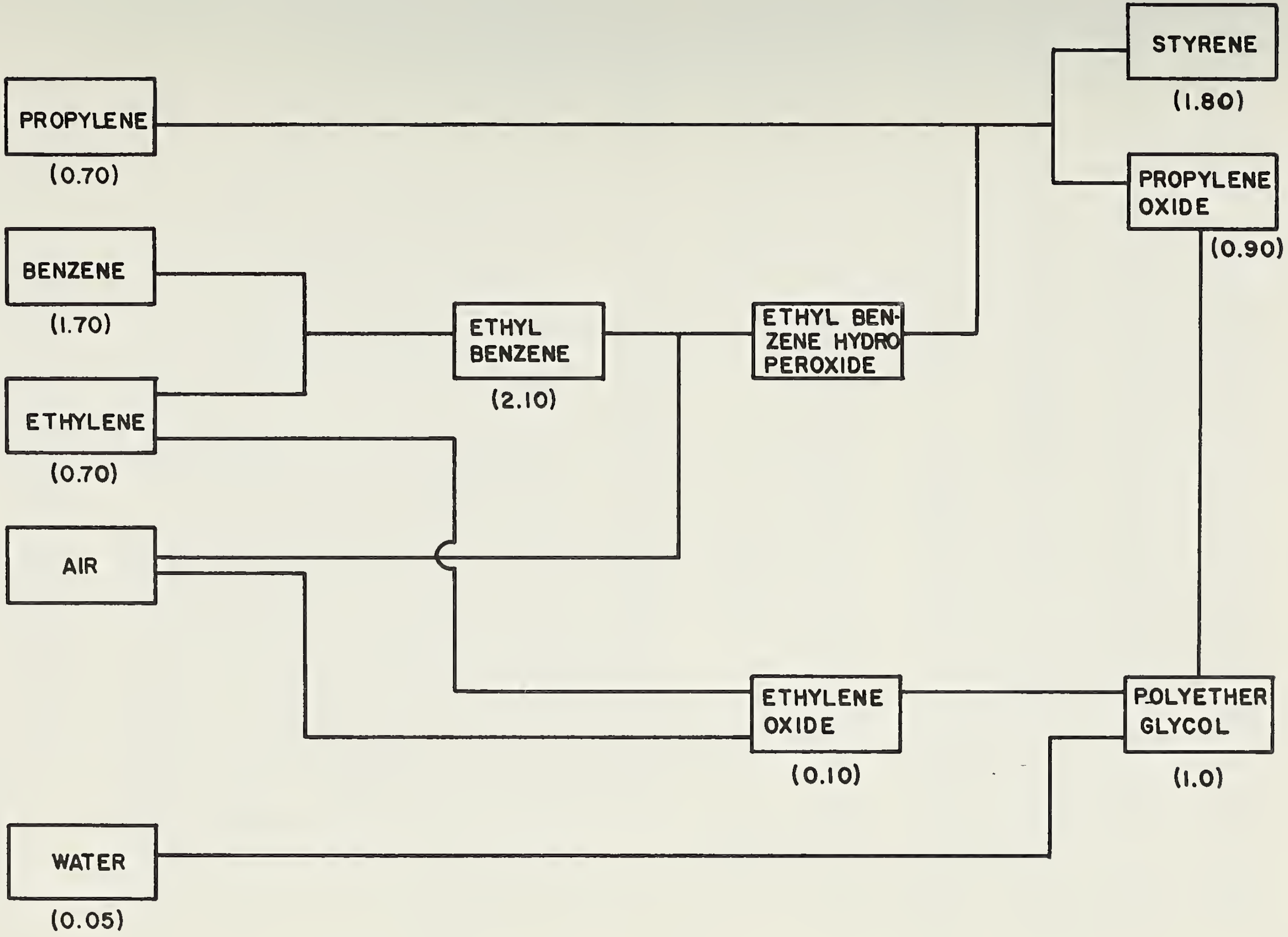


FIGURE G-5. SYNTHESIS OF POLYETHER GLYCOL (POLYURETHANE PRECURSOR)

REFERENCES FOR APPENDIX G

1) Facts and Figures of the Plastics Industry, 1977, p. 41-46, Society of the Plastics Industry, New York, 1977.

2) "MDI, Chemical Profile," Chemical Marketing Reporter, February 21, 1977, p. 9.

3) "Phosgene, Chemical Profile," Chemical Marketing Reporter, February 28, 1977, p. 9.

4) "Polyurethanes - Status Report," Modern Plastics, December 1974, p. 60.

5) R.B. Stobaugh, et al., "Propylene Oxide, How, Where, Who - Future," Hydrocarbon Processing, January 1973, p. 99-108.

6) M. Gans, "Which Route to Aniline," Hydrocarbon Processing, November 1976, p. 145-150.

7) "Aniline Process, Lonza/First Chemical Corp." Hydrocarbon Processing, November 1977, p. 131.

8) "Toluene Diisocyanate Process, Mitsubishi Chemical Industries, Ltd." Hydrocarbon Processing, November 1971, p. 213.

9) "Toluene Diisocyanate Process, The Leonard Process Co., Inc." Hydrocarbon Processing, November 1969, p. 242.

10) "Xylylene Diisocyanate Process, Takeda Chemical Industries, Ltd." Hydrocarbon Processing, November 1975, p. 222.

11) "Ethylene Glycol Ether Process, Shell Development Co.," Hydrocarbon Processing, November 1977, p. 160.

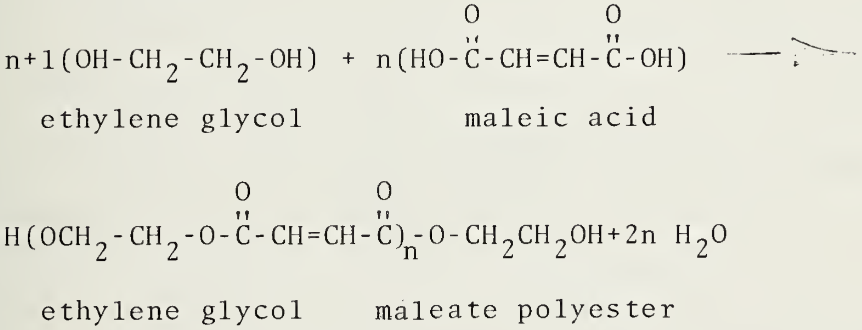
12) "Plastics Monomers Settle into Slower Growth," C and E News, August 18, 1977, p. 9-12.

APPENDIX H:

UNSATURATED POLYESTER

H-1 INTRODUCTION

The essential ingredients in commercial polyester resins are a linear polyester resin that contains unsaturated bonds in its structure, a cross linking monomer, and inhibitors to prevent premature cross linking polymerization. In a typical formulation, propylene or ethylene glycol are reacted with maleic acid, as well as other dibasic acids such as phthalic acid, to form a linear polyester. For example



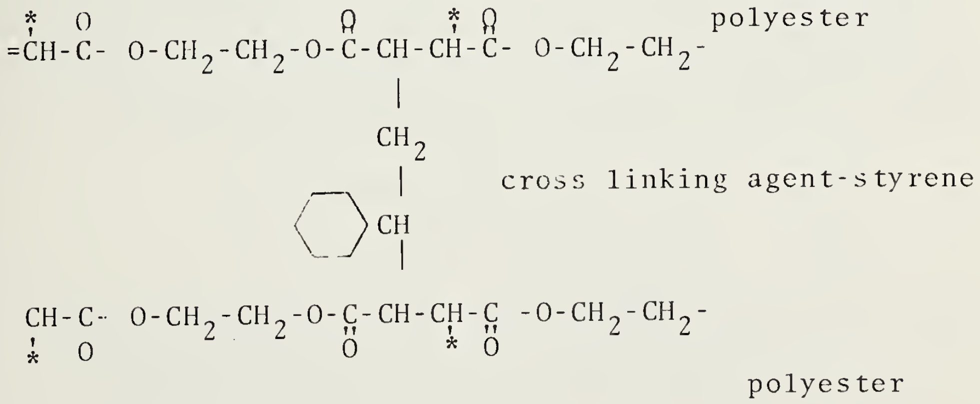
$$n{+}1(\mathrm{OH{-}CH_2{-}CH_2{-}OH}) + n(\mathrm{HO{-}\overset{O}{\overset{\|}{C}}{-}CH{=}CH{-}\overset{O}{\overset{\|}{C}}{-}OH}) \longrightarrow$$

ethylene glycol maleic acid

$$\mathrm{H(OCH_2{-}CH_2{-}O{-}\overset{O}{\overset{\|}{C}}{-}CH{=}CH{-}\overset{O}{\overset{\|}{C}})_n{-}O{-}CH_2CH_2OH} + 2n\ \mathrm{H_2O}$$

ethylene glycol maleate polyester

The polyester units react (copolymerize) with a cross linking agent such as styrene monomer in the presence of a free radical catalyst (peroxide) and/or heat to yield styrene-polyester copolymer resin, or more commonly, a cured polyester product:



---

*Double bond addition sites

Polyester can be formulated to have a wide range of physical properties. It can be brittle and hard, tough and resilient, or soft and flexible. Viscosities at room temperature may range widely. By the appropriate choice of ingredients, particularly in the formation of the linear polyester resin, special properties can be imparted. Fire retardance is conferred by the use of a halogenated intermediate such as tetrabromophthalic anhydride. Use of isophthalic acid increases chemical resistance.

Polyesters can be employed to fabricate a myriad of products by numerous techniques which include open mold casting, hand layup, spray up, bag molding, matched metal die molding, pultrusion, filament winding, etc. The combination of thermosetting unsaturated polyester resins with glass fiber accounts for the bulk of reinforced plastics products. For molding operations, the polyester resin is often compounded with other ingredients into a doughlike mass which is easier to handle and shrinks less upon curing. Bulk molding compound (BMC) is a form of premix that contains thickening agents (such as calcium carbonate), chopped fiber glass, and additives to minimize shrinkage. Sheet molding compound (SMC) consists of polyester resins which are thickened with alkaline earth oxide and combined with filler and additives, to which fiber glass rovings are then added. SMC is formed as a sheet which can then be easily handled in the molding operation. A typical molding compound contains 30 percent resin, 30 percent glass fibers and 40 percent filler. Molding compounds with a much higher glass content that may include continuous strands, are also being introduced (so-called HMC and XMC).

H-2 TYPICAL USES OF UNSATURATED POLYESTERS

General applications:

- Boat Hulls
- Bowling Balls
- Buttons
- Corrugated Panels
- Imitation Marble
- Shower Stalls

Automotive Applicatons:

Exterior:

Front End Panel	Truck Hood Assembly
Rear Wheel Opening Cover	Truck Tilt Front End Assembly
Rear Roof Air Deflector	Truck Engine Cover
Head Lamp Panel	Truck Fan Shroud
Corvette Body Panels	Truck Fender

Interior:

Arm Rest Base	Instrument Panel Cover

Under the Hood:

Fresh Air Vent	Air Conditioner Housing

Unreinforced Polyester - Body Putty

H-3 CURRENT PRICE FOR UNSATURATED POLYESTER RESIN (1/1/78)

General Purpose Resin	36¢/lb

H-4 SUPPLY

Current polyester manufacturing capacity is estimated to be approximately 900,000 metric tons/year. There are at least thirty manufacturers of unsaturated polyester resin in the United States, eighteen of which have a plant capacity greater than 10,000 metric tons per year, as shown in Table H-1. Two manufacturers will be increasing supply by 24,000 tons in 1978, and a new manufacturer will be bringing a 45,000 ton/year on stream in early 1979. Historical supply data are also presented in Table H-2 and in Figure H-1.

H-5 DEMAND

Total sales of unsaturated polyester resins were 477,000 tons in 1977. About 78 percent of this total was used in reinforced polyester products. Major uses were construction (29 percent of total resin production), marine and marine applications (21 percent) and transportation (15 percent). Transportations uses

TABLE H-1. UNSATURATED POLYESTER RESIN U.S. MANUFACTURING CAPACITY

Producer	Capacity as of 1/1/78	1978 Additions	1979 Additions	Projected Capacity as of 1/1/80
	10^3 Metric Tons/Yr			
American Cyanamid	34			34
Ashland	80			80
Cargill	55			55
Diamond Shamrock	14			14
Freeman	32	9		41
W R Grace	115			115
ICI United States	11			11
Interplastics	45			45
Koppers	45	15		60
North American Rockwell	18			18
Owens-Corning	45			45
PPG Industries	70			70
Reichhold	160			160
Rohm and Haas	10			10
Stepan	11			11
U.S.S. Chemical			45	45
Vistron, Silmar Div.	35			35
Whittaker	11			11
Others	75			75
Total	900	24	45	979

TABLE H-2. STATUS- UNSATURATED POLYESTER RESINS

1000 Metric Tons/Year

Year	Total Capacity At Year Start	Total Consumption	Transportation Consumption		Automobile Consumption	
1967		201				
1968		244				
1969		292				
1970		278	54*		33*	
1971		316	38*		33*	
1972		416	45*		38*	
1973		468	51*		44*	
1974		404	50*	59.5(1)	40*	
1975	730	350	48*	54.4(1)	40*	
1976	778	436	67*	65.8(1)	60*	
1977	870	477	90*		81*	64*(3)
1978	900		105*		93*	
1979	924				120*(2)	
1980	979				119*(1)	107*(3)
1985					250*(3)	
1990					410*(3)	

(*) Based on Reinforced Polyester statistics, assuming a 60% polyester content.

Source: Modern Plastics Annual Industry Review, January issue unless noted otherwise.

1) SPI 1977 Facts & Figures
2) Modern Plastics, October 1977, p. 41.
3) C & E News, September 12, 1977, p. 15.

