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BUREAU OF MINES
INFORMATION CIRCULAR/1991

The Lifecycle Analysis of Materials Competition for Pipe in the Construction Industry

By S. Kraemer, D. Ginley, C. Joyce

UNITED STATES DEPARTMENT OF THE INTERIOR

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BUREAU OF MINES
T S Ary, Director

CONTENTS

ILLUSTRATIONS

TABLES

TABLES—Continued

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

d	day	ft	foot
$	dollars	h	hour
$/yd^3	dollars per cubic yard	in	inch
$/d	dollars per day	%	percent
$/ft	dollars per foot	lb	pound
$/h	dollars per hour	lb/ft	pound per foot
$/man·h	dollars per man-hour	lb/in^3	pound per cubic inch
$/st	dollars per short ton		

COMMONLY USED PLASTIC PIPE INDUSTRY ABBREVIATIONS

ABS - acrylonitrile-butadiene-styrene

CAB - cellulose acetate-butyrate

HDPE - high density polyethylene

DWV - drain waste vent

LDPE - low density polyethylene

PB - polybutene

PE - polyethylene

PP - polypropylene

PS - polystyrene

PVC - polyvinyl chloride

RP - reinforced plastic

THE LIFECYCLE ANALYSIS OF MATERIALS COMPETITION FOR PIPE IN THE CONSTRUCTION INDUSTRY

By S. Kraemer,[1] D. Ginley,[2] C. Joyce[3]

ABSTRACT

Consumption of plastics has been growing in both the U.S. and world markets since the mid-1930s. This growth is due to plastics being used to make new products and as a replacement material for existing products. This paper develops an understanding of the replacement process by looking at the use of plastic, specifically PVC, in the construction pipe industry. History details the growth of the plastics industry and a discussion of the material selection process indicates the advantages and disadvantages of plastic pipe.

Analysis shows that the use of plastic, as an alternative material for pipe, is having a significant effect on the cast iron, copper, clay, and steel industries. For the purpose of understanding the replacement process, three example residential systems were examined with a lifecycle cost analysis being performed. PVC was the material of choice in 1988 for all systems. Even though disposal cost was the one area where PVC was not the most cost effective, disposal costs were not sufficient to offset the overall advantage of using PVC on an economic basis. That plastic competes effectively with other materials, in terms of material properties and cost, indicates that further work should be performed to understand the impact plastics have on other material markets.

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INTRODUCTION

In our rapidly changing society, plastics have shown themselves to be the material of choice in a large number of applications. This is due primarily to the adaptability of plastic products and their relative cost effectiveness. Plastic products have made significant inroads in such industries as transportation, electronics, packaging, and construction. Indeed, plastics are present in every facet of daily life, replacing such conventional materials as metal, in a myriad of situations. Understanding this replacement process and the effect it has on our economy is important from the standpoint of future legislation and the economic growth and independence of our nation.

Due to the diversity and extent of the plastics industry, it is not however, reasonable to study the industry as a whole in the scope of this paper. There are simply too many different types of plastics and plastic products. For this reason, only one portion of the industry will be studied. The pipe market in the construction industry is a highly visible portion of the industry that may be readily examined. It is a good example of materials competition and information is available such that a quantitative analysis of this competition may be performed. Therefore, the purpose of this paper will be to investigate the penetration by plastics in the construction industry, specifically as a replacement material for pipe. This investigation of a specific product in the construction industry will further an understanding of plastics as a replacement material. The study will also quantify the impact in other material industries brought about by the use of plastics. This will provide additional insight into the role of the plastics industry in our society.

Before the effects of plastics on the pipe market can be understood, the historical development of pipe must be reviewed. Specifically, the development of plastics as a replacement material for pipe and the role of plastics in the history of pipe need to be looked at. Once an understanding of how plastics began in the pipe market is gained, a comparison of the growth of plastics with respect to the most common materials in the market can be made. This comparison of growth and/or decline rates for the various materials used in pipe will show how plastics has affected the pipe market. However, it will not show why. In order to understand why plastics have affected the pipe market, a material properties comparison and an economic analysis are necessary. Economic analysis is best accomplished by performing a lifecycle cost analysis. Once an understanding is gained of how and why plastics have affected the pipe market, it is possible to make conclusions and recommendations regarding that knowledge as well as highlighting future work and information.

The conclusions made from this study are as follows:

1. Plastics consumption has been growing at a rapid rate in both U.S. and world pipe markets.
2. Since the advent of PVC in the pipe market, PVC has been steadily replacing all other piping materials.
3. Plastics are replacing metals in the pipe industry at a rate that significantly affects these metals industries.
4. Use of PVC as a replacement material is based upon the material properties and the overall cost . Overall cost is the sum of the costs for the raw material, fabrication, installation, maintenance, and disposal of the pipe.
5. Disposal of plastic pipe is not currently a problem from a cost point of view.

Based upon the findings of this study, it is clear that plastics have had a significant impact on the pipe market. This most likely carries through to the construction industry as a whole and to other industries as well. Information of this type is necessary for law makers to make informed, intelligent decisions. For this reason, the following recommendations for future work are suggested:

1. The current study demonstrates the significance of plastics as a replacement material in a market once dominated by metals. Further study is needed to understand the scope of the impact of plastics on this, as well as other metal industries.
2. Investigation of other products in the construction industry where plastics are having a significant effect on the market is needed so that general trends for industry use of plastics can be determined.
3. The availability and accuracy of data for the plastics industry indicate that further work is needed to establish a base of information, including a set of data to be collected and a collection system.
4. Installation costs for the piping systems investigated did not show a significant cost advantage for any of the different materials. Further work is needed to determine if this is true for larger piping systems and the construction industry in general.

DATA ACCURACY STATEMENT

The data presented in this report were obtained from the best known and accessible sources. However, some judgments, assumptions, and correlations were made by the authors to incorporate data from various sources which were reported in dissimilar formats. All figures and tables presented in this report represent U.S. data unless otherwise stated. The U.S. plastics industry is a young industry whose standards in reporting and testing have varied over the years and are still in development. In order to perform any trend analysis some assumptions were necessary. The problem was compounded by the fragmentation of the plastics industry. Each sector is knowledgeable of its own data base but is often unaware of any implications it has on others. Therefore, this paper does not claim extreme statistical precision. The conclusions and trends presented in this paper are believed to be accurate. The authors and the Bureau welcome any comments and input to the material contained herein with the hope of presenting a clearer, more accurate picture of the role played by plastics in today's industries.

ACKNOWLEDGMENTS

This paper was prepared with the help of many persons from the construction, landfill, and recycling industries who supplied information for this report. These include individuals from:

Alpine Pipe & Supply, Co., Denver, CO; CH2M Hill Engineering, Englewood, CO; Denver Arapahoe Disposal Site, Aurora, CO; Dukes Plumbing and Heating, Golden, CO; Expert Piping Supply, Inc., Denver, CO; Fagan Iron & Metal Corp., Denver, CO; Gahagen Iron & Metal Co., Commerce City, CO; Glen Proctor Construction, Christophers Plumbing, Inc., Sheridan, CO; Hutchinson Homes, Alliance Plumbing & Excavating, Inc., Edgewater, CO; Iron & Metals, Inc., Denver, CO; Melody Homes, Water Master Plumbing, Littleton, CO; Pine Crest Homes, Millwood Plumbing & Heating, Inc., Arvada, CO; Pipe Valve and Fitting Company, Thornton, CO; Pulte Homes, Kahar Plumbing, Kansas City, KS; RPS Landfill, Golden, CO; Tony Capra Plumbing and Heating, Denver, CO; Water Products Company, Erie, CO.

THE HISTORY OF PIPE

"The history of pipe is the history of civilization—upon no other single product have the great cities of the world depended in such large measure for their health and comfort."(*1*)[4]

For thousands of years, man has relied upon pipe and piping systems as a means of supplying water, removing waste, and providing all manner of utilities for individual dwellings and cities alike. Evidence of the first crude pipes, made of clay, were found in Babylon dating back to 4,000 B.C. Further evidence of the early use of pipes was discovered when tubes made of pottery were found in prehistoric ruins. Lead pipes, for the conveyance of water, were found to have been in use as early as the first century A.D. London experimented with baked red earth and stone pipes and documents show that cast lead pipe was laid as early as 1235 A.D. in that city. The first waterworks constructed in America, at Boston, Massachusetts, in 1652, used pipes made of hollow hemlock logs. Metals better fit the needs of piping systems and, thus, lead pipes began replacing wood pipes in the U.S. in 1786 and the last pine-pitch pipes were abandoned in 1791.

The use of tin-lined lead pipe started in 1804 to offset the health hazards of pipes made solely out of lead. Prior to this time, potable water pipes were made primarily of lead and knowledge of the deleterious effect of lead pipes was not well understood. The development of this knowledge initiated work into making piping safe for the public. With safety and functionality as the criteria, alternatives were sought to replace lead piping. One alternative to the lead piping problem was wrought iron. Although one of the first applications for wrought iron tubes was for gun barrels, in 1812 the gun barrels were screwed together to form the first continuous pipe to convey gas for lighting purposes. With the understanding that alternate materials could be safer, work better, and be less expensive, a variety of alternative materials began appearing to take the place of the hazardous lead pipes.

[4] Italic numbers in parentheses refer to items in the list of references preceding the bibliography at the end of this report.

Along with piping systems to carry gas and potable water, systems were developed to handle waste. The material needs of these systems were different than the piping systems for water and gas. Hamburg, Germany, gave rise to the first concrete sanitary sewers in 1840. Mohawk, NY, has the earliest recorded concrete pipe sanitary sewer system in the U.S., dating to 1842. Reinforced concrete pipe, as an improvement over straight concrete, had its beginnings in France in 1896 and by 1905 the Packerhead machine for producing concrete pipe was available worldwide. It wasn't long after this that new materials for pipe started to appear. With the rise of the oil industry and the subsequent beginnings of the petrochemical industry, plastics became available as an alternate pipe material. In the mid-1930s limited amounts of PVC pipe were produced in Germany. Throughout the 1940s, 1950s, and 1960s, CAB, saran (vinylidene chloride), PVC, PE, PS, PP, and RP were used as pipe materials. Pipe and piping systems had entered a new age. With the advent of plastics as a piping material, engineering concepts and ideals for piping systems had to be reevaluated.

Table 1 is a chronology of some important dates in pipe history.