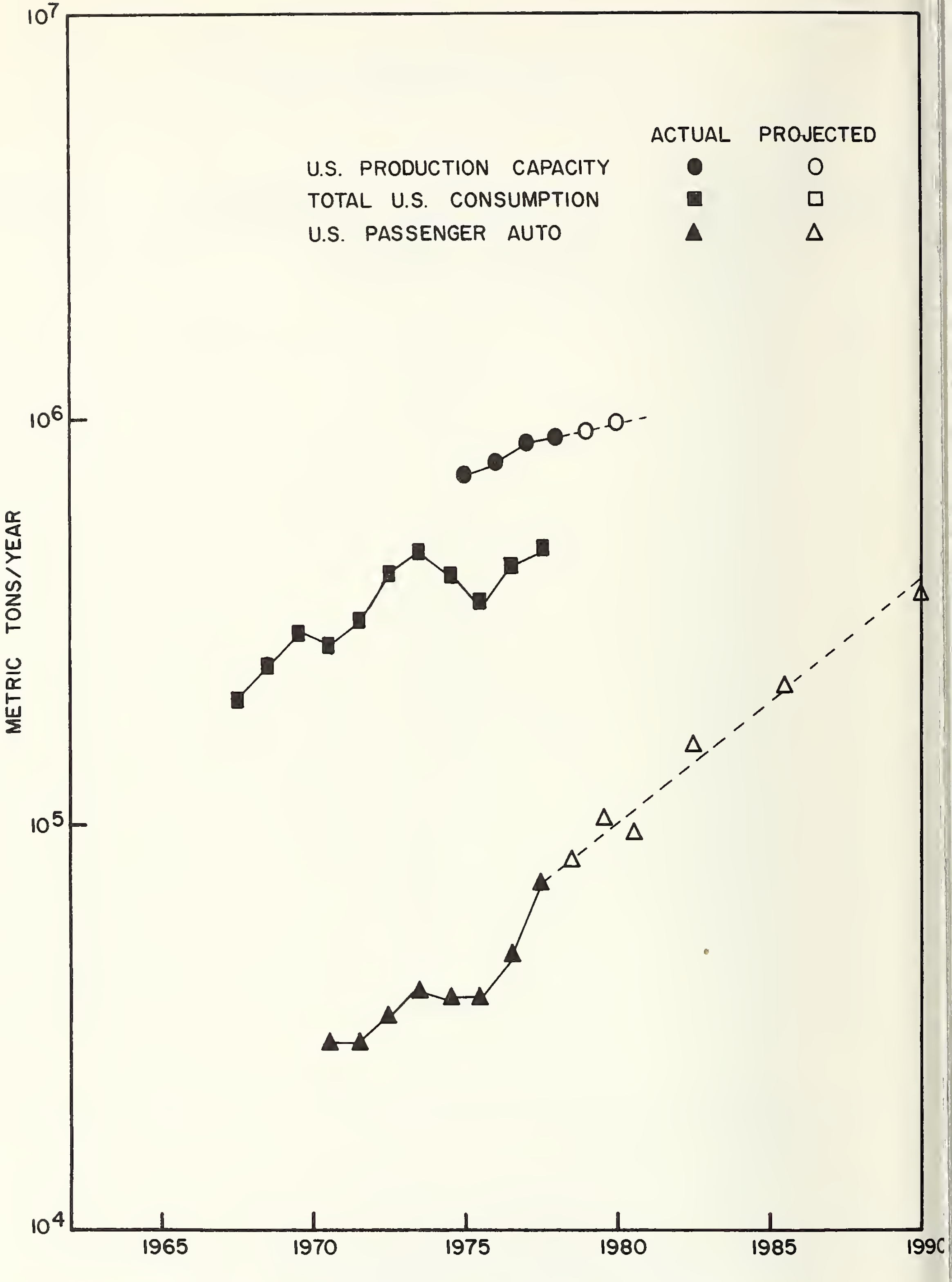


FIGURE H-1. UNSATURATED (THERMOSETTING) POLYESTERS include both reinforced and nonreinforced plastics applications. Historical supply and demand data for unsaturated polyester resins are presented in Table H-2.

Consumption data with regards to polyester resin are usually presented in terms of the consumption of formulated reinforced polyester resin which includes the weight of any fiber glass and other additives and fillers included in the formulation. Consumption data on fiberglass reinforced polyester are presented in Table H-3. The estimated transportation and automobile consumption of unreinforced polyester was obtained by multiplying the published values for reinforced polyester consumption by 0.60, the average polyester content of reinforced polyester consumed in the past eight years. This average content was based on consumption statistics of polyester used as reinforced plastics and of fiberglass reinforced polyester, as shown in Table H-4. Prior to 1970, Modern Plastics published consumption data on reinforced plastics rather than reinforced polyester. The pre-1970 data are not comparable to the post-1970 statistics.

The Modern Plastics data do not include unreinforced polyester consumption in transportation or automotive use. This application is included in the SPI data which were available at this time for 1974 through 1976 only. Autobody consumption of polyester resin was 13,600 metric tons in 1974, 11,800 metric tons in 1975 and 19,100 metric tons in 1976. This consumption is included in the SPI statistics presented in Table H-3. It is presumed that a significant fraction of unreinforced polyester is used in the repair of accident damaged automobiles.

H-6 PROJECTED GROWTH FOR POLYESTER RESINS

Compounded annual growth for unreinforced polyester resins was as follows:

Period	Total	Transportation	Automobile
1968-1977	6.9%	No Data (15% estimate)	No Data (15% estimate)

TABLE H-3. U.S. CONSUMPTION OF FIBERGLASS REINFORCED POLYESTER COMPOSITES

Year	Total U.S. Consumption	Transportation Consumption	Automobile Consumption
	10³ Metric Tons/Year		
1970	311	90.8	54.5
1971	409	63.6	54.5
1972	489	74.5	63.6
1973	555	85.7	72.7
1974	551	84.0	70.0
1975	480	80.5	70.0
1976	635	112.4	100
1977	700	150.0	135
1978		175	155
1979			200(2)
1980			198(1), 179(3)
1985			417(3)
1990			690(3)

Source: Modern Plastics Annual Industry Review in January issue, unless noted otherwise

1) SPI, 1977 Facts & Figures
2) Modern Plastics, October 1977, p. 41.
3) C & E News, September

Period	Total	Transportation	Automobile
1975-1977	0.4%	12.0%	13.0%
1976-1977	9.4%	34.3%	35. %
Reinforced Polyester Consumption			
1970-1977	9.8%	6.5%	12.0%
1976-1977	10.2%	33.5%	35.0%

It is expected that polyester consumption, particularly reinforced polyester consumption, will continue to grow over the next decade because of the relatively low cost, and the ease and flexibility of fabrication. The 1970-1977 trend lines should be applicable over the next decade. By 1990, automotive consumption of reinforced polyester should approach 1977 total consumption of this material. Fiber to resin ratios may shift as the industry continues to develop high volume fabrication processes capable of incorporating high concentrations of continuous strand filaments into the resin matrix. The resulting reinforced plastic would be a structural composite with significantly better mechanical properties than current chopped fiber composites.

H-7 MANUFACTURING

Unsaturated polyesters are manufactured by reacting diacids with glycols. The esterification of a mixture of di-acids or their anhydrides such as phthalic acid and maleic acid, with an equimolar quantity of a glycol, such as propylene glycol or ethylene glycol, is carried out in a well stirred batch reactor maintained at an elevated temperature ($\sim 200^{\circ}C$). Water of reaction is condensed overhead. In a process variation, one company uses propylene oxide as a feed to eliminate the formation of water during esterification. The reaction is carried out under an inert atmosphere of nitrogen or carbon dioxide to prevent product deterioration and discoloration. The linear diester is removed from the first reactor, and is then blended with styrene and an inhibitor in a second externally cooled reactor. Individual batches are then blended in a large homogenization tank, from which the final

TABLE H-4. ESTIMATION OF POLYESTER CONTENT IN FIBERGLASS REINFORCED POLYESTER COMPOSITES

Year	Polyester Consumption in Reinforced Polyester	Reinforced Polyester Consumption	Ratio
	10^3 Metric Tons/Year		
1970	191	231	.577
1971	274	409	.670
1972	326	489	.667
1973	363	555	.654
1974	314	551	.570
1975	270	480	.563
1976	335	635	.528
1977	370	700	.529
	8 years average		.60

product is withdrawn for storage or sale.

Process requirements per ton of polymer produced are typically:

Feedstocks:	
Propylene glycol, kg	35 - 280
Propylene oxide, kg	0 - 220
Phthalic anhydride, kg	250 - 260
Maleic anhydride, kg	150 - 170
Styrene, kg	340 - 400
Utilities:	
Electricity, KwH	30 - 220
Steam, Tons	0.025 - 0.4
Cooling Water, m^3	20 - 60
Inert gas, m^3	4 - 13

A synthesis diagram is given in Figure H-2.

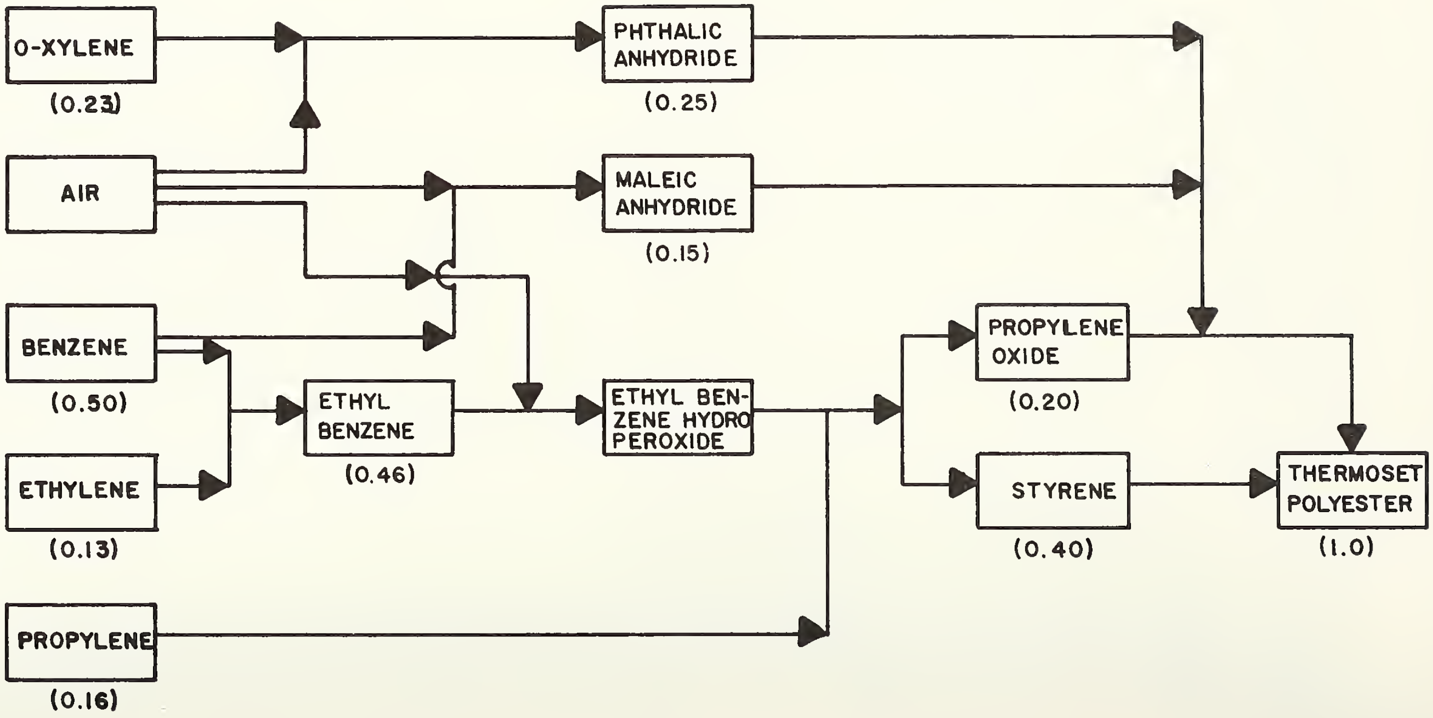


FIGURE H-2. SYNTHESIS OF THERMOSETTING POLYESTER RESIN

REFERENCES FOR APPENDIX H

1) "Polyesters, Status Report," Modern Plastics, January 1975, p. 59.

2) "Polyester Process," Societe Chimique des Charbonnages, Hydrocarbon Processing, November 1975, p. 181.

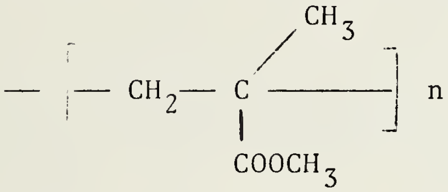
3) J. C. Zimmer, "Cut Polyester Costs - Use PO," Hydrocarbon Processing, December 1977, p. 115.

APPENDIX I:

ACRYLIC RESINS

I-1 INTRODUCTION

Acrylics are a family of polymers based on polymethol methacrylate that have the basic chemical structure shown below:



Acrylics are better known under the commercial trade names of Lucite (E.I.duPont) and Plexiglas (Rohm and Haas Co.). Acrylics have exceptional optical clarity, good weather resistance and adequate mechanical properties. Their weakness is that they are attacked by gasoline and other solvents. Acrylics can be injection molded, extruded, cast, vacuum or pressure formed and machined.

I-2 TYPICAL USES OF ACRYLICS

General:

- Boat Windshields
- Airplane Canopies and Windows
- TV Shields
- Skylights

Automotive:

- Bus Glasing
- Tail light lenses

I-3 CURRENT PRICE FOR ACRYLIC RESINS (January 1, 1978)

Molding Powder	56¢/lb

I-4 SUPPLY

There are currently five suppliers of acrylic resins in the United States with a combined plant capacity of about 500,000 tons/year. The five manufacturers are Rohm and Hass, Inc., I.E. duPont de Nemours & Co. Inc., Continental Polymers Corp. (Compton, CA), Richardson Co., Polymeric Systems Division (Madison, CT), and American Cyanamid Corp. (CY/RO).

I-5 DEMAND

Total U.S. sales of acrylic resins were 240,000 metric tons in 1977. The pattern of consumption is outlined below:

Market	10^3 Tons	Percent
Cast Sheet	65	27
Molding and Extrusion Powder	64	27
Other Grades	37	15
Coatings	47	20
Other uses (emulsions, fibers, etc.)	27	11
	240	100

The construction industry represented 45 percent of the combined markets for sheet and powder. Transportation was the second largest user with 25 percent of the combined markets for sheet and powder. These numbers do not include acrylics consumed in paint and coating applications.

Historical supply and demand data for acrylics are presented in Table I-1 and Figure I-1.

I-6 PROJECTED GROWTH FOR ACRYLICS

Compounded annual growth of acrylic demand was as follows:

Period	Total	Transportation	Automotive
1968-1977	5.2%	10.0%	5.6%
1973-1977	0.6%	13.0%	4.7%
1976-1977	6.2%	(-5.7%)	0

Overall growth of acrylic resin has averaged 5 percent per year over the past decade. Growth in transportation has been

TABLE I-1. STATUS- ACRYLIC RESINS

Year	Total Capacity	Total Consumption	Transportation Consumption	Automobile Consumption
	1000 Metric Tons/Year			
1967		131	11.3	10.3*
1968		145	12.7	11.6*
1969		160	13.6	12.4*
1970		174	15.0	13.6
1971		185	15.4	14.1
1972		208	16.8	15.0
1973		233	17.9	15.9
1974		246	16.4	14.4
1975		193	15.6	13.6
1976		226	35	20
1977	400[1]	240	33	20
1978	500[1]		36	21

Sources: Modern Plastics, Annual Industry Review in January Issue, except where otherwise noted

1) Modern Plastics, December 1976, p. 41.

* Auto consumption estimated at 91 percent of transportation consumption

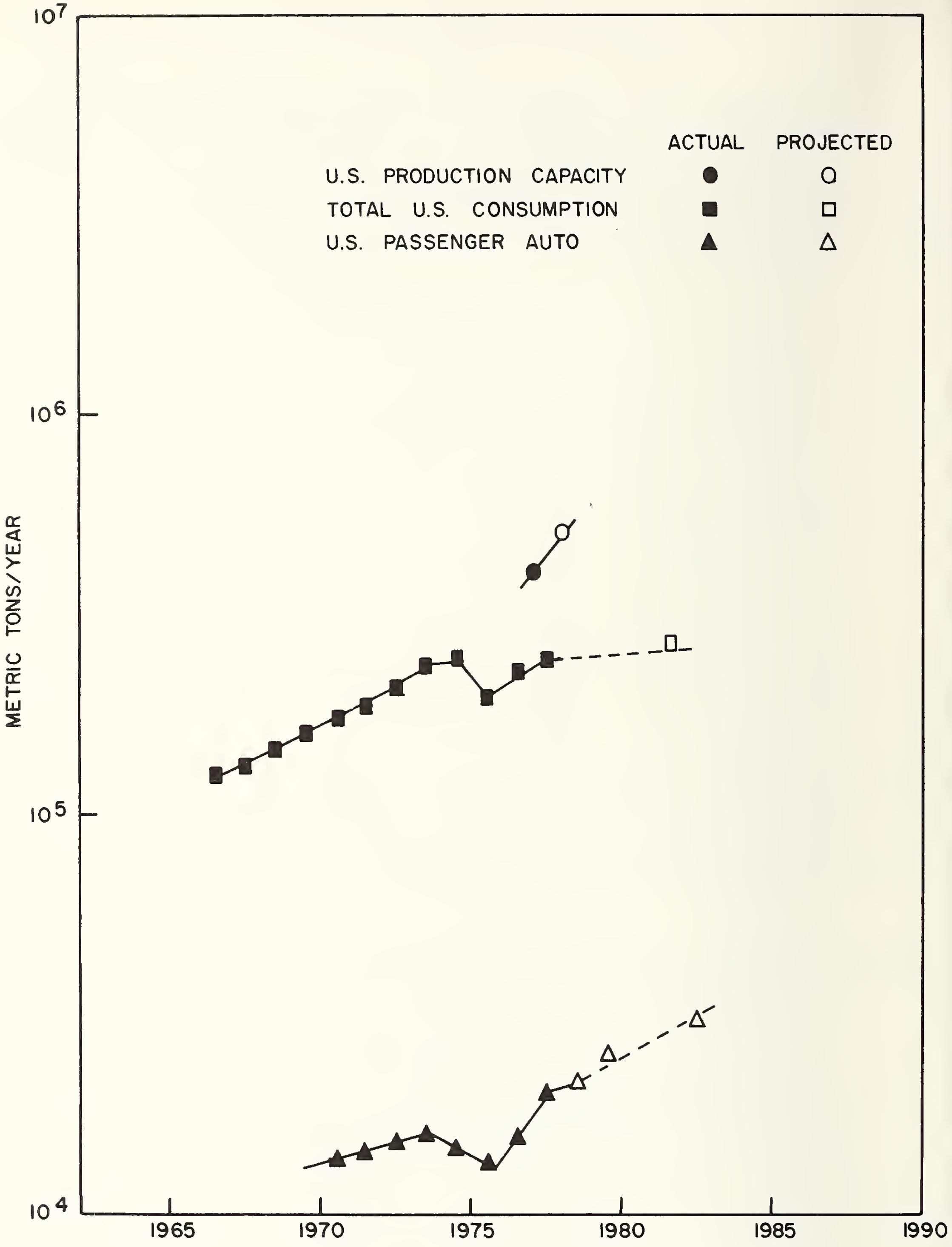
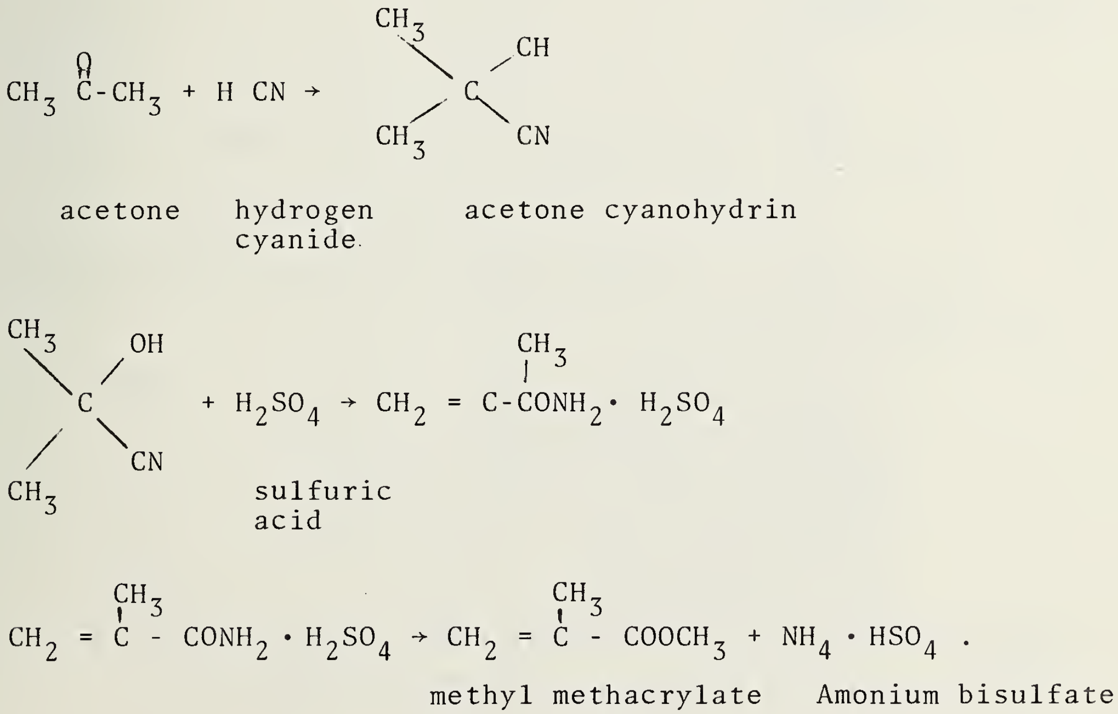


FIGURE I-1. ACRYLICS

twice as high, due mainly to glazing applications in mass transportation systems: aircraft, rail and buses. Automobile use has increased at the same general rate as the total population. Industry soruces project overall acrylic growth at 8 percent per year through 1982 (Modern Plastics, December 1976). This is, in part, based on increased use of acrylics as safety glazing for domestic use (storm doors), and increased use in transportation applications such as the RTS transit but. In view of the historic pattern, these projected growth rates may be optimistic.

I-7 MANUFACTURING

Polymethyl methacrylate is obtained by free radical addition of methyl methacrylate monomer. Traditionally, methyl methacrylate monomer is made by the acetone cyanohydrin process developed by ICI in the 1930's. In this process, acetone and hydrogen cyanide are combined to form acetone cyanohydrin, which is then hydrolized with sulfuric acid to an intermediate amide which is then transformed into methyl methacrylate ester by reaction with methyl alcohol. The reaction steps are:

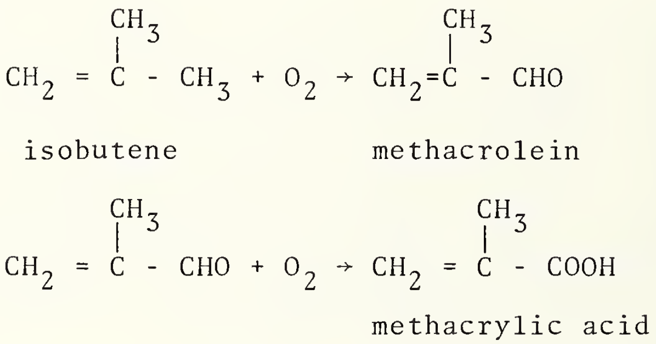


$$CH_2 = \overset{CH_3}{C} - CONH_2 \cdot H_2SO_4 \rightarrow CH_2 = \overset{CH_3}{C} - COOCH_3 + NH_4 \cdot HSO_4 .$$

A major disadvantage of this process is the formation of an extensive amount of waste ammonium sulfate which is not worth recovering.

A new manufacturing process has been recently developed by Asahi Glass Ltd. of Japan which appears to be more economical than the one described above. In the Asahi process, isobutylene is catalytically oxidized to methacrylic acid (MAA) in two steps, which is then esterified to methyl methacrylate by reaction with methanol. The reaction steps are:

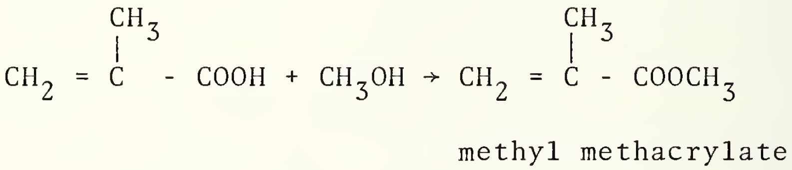
Oxidation



$$CH_2=C(CH_3)-CH_3 + O_2 \rightarrow CH_2=C(CH_3)-CHO$$

$$CH_2=C(CH_3)-CHO + O_2 \rightarrow CH_2=C(CH_3)-COOH$$

Esterification



$$CH_2=C(CH_3)-COOH + CH_3OH \rightarrow CH_2=C(CH_3)-COOCH_3$$

Materials and utilities required per ton methacrylic acid are estimated to be:

Isobutylene, Kg	1280
Catalyst & Chemicals Kg	7
Electric Powder, Kwh	1300
Steam, Tons	2.1
Cooling Water m^3	320
Refrigerator, Kcal	$1.9x10^6$

Approximately 0.92 tons of methacrylic acid are needed per ton methylmethacrylate produced, as shown in Figure I-2.

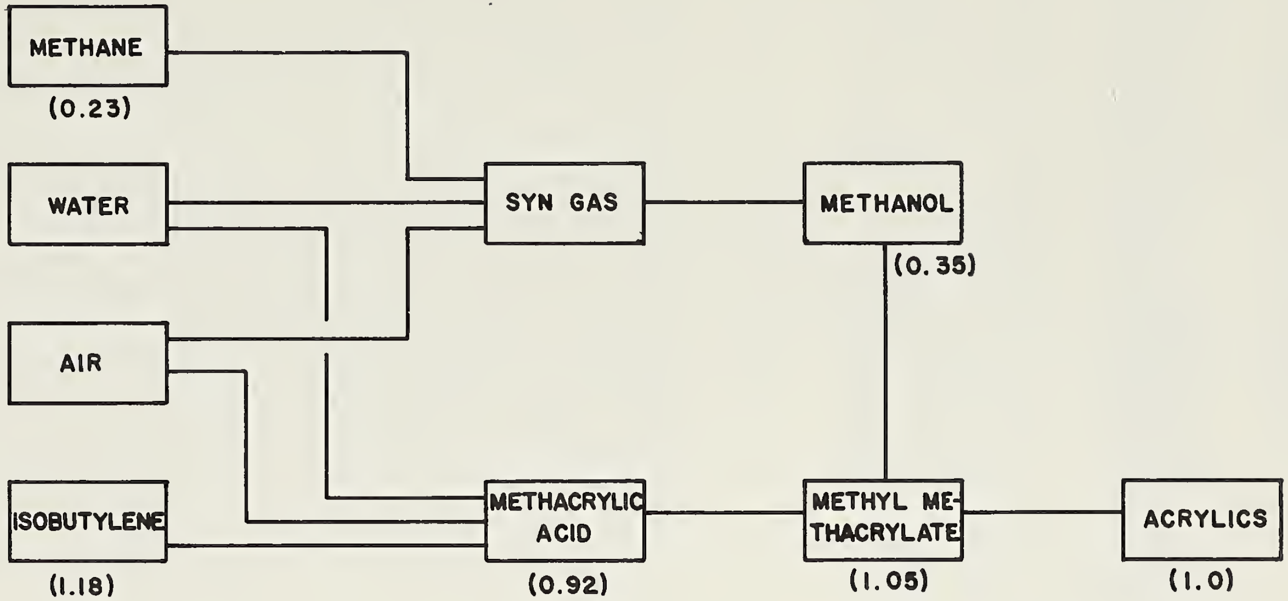


FIGURE 1-2. SYNTHESIS OF ACRYLICS

REFERENCES FOR APPENDIX I

1) A.S. Wood, "In Materials, Processes, and Supply, It's a Whole New Deal for Acrylics," Modern Plastics, December 1976, p. 38-41.