Table 1.—Major dates in pipe history

Date	Event
4000 BC	First crude clay pipe made in Babylon.
1700 BC	2-inch copper drain pipes were used in Egypt.
100 AD	Lead pipes used to transport water.
1235	Cast lead pipe laid in London.
1236	Pipes of stone and red earth, bake pipes experimented with in London.
1313	First manufacture of cast iron pipe.
1350	Terra cotta underground water pipe and wooden pipes used in Greece.
1619	Earthenware pipes used to convey water.
1652	Boston, MA, used hollow hemlock logs for the first waterworks in the United States.
1720	Machine for boring stone for piping.
1741	Machine manufacture of lead pipe.
1746	Flanged cast iron water pipe laid in London.
1773	First gas pipeline used for street lighting in Boston.
1801	First cast iron pipe foundry in America.
1804	Lead pipes found to be deleterious to health. Lead pipes lined with tin.
1808	Introduction of cast iron pipe for gas distribution.
1809	Centrifugal casting of iron pipe.
1810	Manufacture of extruded clay pipe by machinery.
1810	Cast iron pipe introduced into America.
1812	First continuous pipes made of old gun barrels screwed together.
1815	First clay pipe installed in the United States in Washington, D.C.
1817	First iron pipe water line in the United States in Philadelphia, PA.
1822	Extrusion of lead pipe.
1824	Manufacture of pipe made from sheet-iron welded together at the seams.
1832	First butt-welding furnace in the U.S. at Philadelphia, PA.
1838	Extrusion of copper and brass pipe.
1840	First concrete sewer built in Hamburg, Germany.
1842	Completion of 7-foot diameter cast iron aqueduct in New York.
1842	Mohawk, NY, has the earliest recorded concrete pipe sanitary sewer system in the U.S.
1845	Glass pipes patented.
1881	Steel water pipes first used.
1888	Wood pipe made of staves and wire wound or bands for water distribution.
1893	Large diameter steel pipes appear (+18 inches).
1896	First reinforced concrete pipe used in France.
1915	First large diameter (72-inch) cast iron pipe produced in New York.
1920s	Asbestos cement pipe replaces lead-jointed cast iron pipe.
1930	Plasticized PVC tubing appeared.
1935	PVC pipe produced in Germany.
1938	CAB used for irrigation pipe.
1940	Saran (vinylidene chloride) extruded into chemical resistant pipe and tube.
1944	PVC pipe industry born out of rubble of war-torn Germany.
1950	PVC pipe used in Netherlands for pressure water transport.
1954	ABS pressure pipework system pioneered in the U.S.
1955	Glass reinforced plastic pipe used in United States paper mills.
1958	Introduction of multi-screw extruders in Germany.

Table 1.—Major dates in pipe history—Continued

Date	Event
1958	PVC pipe used in Netherlands for sewer applications.
1959	PVC pipe starting to take hold in the United States.
1959	National Sanitation Foundation begins testing and certifying PVC pipe for potable water service.
1962	Styrene rubber pipe installed in Hartford, CT, for new sanitary system.
1967	Corrugated HDPE tubing introduced into United States for drainage systems.
1977	Largest diameter plastic pipe (48-inch HDPE) manufactured in Pasadena, TX, for the transportation of sewer and waste water.
1979	Large diameter (+12 feet) thermoplastic pipe produced in the U.S.
1987	PVC pipe in diameters up to 60 inches produced.

THE DEVELOPMENT OF PVC AS AN ALTERNATE MATERIAL

One of the major types of plastics used for pipe, even in the beginning, was PVC. It was discovered by accident in 1835 when Regnault precipitated a white powder in a sealed tube of gaseous vinyl chloride exposed to sunlight. No use for the powder was found at that time and the substance was all but forgotten until 1860 when Baumann rediscovered PVC and studied it in some detail. It is doubtful if the polymeric nature of the product was apparent at that time. Because of PVC's indestructibility and resistance to change, scientists of the day could not easily form the substance into useful applications. PVC was once again put on the shelf and essentially forgotten.

The commercial and industrial significance of PVC and other vinyl compounds was not realized until the late 1920s when the Goodrich Company, while looking for methods to bond rubber to steel, found rubber-like qualities in properly plasticized PVC. In only a few years, molded and extruded PVC shapes were placed on the market. During the early 1930s in Germany, engineers and scientists developed and produced limited quantities of rigid PVC pipe by extrusion. Some of these early production facilities are still providing satisfactory service today. The decade of the 1930s saw remarkable advances in the PVC and other vinyl industries. Many new uses for these plastics were developed, such as sealants, tin can liners, rigid sheets, flexible sheeting, textile fibers, and low cost moldings and coatings. It was readily apparent that plastic would be a very important material of the future.

The future was not long in coming and a need for plastics soon surfaced. Due to shortages caused by World War II, a temporary replacement for rubber wire and cable insulation was needed. PVC, because of its resistance to water, oils, and chemicals, and its electrical insulating properties, was used and rubber has never been able to recapture the market. The bombing of Germany's cities and the destruction in the Ruhr and Saar minerals regions, forced German scientists to look for alternate/substitute materials for their water and waste pipe systems. The PVC pipe industry was born. Germany and Japan embraced thermoplastic pipe immediately, since it allowed these war-torn countries to manufacture much of their piping needs quickly and economically. Japan and Germany are still among the leaders in the plastic piping industry, in terms of volume and technology.

PLASTICS AND PVC GROWTH AND APPLICATIONS

As has been discussed previously, the use of plastics as a material for pipe started in the 1930s and continued growing through World War II and thereafter. The main plastics used for piping material were, and still are, ABS, HDPE, LDPE, PVC, RP, PB, and a small percentage of other plastic products. Of all the types of plastic used for pipe, PVC is by far the most common and is growing the fastest (see figure 1). PVC in general, as a marketable material, has shown remarkable growth since its commercialization in the 1930s. With a world consumption in 1935 of 24 million lb, use of PVC grew at an average annual rate of over 22%, reaching a level of 485 million lb in 1950. Over the next 30 years world consumption of PVC grew at an average of 14% per year, and by 1980 annual world consumption was almost 25 billion lb (see figure 2).

U.S. consumption of PVC has also shown strong growth. Consumption in 1960 was just over 900 million lb. By 1987, total U.S. consumption was more than 8 billion lb, reflecting an annual rate of growth of 8.5%. Growth of the PVC market in the U.S. can be attributed to the development of PVC products in 4 major categories. These are as follows:

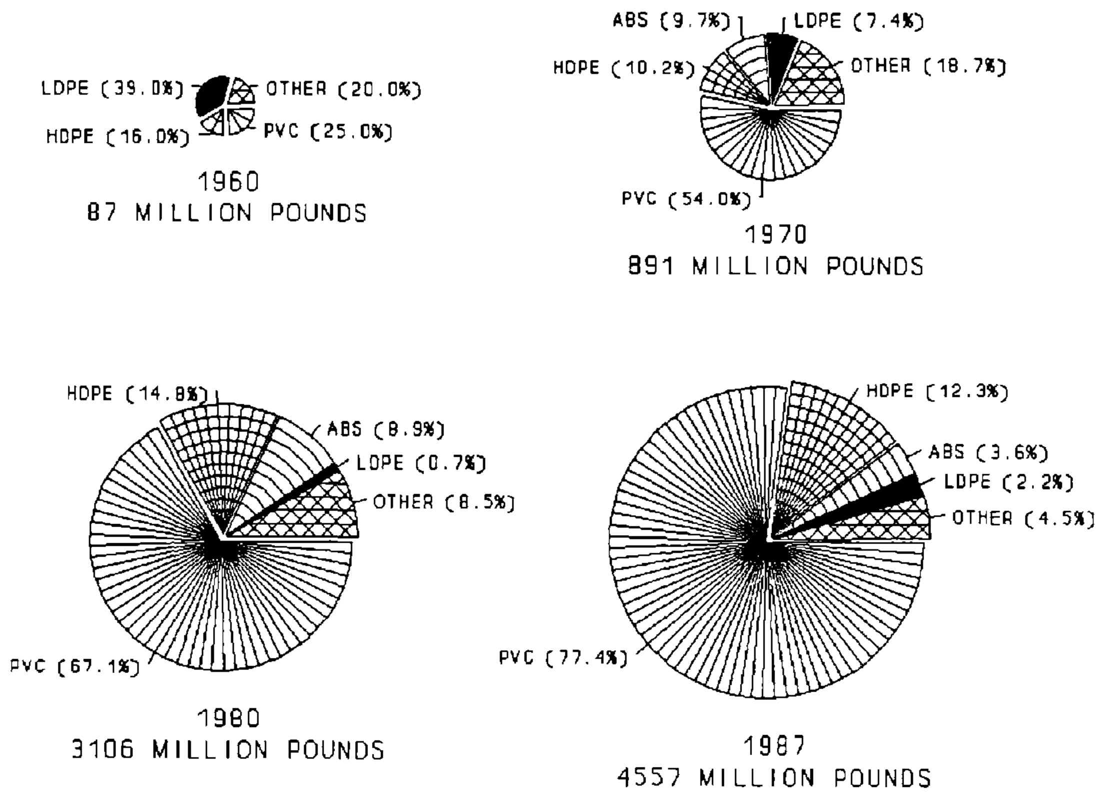

Figure 1.—Percent of major resins used in pipes.