2) Y. Oda, et al, "New Route to Methyl Methacrylate," Hydrocarbon Processing, October 1975, p. 115-117.

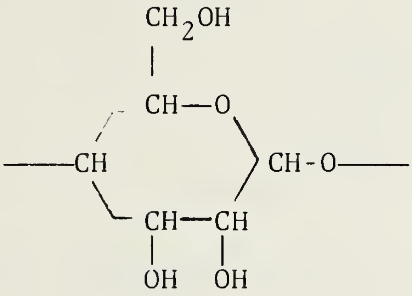
3) J.C. Davis, "Big Changes in Store for Methyl Methacrylate," Chemical Engineering, July 3, 1978, p. 25-27.

APPENDIX J:

CELLULOSICS

J-1 INTRODUCTION

Cellulosics are a class of thermoplastics derived from purified cellulose, which is a natural polymer obtained from wood or cotton. The general cellulose structure is shown below:



The major industrial cellulosic polymers are cellulose esters of acetic acid, propionic acid and butyric acid, and ethyl cellulose, which is an ether adduct. Another cellulosic polyer is nitrocellulose which was patented in 1869 and is the oldest commercial synthetic plastic in existence. Cellulosics are among the toughest of plastics, are generally economical, and are basically good insulators. They can be manufactured to offer a wide range of properties and can be formulated for specific applications. However, cellulosics are temperature limited, and more sensitive to extreme environments than other competing thermoplastics. Cellulose esters are not used when tight dimensional stability under anticipated temperature and humidity conditions are required. Cellulose acetate has better mechanical properties than the propionate or butyrate esters, but poor weathering properties. Ethyl cellulose is dimensionally stable over a wide range of temperature and humidities, but it is attacked by oils and solvents which limits its use in automotive applications. Although cellulosics have been used extensively in injection molding plastics, lower cost synthetic polymers, such as polystyrene and polyethylene, have displaced them in numerous applications.

J-2 TYPICAL USES OF CELLULOSICS

General (not including textile fibers):

- pens
- tool handles
- optical goods
- blister packaging
- toys
- industrial sheeting

Automotive:

- knobs, buttons
- molding strips
- steering wheels
- screw and bolt anchors

J-3 CURRENT FOR PRICE FOR CELLULOSICS (January 1, 1978)

Cellulose Acetate	88¢/lb
Cellulose Propionate	85¢/lb
Cellulose Butyrate	85¢/lb

J-4 SUPPLY

The principal supplier of cellulose ester resins is Eastman Chemical Products Co. of Kingsport, Tennessee. Dow Chemical Company is a major supplier of ethyl cellulose. No capacity data were obtained.

J-5 DEMAND

Total U.S. sales of cellulosic plastic resins (not including textile fibers) were 67,000 tons in 1977. The major application was blister packing with 19,000 tons, followed by personal items (tools, brush handles, pens, etc.) with 15,000 tons. Transportation applications, which were principally automotive uses, accounted for 6,500 tons, or slightly less than 10 percent of the total. Historic consumption data are summarized in Table J-1 and Figure J-1.

TABLE J-1. STATUS- CELLULOSIC RESINS

Year	Capacity	Total Consumption	Transportation Consumption	Automobile Consumption
1966		83		
1967		76		
1968		87	8.1	
1969		89	8.1	
1970		79	8.1	
1971		68	7.7	7.7
1972		75	7.7	7.7
1973		77	7.7	7.7
1974		76	8.7	8.7
1975		56	6.5	6.5
1976		70	7.0	7.0*
1977		67	6.5	6.5*

Source: Modern Plastics Annual Industry Review in January issue

*Automotive assumed equal to transportation for 1976 and 1977 based on historic performance.

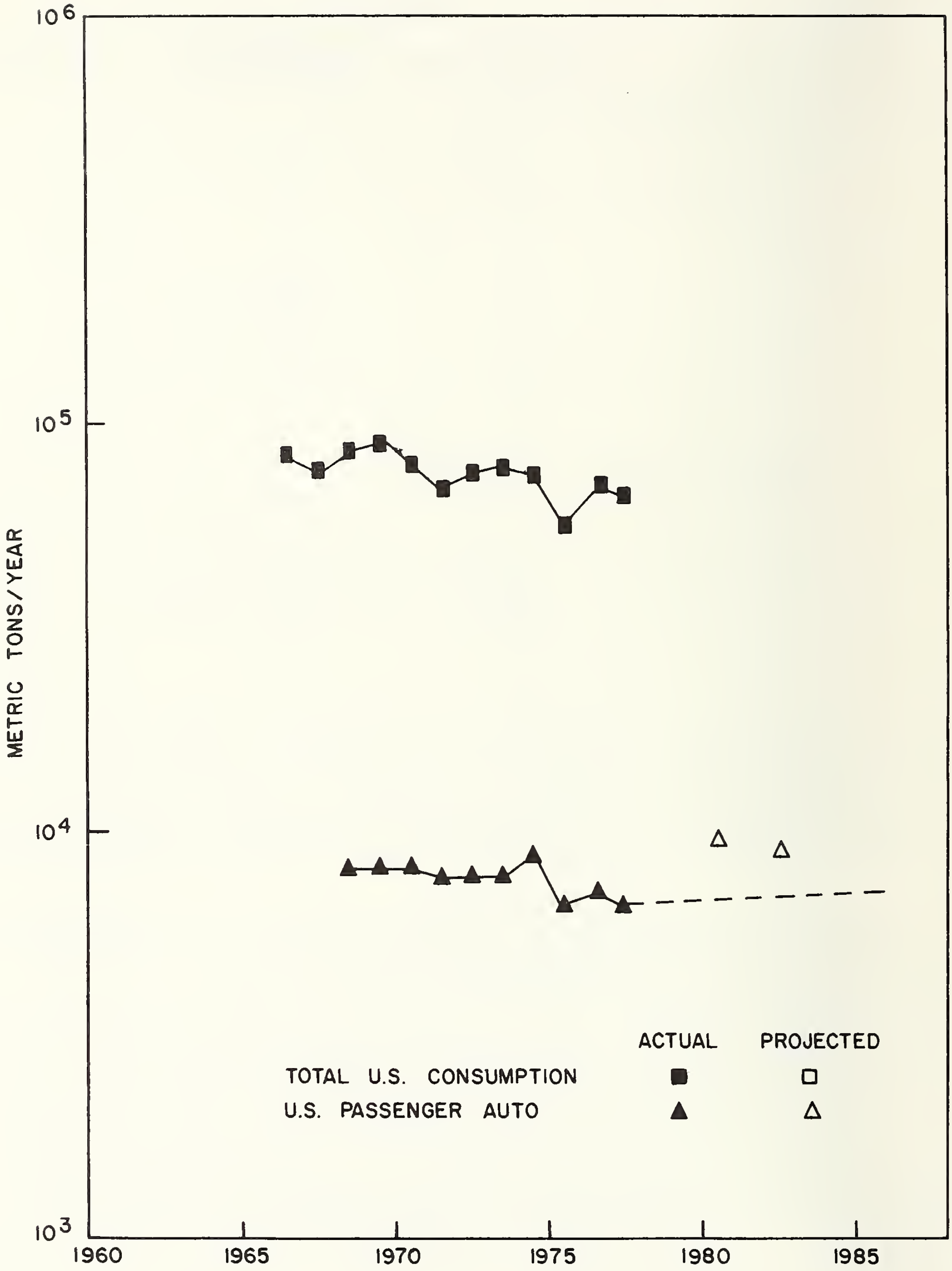


FIGURE J-1. CELLULOSICS

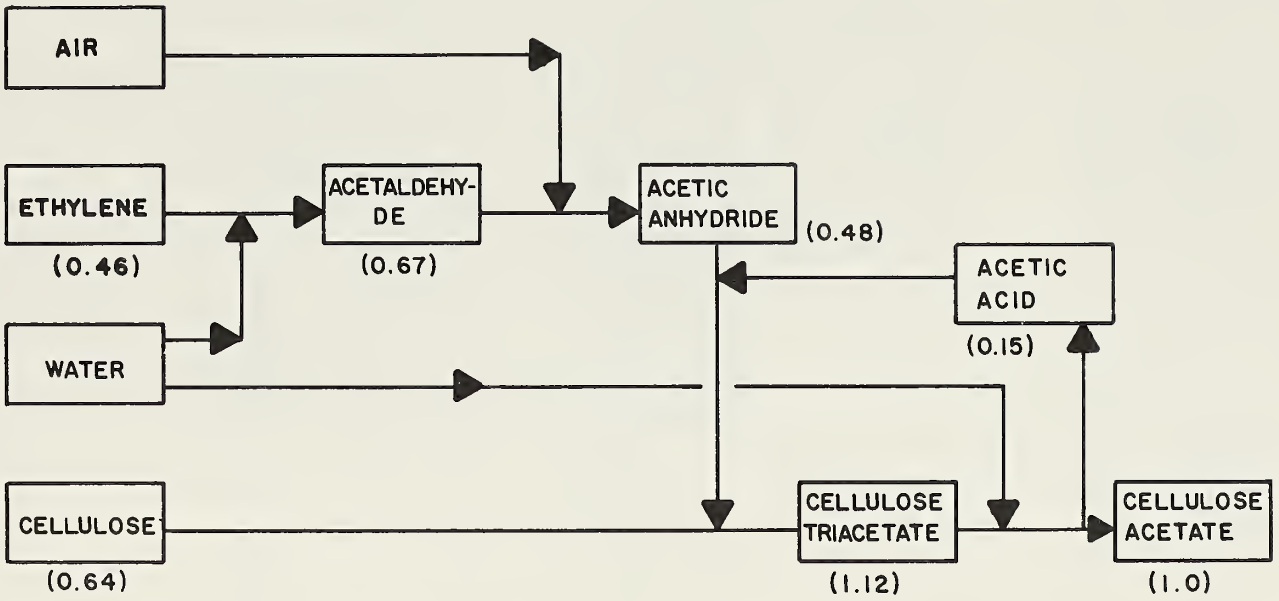


FIGURE J-2. SYNTHESIS OF CELLULOSE ACETATE (REPRESENTATIVE CELLULOSIC)

J-6 PROJECTED GROWTH RATE FOR CELLULOSICS

Compounded annual growth for cellulosic plastics was as follows:

Period	Total	Transportation
1968-1977	(-2.6%)	(-2.2%)
1973-1977	(-2.7%)	(-3.3%)
1976-1977	(-4.3%)	(-7.1%)

J-7 MANUFACTURING

Organic cellulose ester plastics are made by reacting purified cellulose with the appropriate organic acid anhydride(s) in the presence of sulfuric acid which acts as a catlyst. The highly acylated product is then partially hydrolized to the desired hydroxyl content, to obtain a polymer with the desired physical properties. A synthesis diagram for a cellulose acetate with a medium acetyl content is given in Figure J-2. It is estimated that a 25,000 ton/yr plant would require a capital investment of $30MM, or approximately $1200/annual ton.

REFERENCES FOR APPENDIX J

1) Douglas M. Considine, Chemical and Process Technology Encyclopedia, p. 234, McGraw Hill Book Co. Inc., New York, 1974.

APPENDIX K:

NYLON RESINS

K-1 INTRODUCTION

Nylon is a generic term for any long chain synthetic polymeric amide which has recurring amide groups as an integral part of the main polymer chain. The first nylon developed (Type 6/6) was discovered by W. H. Carothers in the late 1930's. Type 6/6 is made by the condensation of hexamethylene diamine with adipic acid acid:

$$n\ NH_2(CH_2)_6\ NH_2 + nHCOO\ (CH_2)_4\ COOH \rightarrow$$

$$-\ NH(CH_2)_6\text{-}NHCO\text{-}(CH_2)_4\text{-}CO\ -_n + 2n\ H_2O$$

Type 6/6 Nylon

Other nylons of commercial importance are Type 6/10, in which hexamethylene diamine is condensed with sebacic acid (which has 10 carbon atoms), and Types 6, 11, and 12 which are self-condensed amino acids. Of the later group, Type 6, made by the self condensation of ε caprolactam, is the most important commercially.

Most nylons are thermoplastics that exhibit a combination of high melt point, high strength, impact resistance, wear resistance, chemical inertness and a low coefficient of friction. Nylons can be modified by the addition of certain plasticizers, fillers, reinforcements and stabilizers.

Textile fibers are the major end use of nylons. Nylons are also used to produce injection molded and extruded items for a variety of applications, as listed below.

K-2 TYPICAL USES OF NYLON

General:

- Apparel
- Carpets
- Electronic Connectors
- Brushes

	Upholstery	Appliance Housings
	Sewing Thread	Gears and Bearings
	Rope and Cordage	Fishing Line
Automotive:		
	Interior:	Seat Belts
		Interior Door Handle
		Window Regulator Handle
	Exterior:	Tire Cord
		Medallion Retainer
		Windshield Wiper Arm End
	Exterior:	Tire Cord
		Medallion Retainer
		Windshield Wiper Arm End
	Under the Hood:	Engine Cooling Fan
		Ignition Housing
		Oil Suction Tube
		Oil Filler Cap
		Nox Valve
	Miscellaneous Functional Uses:	Speedometer Components
		Steering Column Lock Housing
		Thrust Washers
		Window Lift Gear

K-3 CURRENT PRICE FOR NYLON RESINS (January 1, 1978)

Nylon 6	\$1.16/lb
Nylon 6/6	\$1.16/lb
Nylon 11	\$2.07/lb

K-4 SUPPLY

Based on adipic acid and ε caprolactam capacity data, it is estimated that current total nylon manufacturing capacity is of the order 1.2 million metric tons. The bulk of this capacity is devoted to the manufacture of nylon textile fibers. Current manufacturing capacity of nylon molding resins is estimated to be about 140,000 metric tons, as outlined in Table K-1.

TABLE K-1. ESTIMATED U.S. MANUFACTURING CAPACITY FOR NYLON MOLDING RESINS

Known Manufacturers	Estimated Capacity as of January 1, 1077 10^3 metric tons/year
Allied Chemical Co.	9
American Hoechst Corp.	1
Belding Chemical Industries	7
Celanese Plastics Company	11
Custom Resins	3
E.I. Dupont de Nemours & Co., Inc.	68
Firestone Synthetic Fibers Co.	4
General Mills Inc.	1
Monsanto Company	25
Nylene Corporation	2
Nypel, Inc.	5
Rilsan Corp.	4
Wellman, Inc.	1
Total	141

Source: Facts and Figures of the Plastics Industry, 1977
Society of Plastics Industry, New York, New York

K-5 DEMAND

Total U.S. consumption of nylon molding resins was 110,000 tons in 1977. Of this total, 67,000 tons were used for injection molding applications, and 28,000 tons were extruded. The transportation industry, which used over 25,000 tons, was the largest consumer of injection molded nylon resins. The second largest users (~ 13,000 tons/year each) were the electrical industry and a variety of consumer products. Automotive uses represented about 20,000 metric tons in 1977.

Historic data are summarized in Table K-2 and Figure K-1.

K-6 PROJECTED GROWTH FOR NYLON MOLDING RESINS

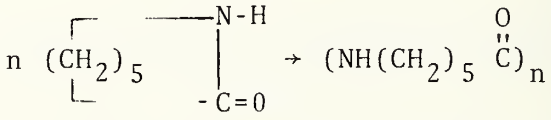
Compounded annual growth for nylon molding resins was as follows:

Period	Total	Transportation	Automotive
1968-1977	12.8%	16.8%	No Data
1973-1977	4.8%	1.5%	4.7%
1976-1977	11.0%	25%	25%

In the near future, it is expected that the overall growth rate for nylon resins will be from 6 to 7 percent per year, similar to that experienced since 1972. Automotive applications should increase at about the same rate.

K-7 MANUFACTURING

Nylon 6 and Nylon 6-6 are the most important commercial grades. Nylon 6 is made from the self-polymerization of ε-caprolactam



$$n\ \left[(CH_2)_5 \begin{array}{l} -N-H \\ \ \ | \\ -C=O \end{array}\right] \rightarrow (NH(CH_2)_5\overset{O}{\overset{\|}{C}})_n$$

Depending on the process, the basic raw materials for caprolactam are either benzene or toluene. For example, benzene is first reduced to cyclohexane with hydrogen, cyclohexane is then

TABLE K-2. STATUS NYLON MOLDING RESINS

Year	Total Capacity At Year Start	Total Consumption		Transportation Consumption		Automobile Consumption Model Year
	10³ Metric Tons Year					
1967		28		4.5		-
1968		33		5.3		-
1969		41		5.7		-
1970		46		9.1		6.8
1971		58		13.2		11.3
1972		67	69[1]	15.8		13.6
1973		87	87[1]	18.6		15.9
1974		83	83[1]	18.3	20[1]	14.8
1975	107[2]	65	65[1]	14.5	15[1]	9
1976	124[2]	100	100[1]	20	29[1]	16
1977	141[1]	110		25		20
1978				28		22

Sources: Modern Plastics, Annual Industry Review in January Issue unless otherwise noted.

1) Facts and Figures of the Plastics Industry, 1977, SPI, New York, NY

2) Modern Plastics, February 1975, p. 52.

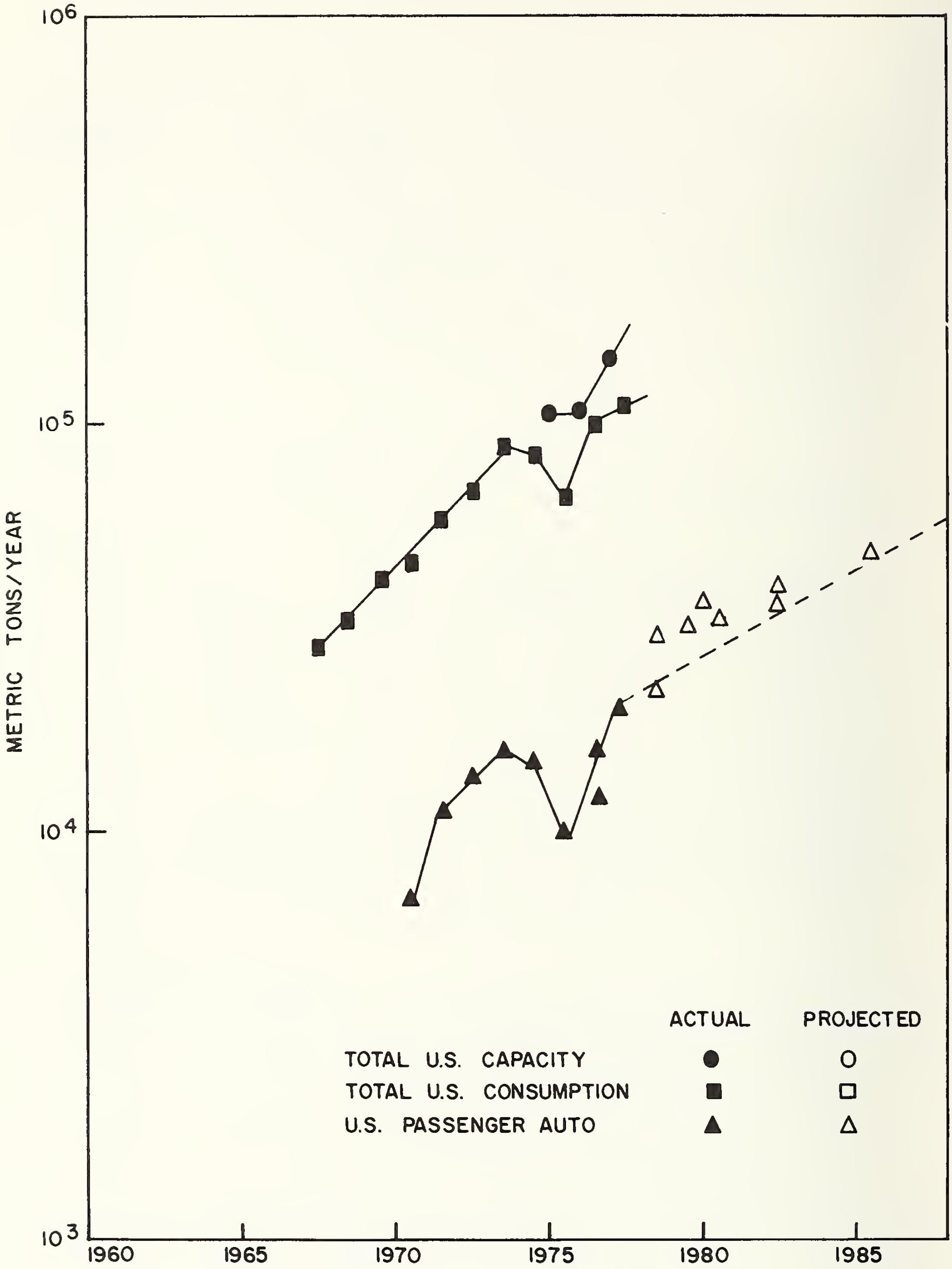


FIGURE K-1. NYLON

oxidized to cyclohexanone which is then reacted with hydroxylamine sulfate (derived from ammonia) to form caprolactam.

As mentioned in the introduction, Nylon 6-6 is made by condensation of adipic acid and hexamethylene diamine. Adipic acid is made by oxidation of cyclohexane which is derived by hydrogenation of benzene. As outlined in Figure K-2, it is also an intermediate in the manufacture of hexamethylene diamine. In the process, adipic acid is first converted to adiponitrile by reaction with ammonia; the adiponitrile is then hydrogenated catalytically at about 20 atmospheres to give hexamethylene diamine.

REFERENCES FOR APPENDIX K

1) "Nylons, Status Report," Modern Plastics, February 1975, p. 52-53.

2) "Adipic Acid, Chemical Profile," Chemical Marketing Reporter, February 20, 1978, p. 9.

3) "Caprolactam, Chemical Profile," Chemical Marketing Reporter, December 19, 1977, p. 9.

4) "Cyclohexane, Chemical Profile," Chemical Marketing Reporter, January 24, 1977.

5) D. N. Considine, Chemical and Process Technology Encyclopedia, p. 786, McGraw-Hill Book Publishing Co., New York, 1974.

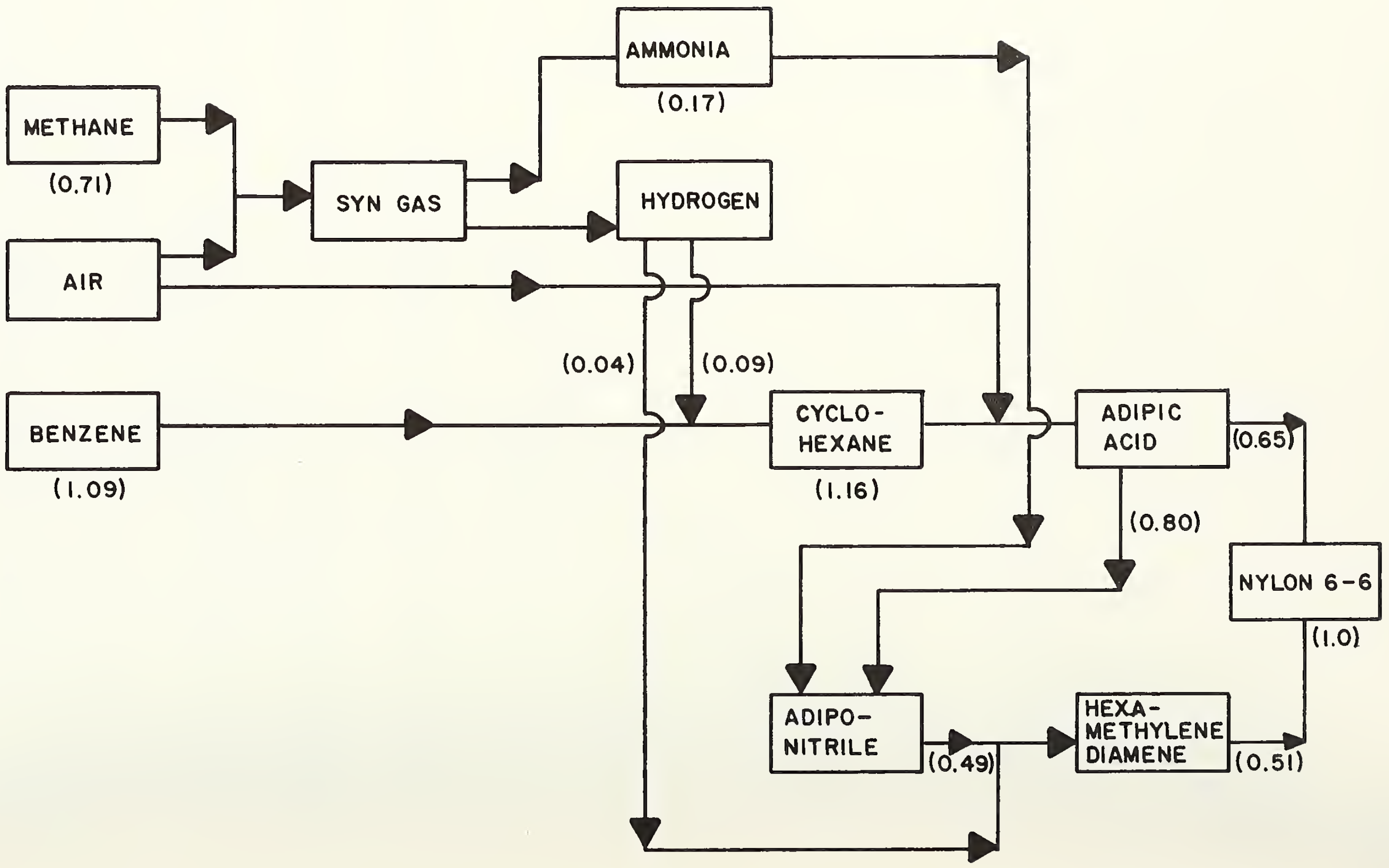


FIGURE K-2. SYNTHESIS OF NYLON 6-6

APPENDIX L:

PHENOLIC RESINS

L-1 INTRODUCTION

Phenolic resins are prepared by reacting phenol with formaldehyde. Phenolics are among the oldest (dating back to 1909) commercially available thermosetting resins. Coatings and adhesives consume about 75 percent of phenolic resins, with the other 25 percent going into molded products which are of present concern in this report. An extremely large number of phenolic materials are available, based on a wide diversity of resin/filler combinations. Of the general purpose molding materials available, phenolics are among the lowest in cost, and are generally very easy to mold.

L-2 TYPICAL USES OF PHENOLIC MOLDING RESINS

General:

- Circuit Breakers
- Pot Handles
- Appliance Knobs

Automotive:

- Distributor Caps
- Fuse Blocks

L-3 CURRENT PRICE FOR PHENOLIC RESINS (JANUARY 1, 1978)

General Purpose Molding Compound	47¢/lb

L-4 SUPPLY

Total phenolic capacity is estimated to be between 800,000 metric and 900,000 metric tons per year. Phenolic molding compound capacity is estimated to be between 200,000 and 220,000 metric tons per year. While there are over thirty manufacturers of phenolic resins in the United States, there are four major manufacturers of molding compounds:

Hooker Chemicals and Plastics Corp. (~90,000 metric ton/year capacity),
Plastics Engineering Co. (~30,000 metric ton/year capacity),
Union Carbide Corp. (~23,000 metric ton/year capacity), and
Reichold Chemical Co. (~16,000 metric ton/year capacity).