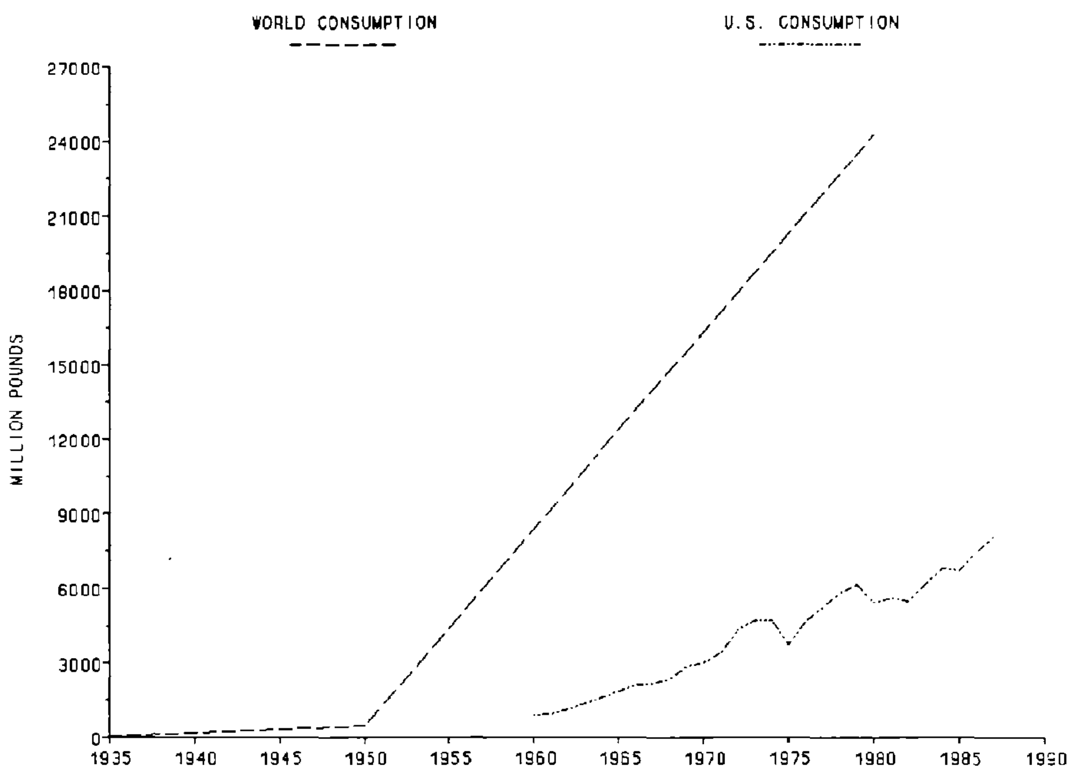

Figure 2.—World vs. U.S. PVC consumption.

1. Building and construction - includes flooring, lighting, pipe, fittings, conduit, rainwater systems, siding, swimming pool liners, water-stops, weather stripping, windows and other profiles.

2. Packaging - includes blow molded containers, closure liners and gaskets, coatings, film, and sheet.

3. Consumer goods - includes appliances, toys, transportation, furniture, electrical, and housewares such as closet accessories, shower curtains, tablecloths, place mats, etc.

4. Other markets - includes wall coverings, garden hose, records, home furnishings, sporting goods and recreational items, tools and hardware, credit cards, laminates, agricultural goods, medical tubing, novelties, stationary supplies, and apparel.

Figure 3 shows the consumption of PVC in these four major industry groupings from 1965 thru 1987. Detailed reporting for these industry categories was not available prior to 1965. The information shows that building and construction, at nearly 450 million lb, accounted for about 25% of the total PVC consumption in 1965. The consumer goods industry accounted for a slightly higher percentage, with electrical and electronics products, furniture, and transportation each providing between 5-10% of the total market. The building and construction industry accounted for approximately 60% of the total PVC consumption in 1987. The most significant other growth market for PVC was packaging, which grew from less than 100 million lb to over 600 million lb during that same period, accounting for approximately 7.5% of the total PVC consumption in 1987. The growth rate for PVC consumption in all industries other than building and construction and packaging was less than 3%. This is similar to growth in real GNP over that period (almost 3%) and indicates that no major substitution of PVC for other materials was taking place outside the building and construction and packaging industries.

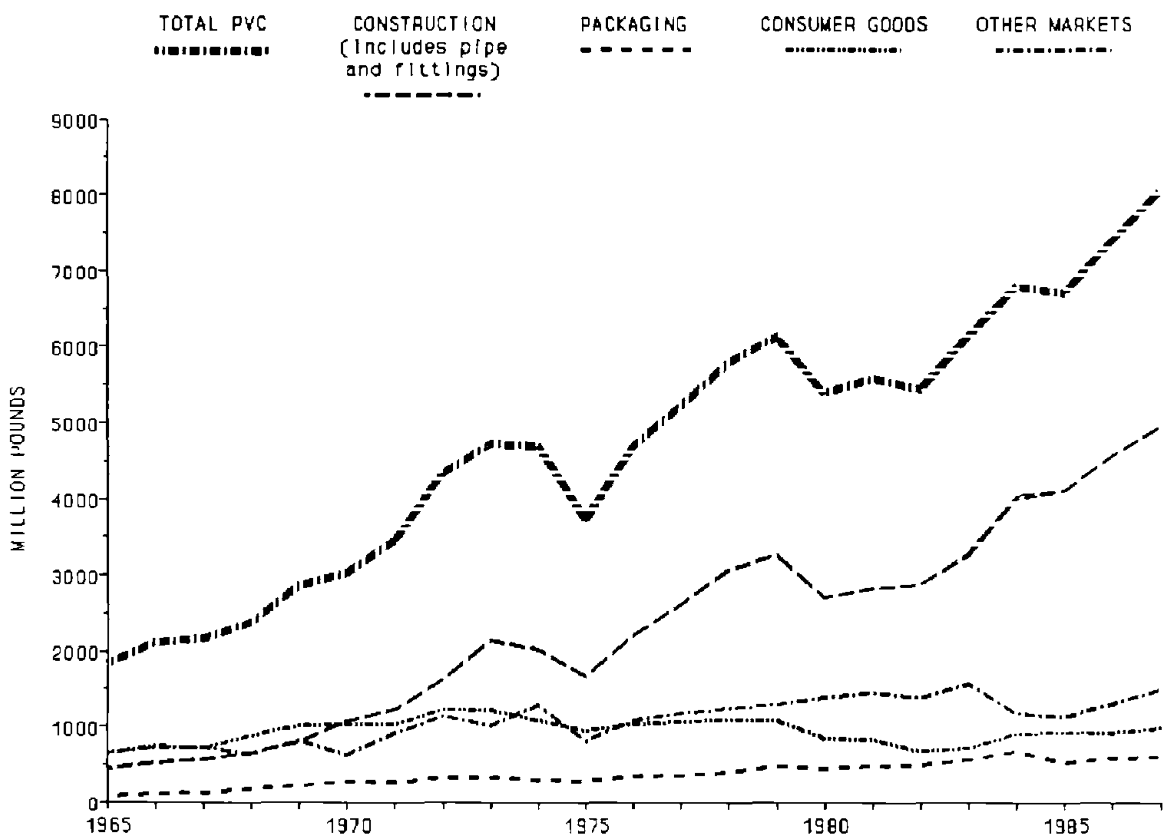

Figure 3.—Major U.S. PVC markets.

From the previous information, it is clear that the building and construction industry is the major contributor to the growth of the PVC market in the U.S. and merits further study. Figure 4 displays the pipe, fittings, and conduit sector of the building and construction industry, hereafter referred to as pipe. As can be seen, PVC pipe comprised 23% of the PVC building and construction market in 1967. By 1987 an increase of over 3.3 billion lb of PVC pipe was observed. This corresponds to an average annual growth rate in PVC pipe usage of 17.8%. This growth rate far exceeds the growth rate of the building and construction industry and indicates that materials substitution was occurring throughout the period. Growth in other construction uses of PVC averaged 6.2%, also showing some expansion into markets traditionally held by other materials. The impressive growth of PVC pipe in the construction industry must be tied to the requirements needed for the various pipe applications in the industry as discussed in the next section.

In summary, since the 1930s, the use of plastics as a material for pipe has been growing. The most dominant plastic used for piping has been and is PVC (77.4% of the market in 1987) and its growth rate has been higher than all other plastics. Due to this growth, as well as advances in other uses for PVC, world consumption has grown at a remarkable rate. Consumption in the U.S. has also grown substantially, with an average growth rate of 8.5% between 1960 and 1987. The largest growth industry for PVC in the U.S. is the building and construction industry, with PVC pipe being the major component involved in this growth. The growth of PVC pipe revolves around the applications that it can be used for in the building and construction industry and, for this reason, a closer look at these applications will be presented.

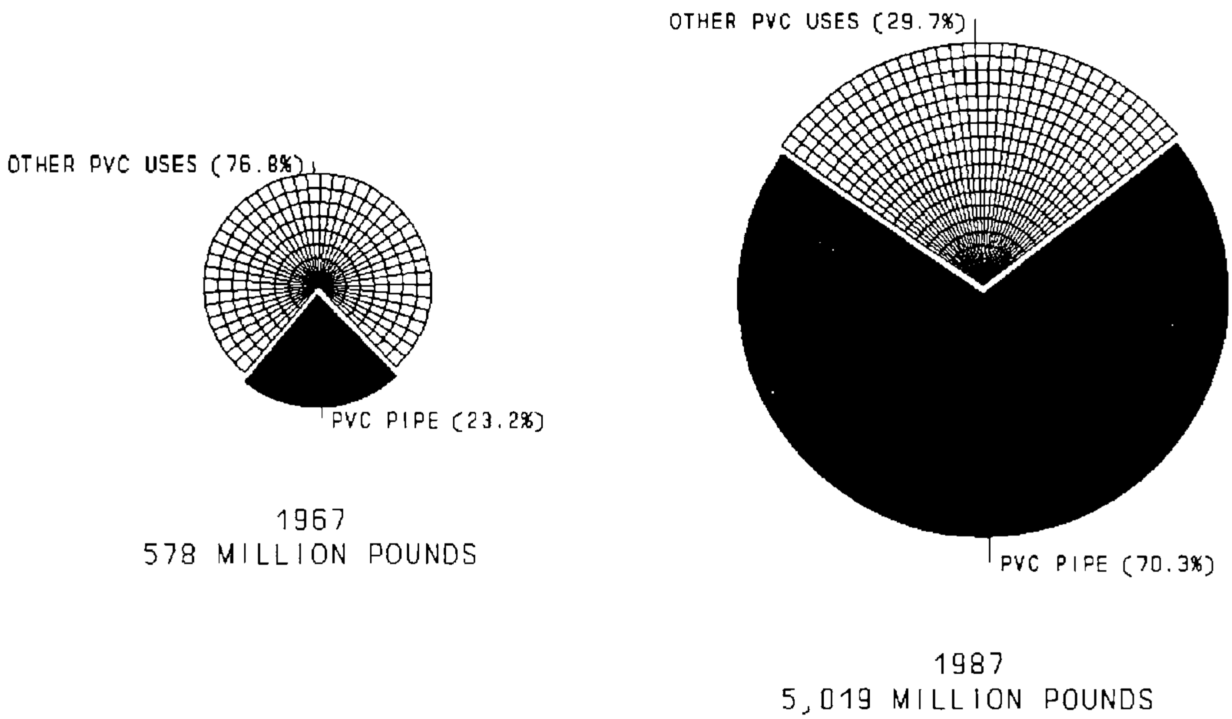

Figure 4.—Building and construction PVC market breakdown.