L-5 DEMAND

Total consumption of phenolic molding compounds was 158,000 metric tons in 1977, or approximately 25 percent of all phenolic resins (638,000 metric tons). Transportation uses consumed 26,000 metric tons of molding compound. Of this amount, 22,000 metric tons were used in automobile manufacture. Historic supply and consumption data on phenolics are summarized in Table L-1 and Figure L-1.

L-6 PROJECTED GROWTH FOR PHENOLIC RESINS

Compounded annual growth for phenolic resins was as follows:

Period	All Phenolics	Molding Compounds		
		Total	Transportation	Automobiles
1968-1977	4.6%	2.1%	3.1%	No Data
1973-1977	0.4%	(-1.8%)	(-3.0%)	(-2.5%)
1976-1977	7.2%	1.9%	(-3.0%)	(-9.1%)

The overall growth of phenolics has been higher than that of phenolic molding powders, which have grown at a compounded rate of 2 percent per year in the past ten years, but dropped at about the same rate over the past five years. Transportation and automotive uses accentuate the overall molding powder trends. The 9.1 percent automotive drop is mainly due to rounding off errors.

No new automotive applications are foreseen for phenolic resin. No significant change is foreseen in automotive consumption, with the possibility that consumption may decrease due to the competition of other plastics.

TABLE L-1. STATUS- PHENOLIC RESINS

Year	Total Capacity at Year Start		Total Consumption		Transportation Consumption Molding Compounds	Automobile Consumption Molding Compounds
	All Phenolics	Molding Compound	All Phenolics	Molding Compounds		
	10^3 Metric Tons/Year					
1967			358	114	14.5	
1968			407	128	19.1	
1969			429	130	26.4	
1970			403	105	27.5	25.0
1971			540	117	27.5	25.0
1972			651	156	27.7	25.0
1973			624	173	30.3	27.3
1974	725	183	549	150	25.9	28.0
1975	800	183	465	102	22.5	20.0
1976			595	155	26.8	24.0
1977		208	638	158	26	22
1978					27	24

Source: Modern Plastics Annual Industry Review in January Issue.

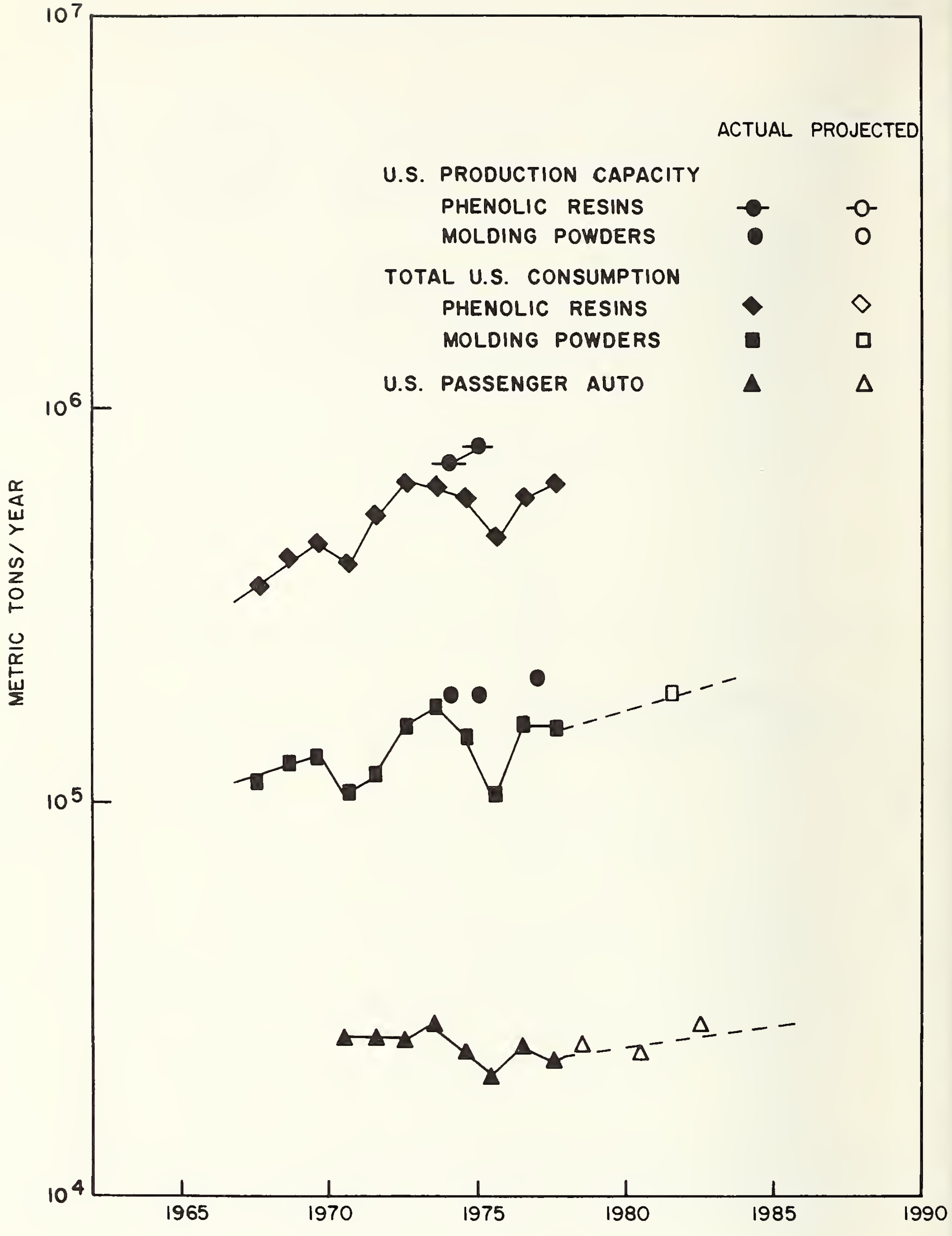


FIGURE L-1. PHENOLICS

L-7 MANUFACTURING

Phenol formaldehyde resins are made by mixing 37 to 40 percent formaldehyde solution with phenol in the presence of ammonia as a catalyst and heating to approximately 80°C - 90°C when a resinous mass is formed. The water is boiled off and the resin is cooled in thin layers. It is then mixed with various modifying agents and fillers to provide a wide range of final properties after curing under pressure and heat in a subsequent operation.

Raw materials requirements per unit weight of phenolic resin are outlined in Figure L-2.

REFERENCES FOR APPENDIX L

1) "Phenolics - Status Report," Modern Plastics, October 1974, pp. 64-65.

2) "Facts and Figures of the Plastics Industry 1977," SPI, New York, p. 34.

3) D. M. Considine, "Chemical and Process Technology Encyclopedia," p. 867, McGraw Hill Book Co., New York (1974).

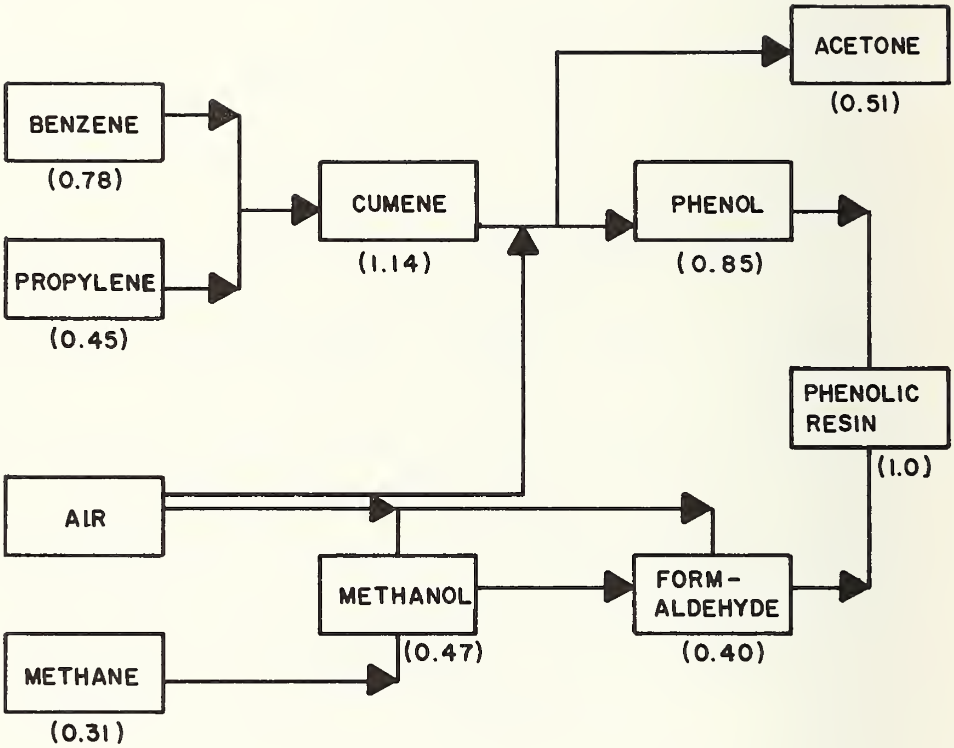


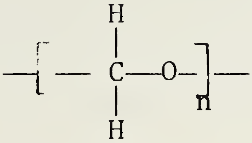
FIGURE L-2. SYNTHESIS OF PHENOLIC RESIN

APPENDIX M:

POLYACETALS

M-1 INTRODUCTION

Polyacetals are among a group of high performance engineering thermoplastics that have the following repeating chemical unit in their general structure:



$$-\!\left[-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-O-\right]_n\!-$$

There are two basic types of acetals, namely the homopolymers made by du Pont, and the copolymers by Celanese.

The outstanding properties of acetals are high tensile strength and stiffness, resilience, good recovery from deformation under load, and toughness under repeated impact. They exhibit excellent long term load-carrying properties and dimensional stability, and can be used for precision parts. Acetals have low static and dynamic coefficients of friction, and are usable over a wide range of environmental conditions.

M-2 TYPICAL USES OF POLYACETALS

General:

- Sinks
- Faucets
- Electrical Switches
- Meat Hooks
- Telephone Pushbuttons
- Zippers

Automotive:

- Bearings
- Cams
- Gears
- Electrical Switches

M-3 CURRENT PRICE OF POLYACETALS (JANUARY 1, 1978)

General Purpose Homopolymer or copolymer 95¢/lb

M-4 SUPPLY

E.I. duPont de Nemours & Co. and Celanese Corporation are the two known suppliers of polyacetal resins in the United States. No data were obtained on plant capacity.

M-5 DEMAND

Total consumption of polyacetals was 42,000 metric tons in 1977. Transportation consumed 11,000 tons or 26 percent of the total. Machinery parts and plumbing each followed with 8,000 tons, or 19 percent of the total consumption. Automotive consumption is estimated to be 90 percent of polyacetals used in transportation equipment. Historic data are summarized in Table M-1 and Figure M-1.

M-6 PROJECTED GROWTH FOR POLYACETALS

Compound annual growth for polyacetals was as follows:

Period	Total Consumption	Transportation
1968-1977	6.9%	10.4%
1973-1977	6.0%	11.1%
1975-1977	7.7%	57.%

The growth rate for polyacetal uses in transportation has been approximately twice the overall growth rate. The growth rate has been maintained over the past ten years. The large apparent jump between 1976 and 1977 has to be discounted until revised statistics for 1977 become available next year. However, there is definitely a growth trend. In view of the electively small level of utilization, polyacetal growth should continue at its historical value of 10 to 11 percent.

M-7 MANUFACTURING

Polymerization of formaldehyde can proceed with a variety of ionic iniators according to the following examplary reaction:

TABLE M-1: STATUS- POLYACETAL RESINS

Year	Total Capacity	Total Consumption	Transportation Consumption	Automobile Consumption
		10^3 Metric Tons/Year		
1967		27.9	3.6	3.2*
1968		21.6	4.1	3.7*
1969		25.2	5.5	5.0
1970		28.0	5.9	5.4
1971		24.6	6.0	5.0
1972		26.5	5.7	5.5
1973		31.4	6.5	6.4
1974		32.3	5.2	4.8
1975		25.8	4.5	4.0
1976		39.0	7.0	5.0
1977		42.0	11.0	9.8*