PVC IN PIPING APPLICATIONS

Growth of PVC in the pipe market is attributable to the use of PVC pipe in several distinct categories based upon a variety of different factors. Included among these factors are the following:

1. In certain situations, PVC pipe has an advantage in terms of physical and chemical characteristics over conventional pipe materials. Compared to metals, PVC is considerably lighter in weight and thereby easier to handle, is easier to assemble, has improved flow characteristics, and is resistant to corrosion and vibration.
2. PVC pipe exhibits appropriate environmental and health safety characteristics for most standard applications. This has led to the relaxation of laws and regulations which previously have prevented the use of PVC pipe in some applications. It has also allowed PVC pipe gradual inroads into new areas.
3. Technological changes such as extruder improvements and advances in polymer chemistry have reduced production costs for PVC. It is much less expensive to manufacture than copper or cast iron and is competitive with steel. In 1988, the price of one pound of pipe grade PVC was $0.38. The comparable prices for copper, cast iron, and steel were $1.07, $0.60, and $0.25 per pound, respectively.
4. Opposition to PVC use from plumber's unions has diminished.
5. Contractor awareness of the use and safety of PVC pipe is slowly expanding.

The combination of these various factors has led to the use of PVC pipe in the major piping categories of pressure water, pressure gas, pressure irrigation, DWV, conduit, sewer/drain, fittings, and other which is a conglomerate of piping applications including oil and gas development, industrial, mining, and miscellaneous applications. Detailed reporting for these categories began in 1979. The amount of PVC used in each of these categories in recent years is illustrated in figure 5.

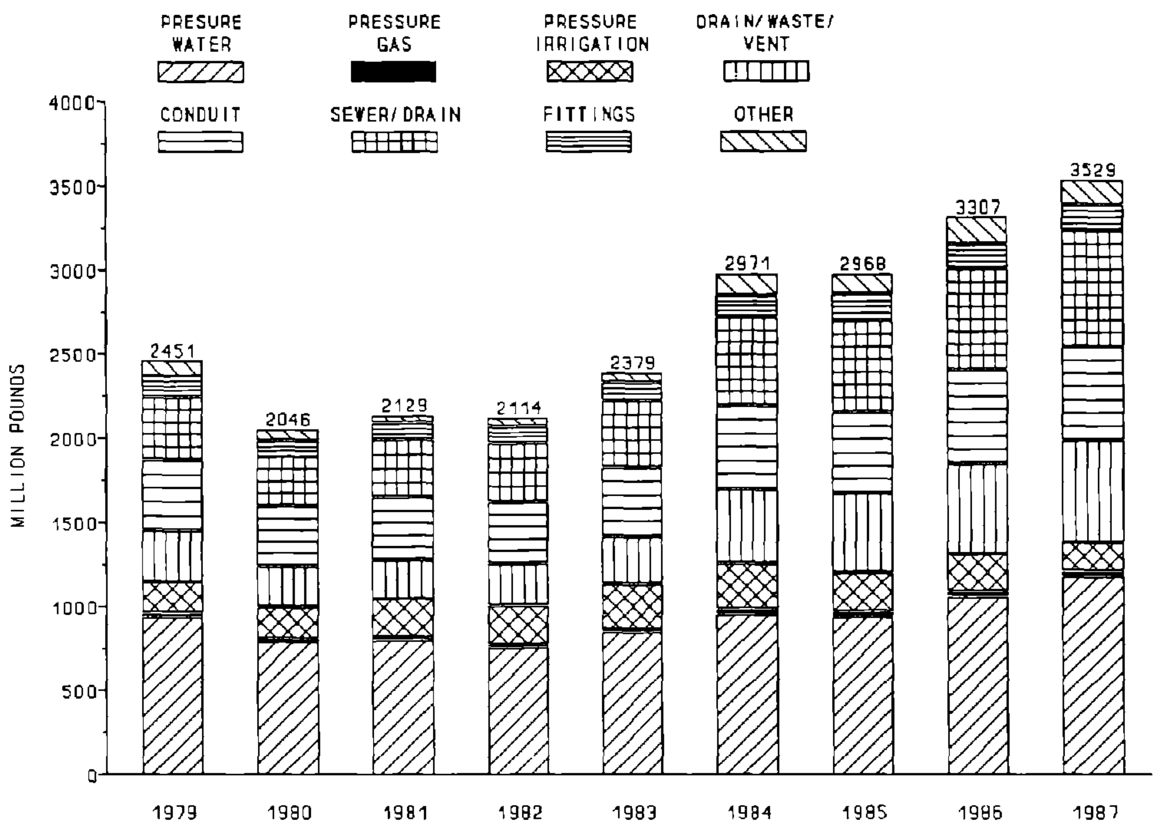

Figure 5.—PVC pipe end uses.

The major end uses that had the greatest increases between 1979 and 1987 are the DWV, sewer/drain, and pressure water categories. This is due primarily to the improved performance of PVC resins and the relaxing of national and local plumbing codes. Additionally, PVC is becoming attractive to contractors because of its low cost and ease of installation. DWV and sewer/drain uses have grown the fastest since these uses are the least demanding applications in terms of heat resistance and strength. The traditional end use for PVC pipe has been for the pressure water application. This application remains the largest single end use of PVC pipe even though its share of the total market from 1979 to 1987 has dropped from 38 to 33%. This is due to expansion of other markets such as DWV and sewer/drain.

The use of PVC pipe for pressure irrigation, comprised of lawn sprinkler systems and rural irrigation systems, has decreased over this period. PVC pipe is less suited to these applications since it is very susceptible to ultraviolet degradation and freeze/thaw breakage. It is also quite rigid compared to pipe made from other plastics which can serve the same market.

In summary, the use of PVC pipe is predicated upon its material properties, low cost, ability to meet national and local plumbing codes, and ease of installation. PVC pipe is used most for pressure water, DWV, and sewer/drain applications. These applications take advantage of the properties of PVC pipe. Use of PVC pipe for pressure irrigation is declining because other plastics are more effective in this type of application. PVC is only one material that may be used for the applications given above. Other materials can be and often are used for these as well as other applications as described in the following section.

PVC USE COMPARED WITH OTHER MATERIALS IN PIPE APPLICATIONS

Because of the many uses for pipe, a number of very diverse materials are being used to fulfill the needs of the piping industry today. The materials most often used are: clay, cast iron, copper, lead, asbestos cement, steel, and plastic. Reported values for use of these materials are normally given in terms of weight. This does not give an accurate representation of the amount of pipe made from each material. This is because the density of each material is very different (see table 2).

Table 2.—Material densities

Material	Density lb/in^3
Asbestos-cement	0.11
Cast iron	0.26
Clay	0.06
Copper	0.32
Steel	0.28
ABS	0.04
HDPE	0.03
PVC	0.05

For example, the weight of a 2-inch diameter steel pipe is 3.6 lb/ft whereas that for a 2-inch diameter PVC pipe is 0.64 lb/ft. This means that a comparison of the different pipe materials by weight is nebulous. It is far better to analyze the growth and/or decline of the various materials by looking at the volume of the material used. Volume will take into account not only the linear dimension of the pipe, but also the wall thickness and nominal diameters of the pipe. It is assumed that in standard applications with pipe diameters 6 inches and under, the wall thickness and nominal diameters of each material are approximately the same. This assumption, although not one hundred percent accurate, allows us, through ease of calculation, to compare the growth and/or decline of the various materials over time. The comparison will enable us to determine if the use of PVC pipe is affecting the consumption of the various alternate materials.

Figure 6 shows a comparison of volumes of materials that are used to make pipe. Steel, clay, and cast iron dominated the pipe market in 1960, but PVC was the third most used material by the early 1970s. PVC was second by 1977 and surpassed steel as the largest volume material used in pipe in the early 1980s. The combination of ABS, PE, and other plastics also constitutes a large fraction of the total volume, with only steel and PVC volumes being greater after 1980. This steady increase in the amount of plastic used, especially PVC followed by ABS and PE with a significant decrease in steel and clay, clearly indicates the desirability of plastics use in the pipe market. If the current trends continue, plastic pipe will remain the dominant material in the piping industry.

An additional indication of this developing dominance of plastics in the piping industry can be seen in table 3, where the dollar values of materials used are given. Even though PVC is considerably lighter and cheaper than most other materials, it is quickly attaining a significant portion of the pipe industry in terms of dollar value.

In reviewing, it is noted that several materials are commonly used in the pipe industry. These are clay, cast iron, copper, lead, asbestos cement, steel, and plastic. Due to the differences in the density of the various materials, a comparison of growth and/or decline is best performed on a volume basis. Over time, PVC has become a dominant material in the piping industry, taking large amounts of the market away from the more conventional materials. The next section quantifies the effect that plastics are having on the use of these materials.

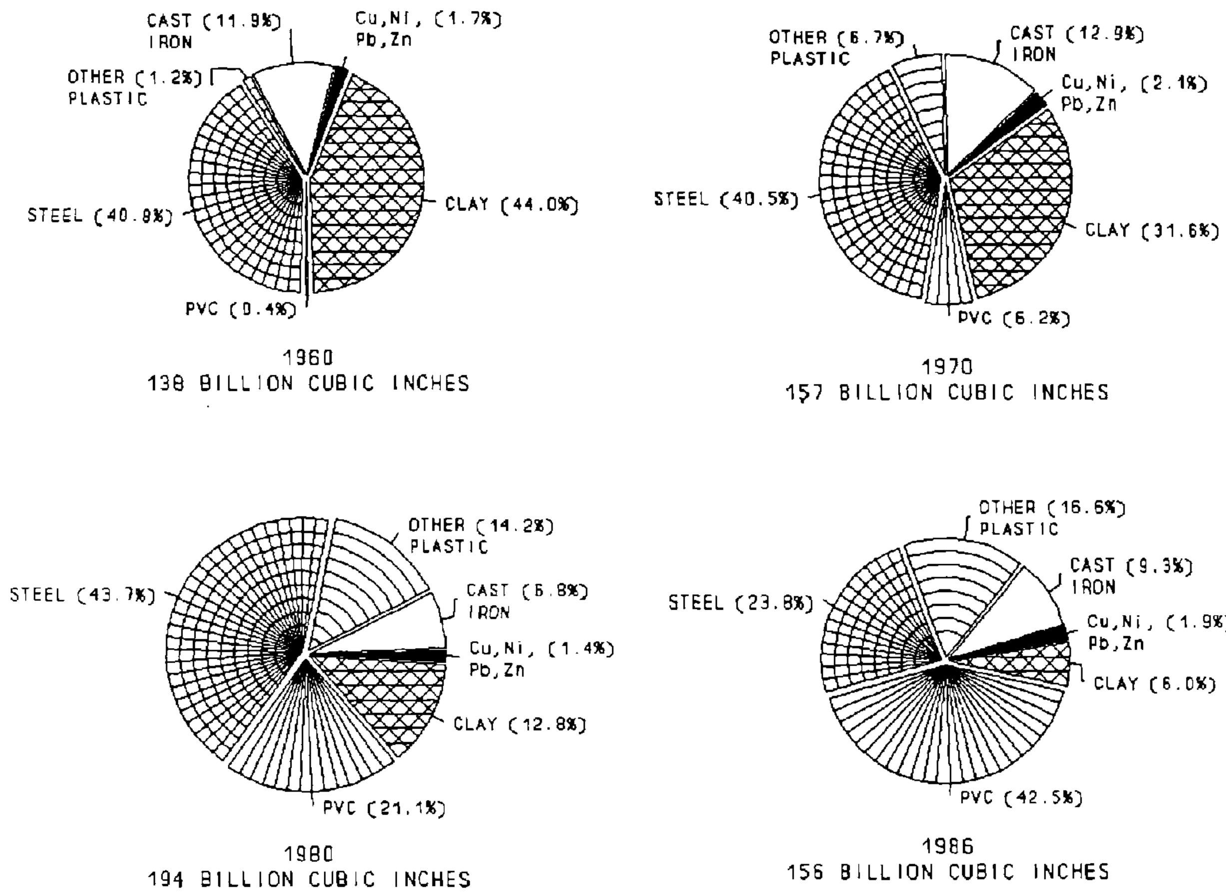

Figure 6.—Volume of materials used in pipes.

Table 3.—Dollar value of materials used in pipe

(thousand actual dollars)

Year	PVC	Steel	Cast Iron	Copper	Clay
1960	4,625	982,452	616,395	176,229	6,310
1961	5,760	1,122,880	652,239	192,600	6,310
1962	5,250	1,084,440	646,560	251,636	6,424
1963	5,250	978,138	763,726	271,964	6,934
1964	9,280	1,117,700	842,278	320,784	7,085
1965	14,700	1,235,460	837,082	351,522	7,243
1966	23,250	1,231,550	804,825	355,386	7,518
1967	28,800	1,278,290	815,480	311,502	6,934
1968	23,000	1,531,730	886,080	346,884	7,898
1969	33,220	1,439,530	881,088	453,613	9,090
1970	56,005	1,375,610	850,500	476,658	8,015
1971	73,700	1,457,150	944,452	449,800	9,106
1972	112,125	1,546,470	1,086,300	458,240	9,849
1973	174,720	1,801,980	1,143,830	584,290	10,186
1974	240,870	2,317,950	1,286,940	584,418	11,113
1975	236,280	2,210,490	1,102,700	372,810	11,236
1976	398,565	2,111,680	1,349,220	490,680	12,105
1977	513,810	2,944,660	1,692,400	521,151	13,176
1978	598,050	3,704,760	1,769,150	555,275	12,884
1979	681,378	3,996,600	1,873,600	832,566	14,091
1980	591,294	5,187,820	1,784,510	780,010	14,651
1981	553,800	7,736,010	1,867,700	650,024	11,355
1982	467,194	4,535,280	1,596,250	528,528	8,892
1983	672,974	2,864,180	1,918,600	562,275	8,014
1984	870,503	4,819,000	2,360,830	559,116	9,051
1985	839,944	4,277,450	2,366,950	559,450	8,243
1986	939,818	2,586,140	2,166,640	585,646	7,102

MATERIAL REPLACEMENT

Technological advances in the synthetic polymers industry, and especially the plastics industry, have created materials that act as an adequate or even superior replacement for more conventional materials. As has been shown, this is especially true of the piping industry where PVC and other plastics have taken over a significant portion of the market. It is important to determine the overall effect of this replacement on the material industries that make up the bulk of the piping market. The material industries examined are asbestos cement, cast iron, clay, copper, and steel.

In order to quantify the amount of plastic pipe that is competing with the other pipe materials, some assumptions must be made. The assumptions that will be used in this comparison are as follows (*2*):

1. All plastic pressure pipe is a metal substitute.
2. All plastic DWV pipe is a metal substitute.
3. 75% of plastic conduit pipe competes with metal.
4. 10% of all sewer pipe competes with metal (clay is still the primary material), except for corrugated PE which is 100% substitutable with steel.
5. All other plastic pipe applications compete directly with metal.

Consumption in terms of volume for the various plastic pipe uses in direct metal competition are listed in table 4 for the years from 1975 through 1986. These volumes take into account the assumptions previously listed and are for PVC, HDPE, and ABS. For the years indicated, these comprised the bulk of the plastic pipe industry (see figure 1). To calculate an apparent replacement volume for the conventional materials (asbestos cement, cast iron, clay, copper, and steel) further information is needed in addition to the volume of plastic used for various pipe types; i.e., pressure, DWV, etc. It is necessary to know the percentage of each competing material used for a given pipe service. This information is in table 5 for 1978, for metals. Asbestos cement is assumed to be the material displaced in 25% of the conduit market and 10% of sewer. Clay is the replaced material in 80% of sewer pipe.

Table 4.—Volume of plastic pipe used as a direct metal replacement

(billion cubic inches)

Year	PVC pressure	PVC DWV	PVC conduit	PVC sewer	PVC other	HDPE pressure	HDPE corru-gated	HDPE other	ABS DWV	ABS other	Total
1975	[1]10.5	[1]2.4	[1]2.7	0.2	0.4e	[1]2.3	[1]3.5	[1]0.3	[1]2.3	[1]1.0	25.6
1976	[1]13.3	[1]3.1	[1]3.2	0.4	0.6e	[1]3.0	[1]5.7	[1]0.7	[1]3.5	[1]1.6	35.1
1977	[1]16.9	[1]4.4	[1]4.0	0.5	0.7e	[1]3.7	[1]8.6	[1]0.8	[1]4.0	[1]2.3	45.9
1978	[1]16.8	5.3	6.4	0.8	0.4	[1]5.3	9.3	[1]1.0	[1]2.9	[1]2.5	50.7
1979	23.2	6.1	6.3	0.7	1.4	4.3	9.4	[1]0.4	[1]2.8	[1]2.7	57.3
1980	20.2	4.8	5.4	0.6	1.0	3.4	8.1	[1]0.5	[1]2.1	[1]1.6	47.7
1981	21.5	4.6	5.6	0.7	0.3	3.9	9.6	3.4	4.2e	1.8e	55.6
1982	20.8	5.0	5.4	0.7	0.2	2.8	8.0	2.8	2.7e	0.9e	49.3
1983	23.5	5.7	6.1	0.8	0.3	1.5	10.1	3.3	4.2	0.8	56.3
1984	26.4	8.8	7.4	1.1	1.2	4.8	8.7	5.6	4.1	0.9	69.0
1985	25.1	9.4	7.2	1.1	1.2	5.0	3.4	5.5	3.3	0.8	62.0
1986	27.4	10.7	8.3	1.2	2.0	5.7	4.1	4.8	3.4	0.8	68.4

e Estimated.
[1]Calculated from Business Communications Co., Inc. data (2).

Table 5.—1978 Allocation of plastic pipe into metal pipe use

(percent)

Material	Pressure	DWV	Conduit	Soil pipe sewer/drain	Corrugated	Other
Cast iron	-	96	-	65	-	53
Copper	4	4	-	-	-	1
Steel	96	-	100	35	100	46

NOTE.—Calculated from Proceedings of the International Conference on underground Plastic Pipe, p. 302.

This breakdown is assumed to be a valid representation of the proportions in which conventional materials are displaced for the year 1986. This, of course, is not completely accurate because plastics have taken a larger share of these markets from 1978 through 1986. However, no complete data set is available for a more recent year and the information listed in table 5 will help to give an indication of what is happening in the pipe industry in 1986. Tables 6 and 7 provide equivalent volume numbers for the conventional pipe materials based upon the information given in tables 4 and 5. The equivalent volumes are the result of multiplying the volume of plastic used for a particular pipe service in table 4 by the percentage end use given in table 5.

Now that an equivalent volume for the various pipe materials has been derived, a comparison can be made to those industries to determine the effect of plastics replacement. Information detailing the volume of pipe material and the percentage of each in the total industry is given in table 8. Information is given for cast iron, clay, copper, and steel for the years 1970 through 1986. Volumes for the total usage of asbestos cement were not available and have been left out of the comparison.

A comparison of the equivalent volumes for metals with the amount actually used yields an approximate percent decline in the total volume for each metal industry. That is, a percent can be calculated which shows how much more of a specific material would have been used if plastics had not replaced it. The percentages for change (decline) in industrial volume are given in table 9.

It can readily be seen from table 9 that plastics has indeed had an impact on several of the metals industries. The use of plastics has significantly affected the cast iron industry by replacing an amount of material equivalent to approximately 27% of the total volume of that industry in 1986. That is a three-fold increase from 1978 when 8% of the total cast iron usage had been replaced by plastic pipe. Similarly, the copper industry has seen an increase of replacement from 6.87% of total U.S. copper consumption in 1978 to an estimated 11% of the total market in 1986. Changes in the clay industry are so small as to be considered insignificant due to the relatively small percentage of clay used for piping purposes. Changes in the steel industry are also small in percentage, but due to the overall size of the industry should be considered important.

Also important is the nearly 55% increase in plastics replacement of steel pipe from 1978 to 1986. That is, the steel market would have been 4.7% larger in 1978 except for the amount of steel pipe replaced by plastic. By 1986, the total steel market could have been nearly 7.3% larger if plastic pipe had not replaced steel pipe in a number of applications. Thus, the information tabulated shows that plastics are replacing metals in the pipe industry to an amount that profoundly affects these industries.