Source: Modern Plastics, Annual Industry Review in January Issue

*Estimated values based on 90 percent of Transportation Consumption

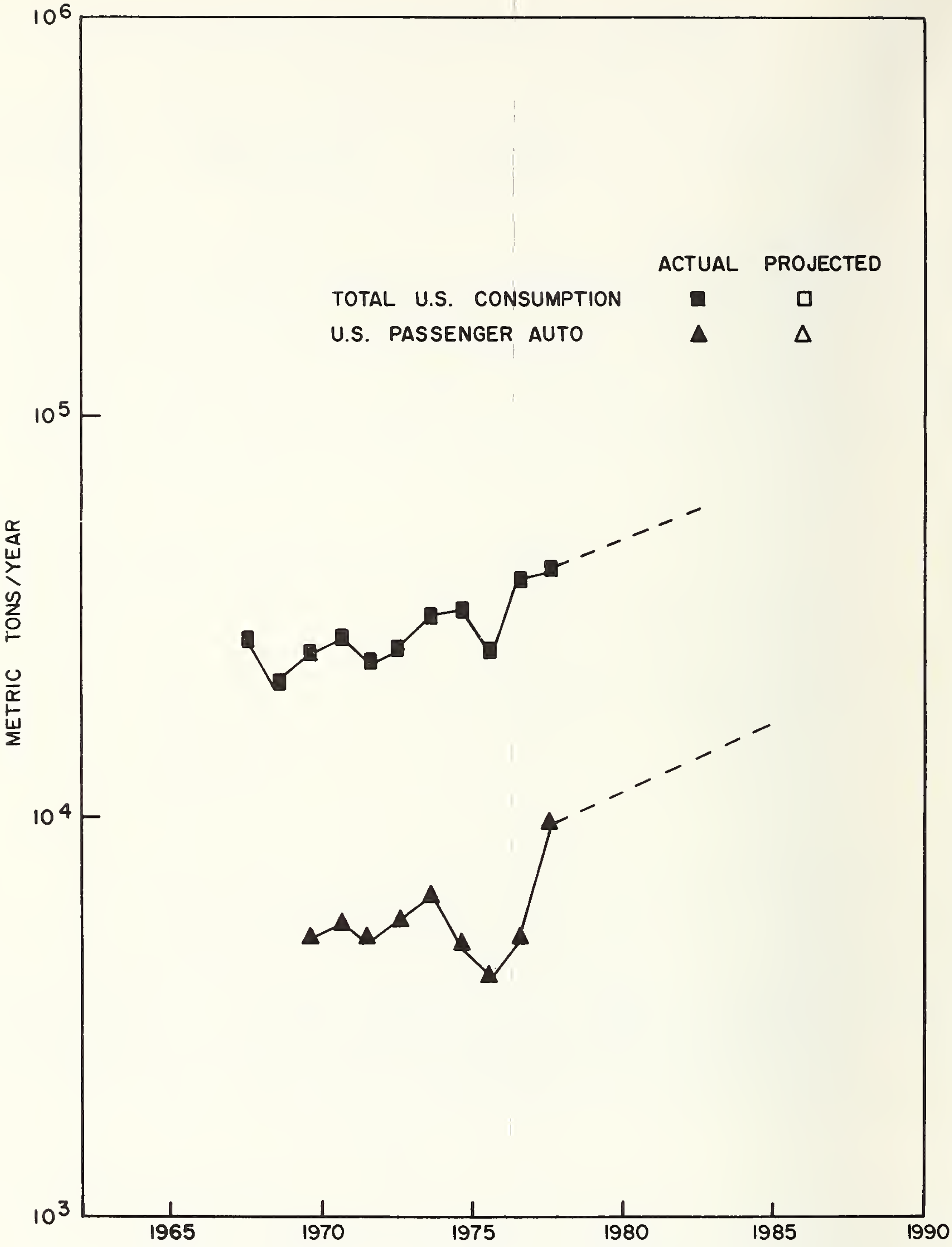


FIGURE M-1. POLYACETAL

$$OH^- + CH_2O \rightarrow HOCH_2O^-$$

$$HOCH_2O^- + n\ CH_2O \rightarrow HO\ CH_2O\ (CH_2O)n\text{-}1\ CH_2O^-$$

Either formaldehyde or the cyclic trimer, trioxane, may be used as the starting material. With trioxane, Lewis acids such as boron trifluoride are the preferred catalysts. Polymerization in the presence of ethylene oxide or 1,3 dioxolane comonomer results in ethyleneoxy, - OCH_2-CH_2-, groups in the polymer chain with the formation of an acetal copolymer. The commercial resins are end capped with a high molecular weight polyoxymethylene glycol.

Raw material requirements for the homopolymer are outlined in Figure M-2.

REFERENCES FOR APPENDIX M

1) D. M. Considine, "Chemical and Process Technology Encyclopedia," p. 16, McGraw Hill Publishing Co., 1974.

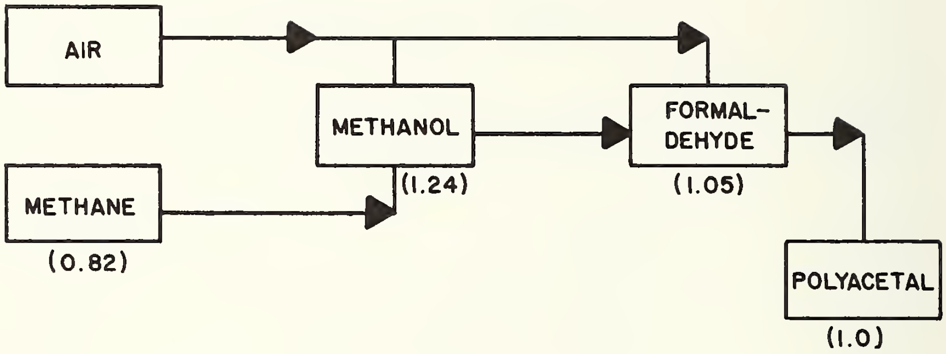


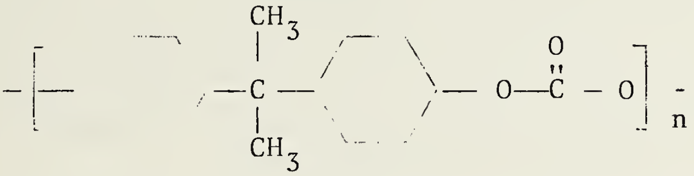
FIGURE M-2. SYNTHESIS OF POLYACETAL

APPENDIX N:

POLYCARBONATES

N-1 INTRODUCTION

Polycarbonates, which were introduced in 1957, are high molecular weight thermoplastics which have the following general structure:



The most commonly useful properties of polycarbonates are creep resistance, dimensional stability, good electrical properties, self-extinguishing characteristics, product transparency (if desired) and exceptional impact strength which exceeds that for essentially all competitive plastics, and compares favorably with the impact strength of zinc and aluminum castings.

N-2 TYPICAL USES OF POLYCARBONATES

General:

- Safety Helmets
- Power Tool Housings
- Pump Impellers
- Air Conditioner Housings

Automotive:

- Battery Hold Down Clip
- Front End Retainer
- Sun Visor Pins
- Window Stabilizer
- Roof Assembly (CJ-7 Jeep)
- Head Lamp Bezel
- Glove Box Lock Housing

N-3 CURRENT PRICE FOR POLYCARBONATE RESINS

General Purpose $1.09/lb

N-4 SUPPLY

General Electric Co. and Mobay Chemical Co. are the two known suppliers of polycarbonates in the United States. No data were obtained on plant capacity.

N-5 DEMAND

Total consumption of polycarbonates was 37,000 metric tons in 1977. Glazing was the largest single use (18,500 metric tons), followed by communications and electronic uses (11,000 metric tons) and appliances (7,400 metric tons). Approximately 5,000 tons were used in transportation equipment. It is estimated that 60 percent for this amount, or 3,000 tons were used in automobile manufacturing as shown in Table N-1 and Figure N-1.

N-6 PROJECTED GROWTH FOR POLYCARBONATE

Compounded annual growth for polycarbonates was as follows:

Period	Total	Transportation
1968-1977	16.6%	25.9%
1973-1977	4.2%	13.1%
1976-1977	11.8%	28.2%

Since 1968, polycarbonates have grown at an average annual rate of 16.6 percent. However, most of this growth occurred prior to 1973. Since 1973, growth has averaged only 4.2 percent per year. Transportation applications have grown more rapidly than the average. The overall 10 year growth rate reflects the novelty of this material in 1968. However, the growth rate in transportation since 1973 averaged over 13 percent, and may be expected to continue, especially if new automotive glazing applications can be found. If scratch resistance can be improved and costs lowered, polycarbonates could become serious contenders for passenger vehicle windows.

N-7 MANUFACTURING

Polycarbonates may be made either by ester exchange between a

TABLE N-1: STATUS- POLYCARBONATES

Year	Capacity	Total Consumption	Transportation Consumption	Automobile Consumption
		10^3 Metric Tons/Year		
1967		10.0	0.1	
1968		12.3	0.5	
1969		13.0	0.7	
1970		18.1	2.3	1.4
1971		20.0	2.3	1.4
1972		25.3	2.1	1.4
1973		46.5	2.7	1.8
1974		51.1	2.5	1.5
1975		40.0	2.4	1.4
1976		51.0	3.9	(2.4)*
1977		57.0	5.0	(3.0)*

Source: Modern Plastics Annual Industry Review in January Issue

( )* Estimated use based on 60 percent of transportation use

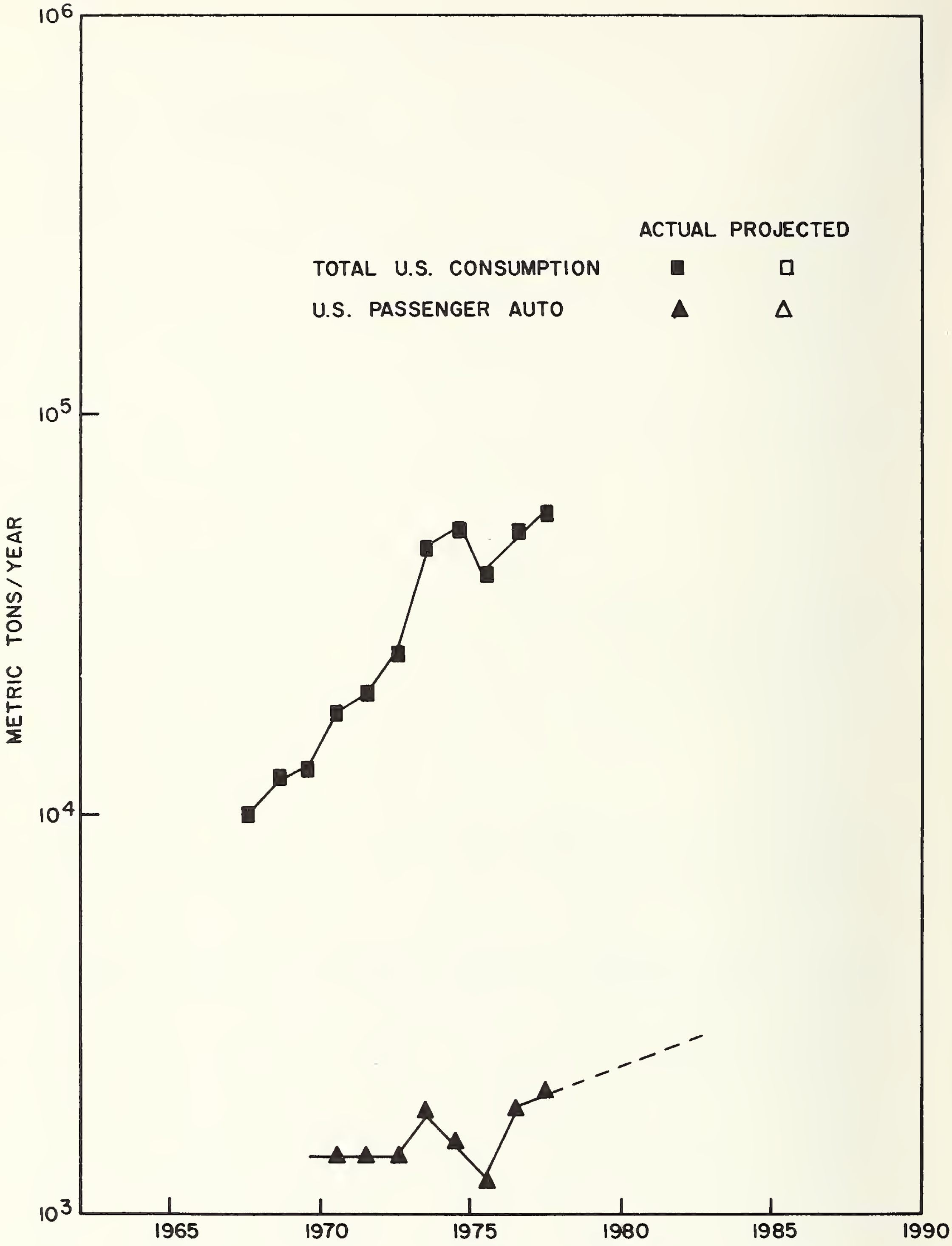


FIGURE N-1. POLYCARBONATE

carbonate diester and a dihydroxy aromatic compound, or by the phosgenation of a dihydroxy aromatic, such as Bisphenol A (2.2 bis (4-hydroxyphenil)). Raw material requirements for the second process are outlined in Figure N-2.

REFERENCES FOR APPENDIX N

1) Douglas M. Considine, "Chemical and Process Technology Encyclopedia," p. 894, McGraw Hill Book Company, Inc., New York, 1974.