In summary, the amount of plastics used in various pipe applications was determined through the use of historical data. Further historical information provided an end use breakdown in the various pipe applications for the conventional materials of asbestos cement, cast iron, clay, copper, and steel. A set of assumptions allowed a simple calculation to be made which established a table of equivalent volumes of the conventional materials replaced by plastic for the years of 1978 and 1986. These values were in turn compared to historical values of materials use in the materials industries with the following results:

1. Plastics are replacing metals in the pipe industry to an extent that significantly affects these industries.
2. Plastics replacement for cast iron has risen threefold from 1978 to 1986 and now replaces a volume amount equivalent to approximately 27% of the total cast iron industry.
3. Plastics replacement for clay is not significant. This is because the portion of clay used for piping purposes is very small.
4. Plastics replacement for copper has risen from 6.87% of the total market for copper in 1978 to an estimated 11.26% in 1986. This represents a significant portion of the total copper industry.
5. Plastics replacement for steel comprises, as yet, only a small percentage of the total steel industry (approximately 4.7% in 1978 and 7.3% in 1986). However, due to the overall size of the industry, the replacement is consequential. Also important is the fact that plastic pipe used as a replacement material for steel pipe has risen to a level almost as large as the amount of steel pipe still being utilized.

The above results indicate that plastics replacement of metals in pipe is not only a reality, but one of significance. To understand the reason for this replacement and to determine if this is a cyclical situation or a permanent trend in the piping industry, one must look at how and why this replacement has occurred. The next section details the material properties and advantages and disadvantages of all the competing materials. It also discusses the material selection process that allows plastics to be compared, on an application basis, with asbestos cement, cast iron, clay, copper, and steel.

Table 6.—1978 Equivalent volumes of pipe materials

(billion cubic inches)

Material	Pressure	DWV	Conduit	Soil pipe sewer/drain	Corrugated	Other	Total
Asbestos cement	-	-	2.1	0.72	-	-	2.82
Cast iron	-	7.87	-	0.50	-	2.07	10.44
Clay	-	-	-	6.48	-	-	6.48
Copper	0.88	0.33	-	-	-	0.04	1.25
Steel	21.2	-	6.4	0.30	9.3	1.79	38.99

Table 7.—1986 Equivalent volumes of pipe materials

(billion cubic inches)

Material	Pressure	DWV	Conduit	Soil pipe sewer/drain	Corrugated	Other	Total
Asbestos cement	-	-	2.8	0.94	-	-	3.74
Cast iron	-	13.54	-	0.80	-	4.03	18.37
Clay	-	-	-	9.86	-	-	9.86
Copper	1.32	0.56	-	-	-	0.07	1.95
Steel	31.78	-	8.3	0.40	4.1	3.50	48.08

Table 8.—Industry use of materials

Year	Cast iron pipe: Billion cubic inches ([1])	Cast iron pipe: % in total cast iron market ([2])	Clay pipe: Billion cubic inches ([3])	Clay pipe: % in total clay market ([2])	Copper pipe: Billion cubic inches ([4])	Copper pipe: % in total copper market ([5])	Steel pipe: Billion cubic inches ([6])	Steel pipe: % in total steel market ([2])
1970	20.19	17.74	53.43	2.75	2.56	NA	63.80e	9.05
1971	21.12	18.62	63.23	3.14	2.70	15.97	61.95e	8.34
1972	23.21	18.40	63.13	2.98	2.81	14.90	61.37	7.91
1973	23.28	16.72	60.63	2.65	3.07	14.80	68.48e	7.70
1974	20.54	16.08	52.92	2.47	2.37	13.47	73.91	8.50
1975	13.55	13.34	43.85	2.55	1.81	14.30	60.26	9.28
1976	14.74	12.78	40.35	2.18	2.20	13.52	52.79	7.44
1977	17.08	13.71	40.67	2.17	2.43	14.13	67.41	8.07
1978	16.40	13.00	34.08	1.70	2.61	14.35	73.51	8.92
1979	15.43	12.46	30.50	1.60	2.82	14.77	71.37	8.47
1980	13.25	14.35	26.83	1.60	2.41	15.30	85.38	11.86
1981	12.67	13.39	17.05	1.12	2.41	14.64	114.17	13.68
1982	10.53	16.11	12.67	1.05	2.27	17.80	64.02	11.19
1983	12.18	16.66	11.72	0.83	2.30	15.40	39.04	6.59
1984	14.79	17.48	12.78	0.85	2.62	15.23	63.04	8.84
1985	15.59	22.27	12.27	0.79	2.61	17.23	55.35	7.94
1986	14.44	21.58	10.12	0.66	2.77	NA	37.24	5.66

e Estimate.
NA Not available.
[1]From Metal Statistics.
[2]Calculated from Mineral Commodity Summary.
[3]From Brick and Clay Record.
[4]From Minerals Yearbook and Metal Statistics.
[5]Calculated from Nonferrous Metal Data.
[6]From Metal Statistics and American Bureau of Metal Statistics Yearbook.

Table 9.—Industry decline due to plastic replacement in pipe

Industry	Pipe usage of total industry, %	Volume of pipe actually used, billion cubic inches	Volume of pipe replaced by plastics, billion cubic inches	Decline, %
Cast iron:				
1978	13.00	16.40	10.44	8.28
1986	21.58	14.44	18.37	27.45
Clay:				
1978	1.70	34.08	6.48	0.32
1986	0.66	10.12	9.86	0.64
Copper:				
1978	14.35	2.61	1.25	6.87
1986	16.00e	2.77	1.95	11.26e
Steel:				
1978	8.92	73.51	38.99	4.73
1986	5.66	37.24	48.08	7.31

e Estimate.

MATERIAL SELECTION CRITERIA FOR PIPING APPLICATIONS

To understand why plastics have gained such a large share of the piping market, it is important to look at the material selection process. The key to this process is the engineer responsible for the system design. The engineer strives to select the appropriate material for a piping application which meets the specified performance criteria at minimum cost. In designing a piping system the engineer first considers (1) the piping requirements; i.e., flow rate, pressure, temperature, (2) the operating conditions; i.e., corrosive atmosphere or fluids, and (3) the environmental conditions; i.e., physical and thermal shock. After a determination of these fundamental requirements has been made, the mechanical properties; i.e., tensile strength, resistance to buckling and bending, fracture and fatigue resistance, must be determined. Consideration must also be given to long term effects such as creep, permanent load deformation, and wear resistance. Temperature specifications are considered as they can greatly influence the mechanical properties.

Once the requirements and criteria are determined, the engineer decides which type of pipe best suits the application while remaining the most cost effective. At this point the ease of installation, maintenance, functioning life time, and recyclability are considered along with the cost and availability of the material.

A comparison of uses and qualities in pipe materials is a practical way of determining which material best suits a particular design. Tables 10 and 11 list pipes made of different materials and give their primary uses and qualities. As can be seen from the tables, most pipe is limited in its use because the performance characteristics for the pipe material is narrow. Conversely, plastic pipe qualities are very diverse, thus making plastic pipe a competing material for a variety of uses.

Engineers and contractors are choosing to take advantage of the unique capabilities of plastic pipe, specifically PVC, for two main reasons. PVC pipe is capable of meeting the specific needs of the piping project and has low material and installation costs. And, PVC pipes are much easier to install and repair because they only require cutting with a common saw and gluing pieces together with a solvent. Conversely, steel pipe must be cut with special saws or torches and segments must be welded or soldered together. A survey of plumbers in Colorado (see acknowledgment list) estimated an installation savings over copper of 60-70% when using PVC pipe.

Besides their lower costs and ease of installation, plastic pipes exhibit several properties that engineers and contractors find very beneficial. The plastic pipe has a high resistance to fatigue and corrosion. It behaves very well as an insulator in electrical uses, has low heat conductivity, and provides a smooth surface which imparts good flow characteristics. The chemical structure of PVC makes it much less likely to fail under a fluctuating load where metals can have catastrophic failures at a relatively low number of repetitions in loading. PVC is also much more resistant to many chemicals, such as chlorine, and does not rust or corrode like steel. Finally, because PVC does not corrode, pipe walls remain smooth and the flow will not be hampered, lessening the tendency of clogging in the piping system.

Many contractors and plumbers agree that PVC and other plastics are making a large impact on the piping market. Some feel that plastic will completely take over the market and prefer to use it, while others do not trust PVC and prefer to continue installing traditional copper and steel pipes. The eventual use or avoidance of plastics may well depend upon the design engineer. It is the engineer who will specify what material is to be used in which application. The main criteria of performance and price involved in this decision is detailed below.

Table 10.—Pipe uses

Material	Water	DWV	Storm sewer	Oil/gas services	Pressure gas	Soil pipe	Chemical/ Industrial	Nuclear	Other[1]
Alloy								X	
Aluminum			X				X		X
Asbestos cement	X		X			X			
Cast iron	X	X			X	X	X		X
Clay						X	X		X
Concrete			X			X			X
Copper and brass	X	X					X		X
Glass							X		
Lead							X		
Other plastic	X	X	X	X	X	X	X		X
PVC	X	X	X		X	X	X		X
Stainless steel							X	X	
Steel/wrought iron	X			X		X			
Titanium							X		
Wood	X					X			

[1]Includes steam, sprinkler systems, heating, water storage.

NOTE.—An X in a particular cell indicates that a pipe made of that material is well suited for or can withstand the particular condition identified by the column headings.

Table 11.—Pipe qualities

Material	High flexibility	High pressure	Low pressure	High temperature	Low temperature	Corrosion resistance	Vibration tolerance	High velocities	High shock
Alloy		X		X		X	X	X	X
Aluminum[1]		X	X	X	X	X		X	
Asbestos cement			X		X	X	X		
Cast iron			X	X	X	X	X		
Clay			X		X	X	X		
Concrete			X		X		X		
Copper and brass			X	X	X	X			
Glass			X			X			
Lead						X	X		
Other plastic	X	X	X	X	X	X	X	X	X
PVC	X		X		X	X	X		
Stainless steel		X		X		X	X	X	X
Steel/wrought iron			X		X		X		
Titanium		X		X		X		X	
Wood			X			X	X		

[1]Composition determines qualities.

NOTE.—An X in a particular cell indicates that a pipe made of that material is well suited for or can withstand the particular condition identified by the column headings.