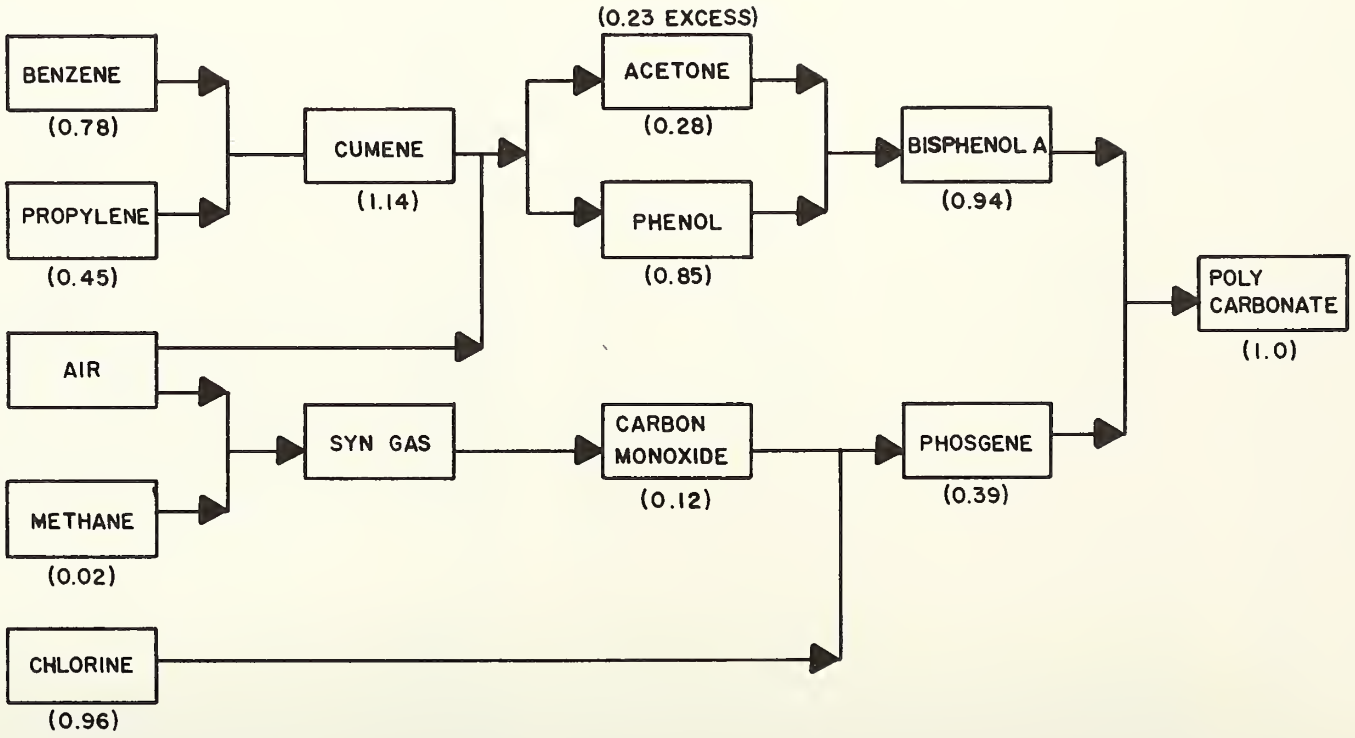


FIGURE N-2. SYNTHESIS OF POLYCARBONATE

APPENDIX O:

THERMOPLASTIC POLYESTERS

O-1 INTRODUCTION

Thermoplastic polyesters, principally polyethylene terephthalate, (PET), have been extensively used for a long time in the production of film and fibers. Chemically related thermoplastic polymers, principally poly 1, 4, -butylene terephthalate (PBT), have found increasing use as high performance molding resins. The unreinforced resin is hard, strong and extremely tough. It exhibits a high abrasion resistance and low coefficient of friction. It has good stress crack and resistance properties. The glass reinforced polyesters are exceptional in that they are the first thermoplastics that can compete with thermosets in terms of electrical mechanical, dimensional and creep properties at elevated temperatures (150°C) while exhibiting superior impact properties.

O-2 TYPICAL USES OF THERMOPLASTIC POLYESTERS

General:

- Electrical Bobbins
- TV Tuners
- Pump Impellers and Housings

Automotive:

Interior	Speedometer Frame
Exterior	Headlamp Housing
	Rear End Panel
	Louvers
Under the Hood	Electrical Junction Box
	Ignition Coil and Bobbin
	Molded on Wire Connectors
	Rectifier Bridge
	Governor Cover

O-3 CURRENT PRICE FOR THERMOPLASTIC POLYESTER

Unfilled PBT	98¢/lb

O-4 SUPPLY

There are currently six known manufacturers of thermoplastic polyesters in the United States. These firms are Allied Chemical Corp., Celanese Plastics Co., E. I. duPont deNemours and Co., Eastman Chemical Corp., General Aniline and Film Co., General Electric Company and the Goodyear Corp. No data were obtained on manufacturing plant sites and capacities.

O-5 DEMAND

In 1977, total consumption of thermoplastic polyester resins (PBT) was 21,000 metric tons. Automotive transportation was the largest consumer with 9,000 metric tons or 43 percent of the total output. The electronic and electrical industries were the second largest consumers, 5,000 metric tons, or 24 percent of the total. Historical consumption data are presented in Table O-1 and Figure O-1.

O-6 PROJECTED GROWTH FOR THERMOPLASTICS POLYESTERS

Compounded annual growth of thermoplastic polyester demand was as follows:

Period	Total	Automotive
1968-1977	No Data	No Data
1972-1977	200%	" "
1973-1977	37%	31%
1976-1977	46%	34%

PBT thermoplastic polyesters were introduced in the early 1970's and currently have less than 10 years commercial life. Consumption is growing rapidly, at approximately 30 to 40 percent per year. This growth reflects the novelty of the product and the relatively small current demand base. Use of thermoplastic polyesters should increase, most probably at the expense of phenolics

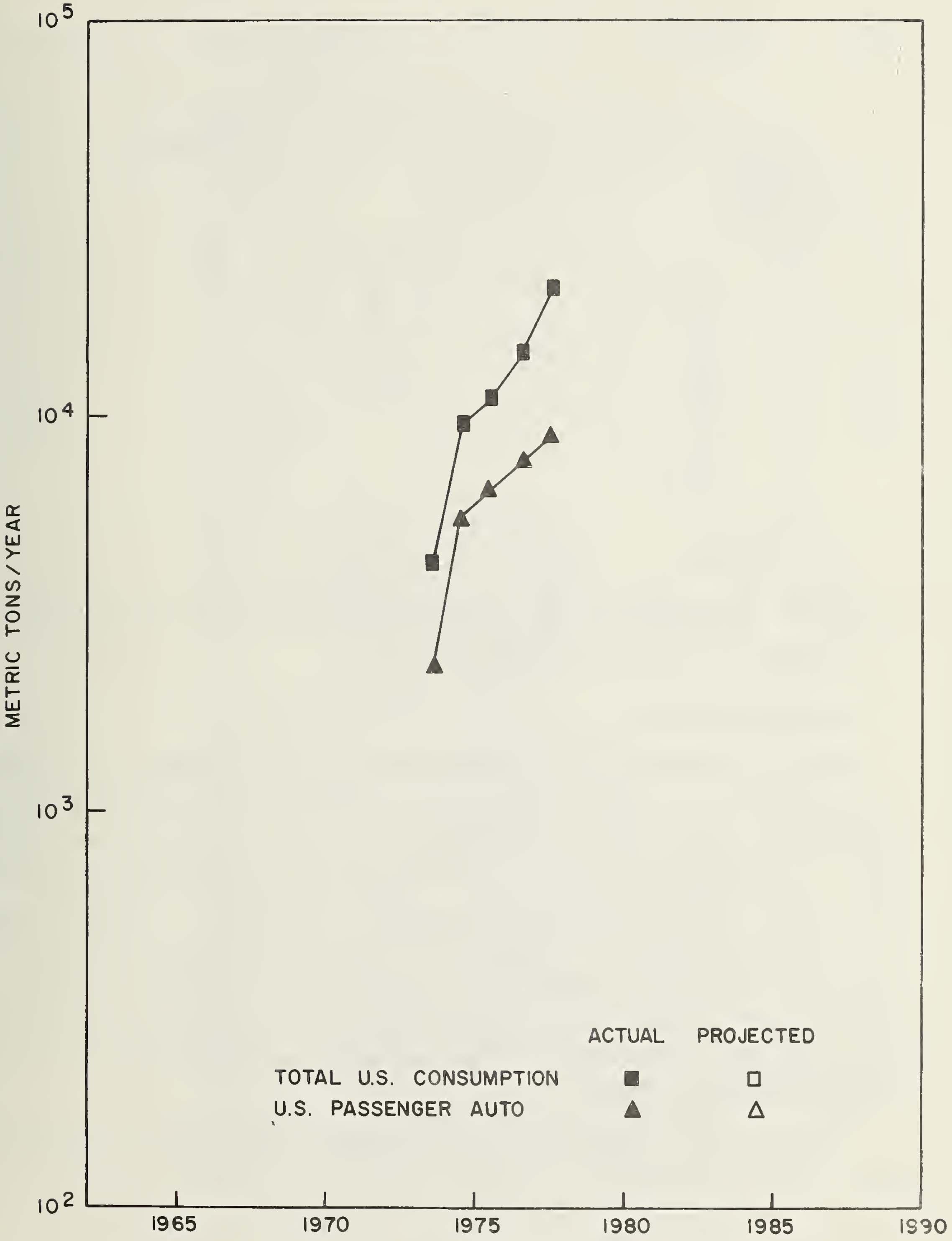


FIGURE O-1. THERMOPLASTIC POLYESTER

TABLE O-1. STATUS- THERMOPLASTIC POLYESTER RESINS

Year	Plant Capacity	Total	Transportation	Automobile
		Consumption		
	10^3 Metric Tons/Year			
1972		0.3 (est)		
1973		4.3	2.3	2.3
1974		9.6	5.7	5.7
1975		11.1	6.4	6.4
1976		14.4	6.7	6.7
1977		21.0	9.0	9.0

and other thermosets. The automotive manufacturers should continue to remain important consumers.

0.7 MANUFACTURING

The raw materials for manufacturing polybutylene terephthalate (PBT) are 1-4 butanediol, and dimethyl terephthalate (DMT) or terephthalic acid (TPA). Polycondensation is carried out in two steps. In the first step, 1-4 butanediol is esterified with either DMT or TPA to form diglycol terephthalate (DGT). If DMT is used as the raw material, methanol is released which can be recycled to a DMT plant or sold separately. The DGT intermediate product is further reacted in a heated agitated vacuum reactor to form the high molecular weight PBT. The resulting polyester melt is cooled and granulated to chips.

Process requirements per ton of PBT produced are estimated to be:

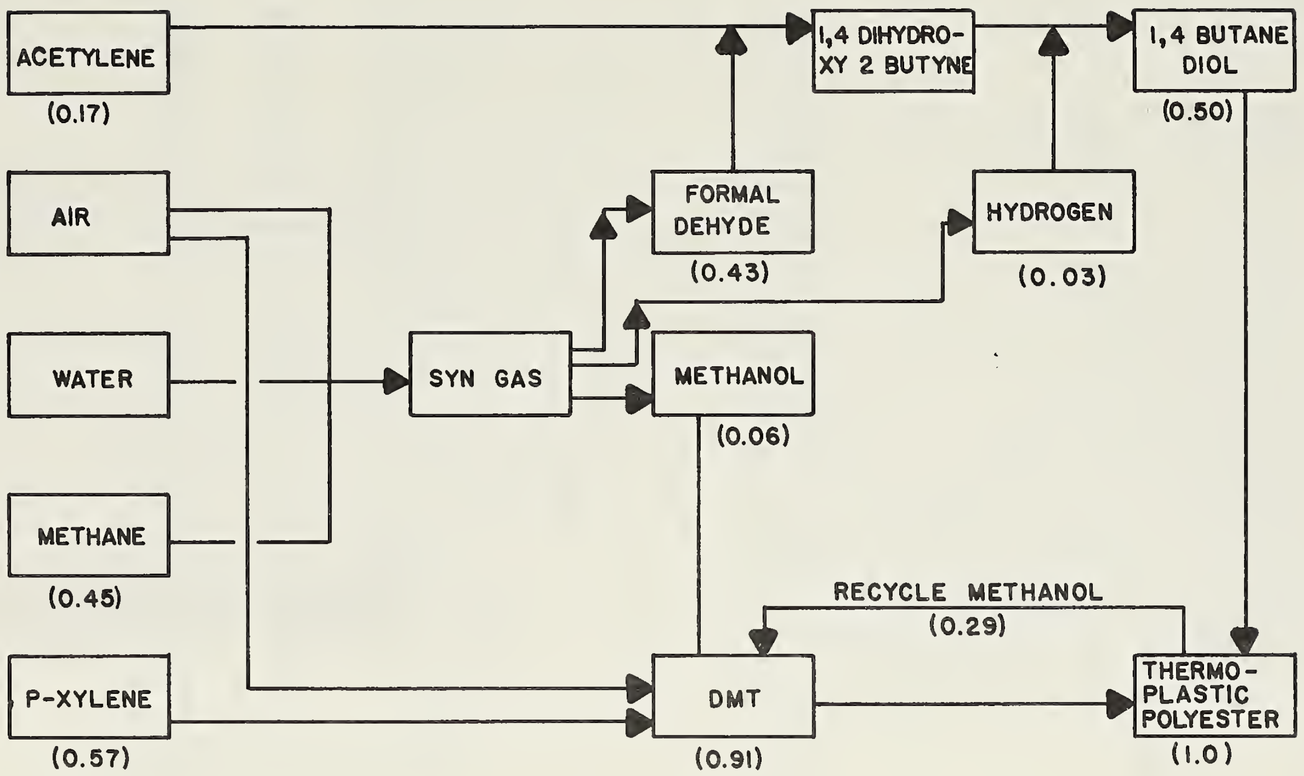


FIGURE O-2. SYNTHESIS OF THERMOPLASTIC POLYESTER (POLYBUTYLENE TERAPHTHALATE)

Raw Materials

Dimethyl terephthalate, kg	910
1, 4 Butanediol, kg	500
Methanol recovery, kg	290

Utilities

Steam, kg	900
Cooling water, m^3	150
Electricity, Kwh	280
Fuel 10^6 Kcal	1.1
Inert Gas Nm^3	60
Compressed Air Nm^3	40

A conceptual synthesis diagram for the manufacture of PBT from basic petrochemicals is presented in Figure O-2.

REFERENCES FOR APPENDIX O

1) C. A. Harper, "Fundamentals of Plastics and Elastomers," Chapter 1, pages 1-87, in "Handbook of Plastics and Elastomers," C. A. Harper, Editor, McGraw Hill Book Publishing Co., Inc., New York, N.Y., 1975.

2) "Polyester Process," Hoechst, A.G., Hydrocarbon Processing, November 1977, p. 202.

3) "Polyesters Process," Inventa A.G., Hydrocarbon Processing, November 1977, p. 203.

APPENDIX P: REPORT OF NEW TECHNOLOGY

No subject inventions were achieved during the performance of the assessment work performed under this contract. This report provides DOT with a current evaluation of the status of the U.S. plastics industry, with a detailed analysis of the impact of the passenger automobile market on the manufacture of sixteen major types of plastics, including manufacturing techniques and projected capital investments on an industry wide basis.

J.S. DEPARTMENT OF TRANSPORTATION
SEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE, CAMBRIDGE, MA. 02142

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF TRANSPORTATION
613

U.S MAIL