DETAILED CRITERIA FOR PIPE APPLICATION

Materials are selected based upon performance criteria. The specific factors that the engineer uses to decide on piping materials are as follows:

1. Price - The price of the piping material, with respect to length rather than weight, must be within reasonable limits in order to make the project profitable.
2. Costs - Pre-installation costs such as engineering, financing, and transportation of the materials to the site; installation costs such as jointing, ancillary equipment, wages, etc.; and post-installation costs such as operating expense, taxes, maintenance and repair expense, and intangibles such as esthetics and safety all must be taken into account.
3. Availability of the material - This includes the availability of special parts and fittings, such as connections, junctions, bends, adapters, etc.
4. Useable life - The life expectancy of the material, as well as the projected life expectancy of the project as a whole, must be taken into account.
5. Ease of handling, laying, and assembling - The work place and the material must be considered. The weight of the material, and the types of connections, gaskets, etc., that are used can be limiting factors. The workplace must be able to accommodate all equipment necessary to properly complete the job.
6. Pressure rating - The internal surge and line pressures and the external ground pressures determine the wall thickness.
7. Flexibility or stiffness - The material's resistance to external loading will confine the pipe to specific uses and determine the structural support needed. Generally, since plastics are not as stiff, they require more support.
8. Temperature adaptability - The temperature of the surroundings as well as the temperature of the fluid in the pipe must be within the limits of the pipe materials' specifications. Temperature effects the strength, creep, and flexural properties of the pipe.
9. Corrosion - Pipe corrosion, internal as well as external, can be very detrimental to the system. Corrosion may create rough surfaces and even holes inside the pipe.
10. Breakage and damage - The pipe system must be able to sustain a limited amount of abuse without being damaged beyond repair. Abuse is considered to be such things as excessive vibration, rough handling, and inadequate installation.
11. Environmental effects - The consequences of thermal effects, biological attack, weathering, ultraviolet radiation, and abrasion must be considered for their detrimental effect on pipe systems.
12. Proven performance of the material - Proof that the material has successfully performed well under similar conditions.

By analyzing these criteria, a set of performance characteristics may be chosen. Once the characteristics of the piping system have been specified, the engineer or contractor is free to select from the many materials meeting these criteria. The following is an example comparison, in general terms, for common pipe materials.

ADVANTAGE/DISADVANTAGE COMPARISONS

All materials have applications that they are more suited for and applications that they are ill suited for. It is important to be able to ascertain which applications and which materials go together. Table 12 discusses some of the benefits and drawbacks of each of the different pipe materials. Most of the information is of a general nature and figures prominently in deciding whether or not a material is feasible for a particular application. Some of the information is useful in helping to determine the costs of alternative piping systems. The actual cost calculations and cost comparisons are made in following sections.

By carefully considering the advantages and disadvantages of the various pipe materials and measuring these materials against the design criteria, the engineer can successfully select only those materials that are appropriate for the project. It is also necessary to choose the one material that will work the best at the lowest overall cost. To do this, a lifecycle cost analysis should be performed. This type of analysis considers all of the costs associated with a project and material. These include the costs of materials, installation, maintenance and repair, and recycle and/or disposal for the material used. In the following sections, an example of a lifecycle cost analysis will be performed for three different piping systems.

Table 12.—Material advantages and disadvantages

Material	Breakthroughs and advantages	Deterrents and disadvantages
PVC	Studies show "that PVC pipe poses no greater threat to health than metal pipe, and in some cases may be preferred for potable water."(3)	Codes do not allow PVC pipe for potable water in many areas of the nation at present.
	It is now possible to produce heavy-duty PVC pipe in bores from 27-60 inches or big enough to compete with concrete pipe in a very large market now closed to vinyl.	Plumbers unions have fought the inclusion of plastic pipe in the codes. The fear they will lose a considerable amount of business if the pipe can be installed by the layman. And the amount of time it will take the plumbers to install the pipe will be decreased considerably.
	PVC has a low coefficient of friction which reduces the chances of blockage and reduced flow rates.	Plastic pipes generally have less strength than metals and damage by third parties is more possible; i.e., backhoes, trenching machines, etc.
	PVC is very low in price and easy to handle with a minimum of ancillary equipment; i.e., for a 1-foot length of 6-inch pipe PVC weighs 8.22 lb and costs $4.04, while steel weighs 18.97 lb and costs $12.73, and cast iron weighs 26.9 lb and costs $65.25.	Plastic pipe is flammable.
		Buried plastic pipe is difficult to find after installation.
	Plastic is not susceptible to tree root penetration.	Plastic pipe can be damaged by rodents.
		Plastic pipes can be susceptible to temperature extremes—becoming brittle at low temperatures and soft at high temperatures.
		Most plastic is susceptible to ultraviolet light degradation.
Copper	Pipe is somewhat flexible and can withstand external movement.	The EPA is trying to reduce lead threshold levels and has "banned the use of lead solder by 1989."(*4*)
	Resistant to corrosion.	
Steel	Available in wide range of tensile strengths.	Corrodes rapidly in areas where the pH is less than 4.
	Stainless steel is highly corrosion resistant.	Will rust through in time.
Cast iron	Cast iron has a very long life—over 100 years. Oldest known pipe still in operation is in Versailles, France installed in 1664.	Cast iron is very heavy.
		Weak in tension.
	High flow capacity.	Material is very brittle.
	Trouble-free service.	
	Corrosion resistant.	
	High structural strength.	
	Tight joints.	
	Readily machinable.	
	Temperature resistance.	
Concrete	Useful life of 100 years.	Concrete is very heavy.
	Concrete gets stronger as it ages.	Weak in tension.
	High compressive strength.	
	Low coefficient of thermal expansion.	

Table 12.—Material advantages and disadvantages—Continued

Material	Breakthroughs and advantages	Deterrents and disadvantages
Clay	Highly resistant to chemicals and soil moisture.	Clay pipe is very heavy.
	Has a useful life of 150 years.	Susceptible to tree root penetration.
Asbestos-cement	Pipe has useful life of over 50 years.	Pipe is very heavy.
	Pipe strengthens while in the ground. Corrosion resistant.	Pipe will eventually be barred from use due to asbestos fibers. "On December 13, 1985, the EPA submitted to the Office of Management and Budget a proposal to immediately ban the manufacture, importation, and processing of certain asbestos construction materials (asbestos cement pipe and fittings, roofing felts, flooring felts, felt back sheet floorings, vinyl asbestos floor tile, and asbestos clothing) under section 6 of the 1976 TSCA. In addition, the mining and importation of asbestos products not directly banned would be placed under a permit system. The permit system would limit the mining and importation of asbestos to 30% of the 1981, 1982, and 1983 average values and would phase out asbestos use within 10 years."(5)

EXAMPLE COST ANALYSIS FOR THREE PIPING SYSTEMS

The authors of this paper have elected to perform cost analyses for three separate piping systems to illustrate the cost differences between alternative materials. The cost of any piping system will depend largely on the complexity of the piping run, method of joint make-up, number of fittings, pipe diameter, pipe wall thickness, fabrication, and installation techniques as well as material costs and labor rates. These analyses will compare linear feet of material which is a more practical comparison from a plumber's perspective. By using linear feet of material, the wall thickness is assumed to be appropriate to perform the designated task. Thus, the wall thicknesses for steel and PVC are comparable, while that for copper is thinner, and those for clay and cast iron are thicker. The wall thicknesses for PVC and steel pipes are 0.113, 0.154, and 0.280 inches in nominal diameters of 3/4-inch, 2-inch, and 6-inch pipe applications, respectively. Copper pipe wall thicknesses are 0.065, 0.083, and 0.192 inches for the same 3/4-inch, 2-inch, and 6-inch pipe applications, respectively. This means that some difference in the volume of material used will occur for a given linear measure of pipe, and for this reason, a linear analysis is best. Not all of the pipe materials are acceptable for every application. For this reason, three different systems will be looked at for the analyses. The three piping applications selected for study are:

1. 3/4-inch residential plumbing system.
2. 2-inch residential sprinkler system.
3. 6-inch residential drain/waste line.

A representative system for each pipe diameter has been designed. Each design is an approximation of what may actually exist in service at some residences today. They are not intended to be construed as a complete system design for residential housing. The design for the 3/4-inch residential plumbing system consists of 500 feet of pipe with four tees and six 90-degree elbows. Although residential plumbing systems vary with the number of bathrooms, house size, and house layout it was felt that this system closely approximated existing residential plumbing systems. The piping design for the residential sprinkler system is largely a function of the lot size and the available water pressure. This particular case study utilized 1,500 feet of 2-inch pipe, four tees and six elbows. The third case study consisted of 150 feet of 6-inch pipe, one tee and two elbows in a drain/waste line application. This is an approximation of a typical system which connects the house drainage network to the residential or community conduits.

PIPING SYSTEM COST COMPARISONS

The following sections present cost estimates for the three piping systems described. These estimates were derived by contacting a large number of plumbers, contractors, and supply houses in the Denver, CO, area and obtaining quotes for each stage of the process. Material costs, installation costs, utility/maintenance costs, and recycle and disposal costs are each estimated separately. Raw material costs are based on annual average costs as quoted in the Minerals Yearbook, unless otherwise stated. Labor rates were based on a national average of $22.50/h in 1988, and disposal costs are based on rates prevailing in Denver, CO, as of January, 1988. Cost values are estimated for the Denver area as a means of demonstrating the comparison costs for the various materials. Different parts of the country will exhibit slightly different cost values although the basic information generated by the analysis will remain the same. All of the costs for a particular system and a specific material comprise the elements of the lifecycle cost analysis.

MATERIAL COSTS

The first portion of the cost comparison analysis is the material cost of the product. The material cost may be looked at in terms of either the total cost of the material or the raw material cost. The total material costs are based on off-the-shelf prices to the contractor and include profit and overhead in the cost values. The raw material costs are based on the volume of raw materials and are reported separately. Total material costs and raw material costs for the residential plumbing, residential sprinkler, and residential drain/waste piping systems are reported in tables 13, 14, and 15 respectively.

Table 13 gives the material costs for a 3/4-inch residential plumbing system. It is based on 500 feet of pipe and includes four tees and six elbows. All pipe sections were of standard 20-foot lengths. The costs are based on cemented joints for the PVC, welded for steel, and soldered for copper. All welding and soldering materials and solvent cement are included in the material costs. It is assumed that the entire system is constructed of only one material.

Table 13.—Material costs for a 3/4-inch residential plumbing system

(actual dollars)[1]

Material	1967		1979		1988	
	Total materials cost	Raw materials cost	Total materials cost	Raw materials cost	Total materials cost	Raw materials cost
PVC	166	12.2	409	22.6	98	33.4
Cast iron	NAp	NAp	NAp	NAp	NAp	NAp
Clay	NAp	NAp	NAp	NAp	NAp	NAp
Copper	210e	118.8	420e	276.5	560	320.9
Steel, carbon	290	29.6	529	91.2	1,191	113.9
Steel, stainless	1,812	NA	3,358	NA	3,951	NA

e Estimate.
NA Not available.
NAp Not applicable.
[1]The prices used are a quarterly average for 1967 and 1979. For PVC and copper, the 1988 price is the January value and the steel price is actually the average 1987 value.

Table 14.—Material costs for a 2-inch residential sprinkler system

(actual dollars)[1]

Material	1967 Total materials cost	1967 Raw materials cost	1979 Total materials cost	1979 Raw materials cost	1988 Total materials cost	1988 Raw materials cost
PVC	1,397	131.6	3,111	243.8	959	359.6
Cast iron	NAp	NAp	NAp	NAp	NAp	NAp
Clay	NAp	NAp	NAp	NAp	NAp	NAp
Copper	1,214e	(2)	2,425e	(2)	6,222	3,238.6
Steel, carbon	1,083	319.2	2,344	982.3	6,026	1,227.8
Steel, stainless	10,640	NA	22,768	NA	28,000	NA

e Estimate.
NA Not available.
NAp Not applicable.
[1]The prices used are a quarterly average for 1967 and 1979. For PVC and copper, the 1988 price is the January value and the steel price is the average 1987 value.
[2]Raw material cost is close to the total cost of materials. It is unlikely copper would be used for this application. Quotes from contractors for the copper system assume a high proportion of other materials.

Table 15.—Material costs for a 6-inch drain/waste line

(actual dollars)[1]

Material	1967 Total materials cost	1967 Raw materials cost	1979 Total materials cost	1979 Raw materials cost	1988 Total materials cost	1988 Raw materials cost
PVC	885	72.7	1,770	134.7	563	198.7
Cast iron	464	NA	1,015	NA	9,836	NA
Clay	212e	NA	314e	NA	476	NA
Copper	2,840e	820.7	5,830e	1,960.4	7,478	2,275.1
Steel, carbon	439	176.4	1,170	542.7	2,603	678.3
Steel, stainless	3,560	NA	8,610	NA	10,730	NA

e Estimate.
NA Not available.
[1]The prices used are a quarterly average for 1967 and 1979. For PVC and copper, the 1988 price is the January value and the steel price is the average 1987 value.

Material costs for PVC pipe in the residential plumbing system are lower in all three years than for the other materials. If the material selection were based on material cost alone, PVC would be chosen for this application with copper a close second in 1967 and 1979, but only a distant second by 1988. Raw materials cost for PVC in the earlier years accounted for a small portion of the total costs, but currently accounts for a full third of the costs. This is due to better, more cost effective pipe production methods. Raw material costs are also a major portion of copper pipe costs, and the total materials cost is very dependent on the price of copper. In contrast, the raw materials content of the carbon steel plumbing system represent only a small percentage of total materials cost.

Table 14 gives the material costs for a 2-inch residential sprinkler system. It is based on 1,500 feet of pipe and includes four tees and six elbows. All other assumptions from the 3/4-inch system are still applicable.

PVC is again the preferred material in 1988 based on material costs alone. Carbon steel comes in a distant second followed closely by copper. However, in 1967 and 1979 PVC was ranked third for material costs. Carbon steel and copper were ranked 1 and 2, respectively. This shows that the raw material and fabrication costs of PVC have decreased enormously over the last nine years, making PVC a more attractive material. Once again the cost of the raw materials for PVC has become a larger factor in the overall cost due to better manufacturing. At this diameter copper is not as dependent upon total material costs, whereas steel is more dependent on raw material costs.

Table 15 gives the material costs for a 6-inch drain/waste line. It is based on 150 feet of pipe and includes one tee and two elbows. Cast iron pipe is assumed to be in 20-foot lengths and clay in 5-foot lengths. Mechanical joints are assumed for cast iron and bell for clay. All other assumptions from the 3/4-inch system are still applicable.

The table indicates that in 1988 clay is the cheapest material for the drain/waste system. PVC is a close second place and carbon steel is a distant third. Clay was also the cheapest material in 1967 and 1979, PVC was ranked fourth in both years. Cast iron and carbon steel had material costs far below that of PVC in both 1967 and 1979. By 1988, however, cast iron had dropped in the standings to fifth place, due to high manufacturing and material costs compared to PVC. The raw material costs to overall cost ratios in this piping application are similar to the values for those for the sprinkler system.

The material costs for PVC in the 3/4-inch pipe application is definitely lower in all three years than for the other materials. This indicates that, strictly from a materials cost standpoint, PVC has been the material of choice for residential plumbing for some time. When the diameter is increased to 2 inches the material of choice in 1967 and 1979 was carbon steel, but PVC is again the clear-cut option in 1988. This indicates that PVC would be a good current choice for residential sprinkler systems and has improved its competitive position over time. At 6 inches, clay remains the least expensive material, although the relative position of PVC has improved markedly. Six-inch drain/waste lines, based on material costs alone, would be best constructed of clay. However, material costs are not the only costs to be considered. This is true for all three residential piping systems. The next component for cost comparison to be considered is the installation cost.

INSTALLATION COSTS

The installation costs of any piping system depend on pipe diameter, pipe thickness, complexity of the piping system, fabrication and installation techniques, labor rates, labor productivity, ease of handling, piping environment, and method of joint make-up. These costs can easily be as high as 200% of the material costs. For our example, the estimated installation costs given for the three residential piping systems will include only labor charges. Piping labor charges consist of the work involved in receiving, transporting, distribution, site preparation, cutting, fitting, cementing, welding, threading, field assembly, alignment, testing, and backfilling. Joint make-up, as a part of the assembly process, has a substantial effect on piping costs. In order to eliminate as much bias as possible in the economic analysis of the materials, similar methods of joint make-up were assumed for the various materials. The method of joint make-up for stainless steel and carbon steel was butt-welding. PVC required the use of solvent cement joints while copper was soldered. Cast iron was analyzed using mechanical jointing methods and clay with bell and spigot joints. These are all very common methods of joint make-up for these materials.

The installation cost estimates were based on an 8-hour day. The labor rate was based on a national average of $22.50/h in 1988. This wage rate includes direct wages and fringe benefits as defined by the ENR Skilled Labor Index commonly utilized by the building and construction industry to estimate costs. The wage rate given does not include any additional contractor overhead or profit in excess of the amount implied in the total material costs. Labor rates for 1967 and 1979 were $5.54/h and $14.25/h, respectively. With a history of steadily rising labor costs it becomes much more important to use the most efficient assembly methods available. The increase in installation costs and a comparison of the installation costs for the various materials, in each system, is shown in tables 16, 17, and 18. The increases observed are due totally to the increased wages and better fringe benefits.

Table 16.—Installation costs for a 3/4-inch residential plumbing system

(actual dollars)

Material	1967	1979	1988
PVC	258	665	1,051
Cast iron	NAp	NAp	NAp
Clay	NAp	NAp	NAp
Copper	332e	855e	1,350
Steel, carbon	312	804	1,269
Steel, stainless	725	1,865	2,945

e Estimate.
NAp Not applicable.

Table 17.—Installation costs for a 2-inch residential sprinkler system

(actual dollars)

Material	1967	1979	1988
PVC	1,274	3,278	5,175
Cast iron	NAp	NAp	NAp
Clay	NAp	NAp	NAp
Copper	1,529e	3,933e	6,210e
Steel, carbon	1,546	3,976	6,278
Steel, stainless	2,759	7,097	11,205

e Estimate.
NAp Not applicable.

Table 18.—Installation costs for a 6-inch drain/waste line

(actual dollars)

Material	1967	1979	1988
PVC	360	926	1,463
Cast iron	367	944	1,491
Clay	460e	1,183e	1,868
Copper	471e	1,211e	1,913
Steel, carbon ...	389	1,000	1,575
Steel, stainless ..	748	1,924	3,038

e Estimate.

The installation costs for the residential plumbing system are shown in table 16. PVC is the cheapest material to install in all years evaluated, with carbon steel second and copper third. Difficulties in handling and connecting for the metal pipes adds significantly to the installation costs. Further, the level of expertise necessary for a functional installation is greater for the metal work, thus entailing a greater installation expense.

Installation costs for the 2-inch sprinkler system are presented in table 17. PVC was again the cheapest material to install, in all years, with copper second and carbon steel third. The increase in pipe diameter greatly increases the weight of the nonplastic pipes, causing handling problems to occur. The installation costs for copper and carbon steel differ by only $68 (1%) in 1988. This indicates that joint make-up is not as important a consideration as is the handling and fitting of the pipe. A quick glance at the installation costs for stainless steel shows it to be much more expensive to install. This higher cost is because of handling, fitting, and jointing difficulties and is indicative of why stainless steel is only used when its superior properties are needed.

Installation costs for the drain/waste line are shown in table 18. PVC has the lowest installation costs, but is followed closely by cast iron. The difference between the two is less than 2%. Carbon steel was the third cheapest material with clay, copper, and stainless steel rounding out the group in that order. PVC and clay costs are about the same since the bell joint installation is about as easy as cementing PVC joints. The major installation cost difference for all materials, except stainless steel, comes from material handling and site preparation. Stainless steel is the most expensive because it is very difficult to work with.

Costs of installation alone for all diameter pipe systems indicate that PVC is the preferred material for all systems in all years. However, the ordering of the remaining materials is different in each system. Carbon steel was the second choice for the 3/4-inch system, copper was the second choice for the 2-inch pipes, and cast iron was the second choice for the 6-inch line. Installation costs for all materials in all applications rose from 1967 to 1988 and the expectation is that costs will continue to climb as the labor rate rises.

Two pieces of the cost comparison analysis have now been looked at. In both, the material costs and the installation costs, PVC has been the best material to use from an economic point of view. Tables 19, 20, and 21 show the total of material and installation costs for the three piping systems. In the 3/4-inch residential plumbing system, PVC is the least expensive material, with copper the second choice, in all three years. In the 2-inch residential sprinkler system, PVC becomes the best choice in 1988. Prior to this time, carbon steel is the best choice, with copper being very competitive. In the 6-inch residential drain/waste line, PVC is marginally the best choice over clay in 1988. Prior to this time, clay, cast iron, and carbon steel are all better choices. Thus, the combination of material and installation costs gives us a slightly different picture of the material comparison. It shows that material costs alone are not an effective method of selecting a material. Installation costs must also be considered. If this is the case, then it follows that the utility/maintenance costs must also be analyzed. The next component of the cost comparison analysis is the utility/maintenance cost.

Table 19.—Material and installation costs of a 3/4-inch residential plumbing system

(actual dollars)[1]

Material	1967	1979	1988
PVC	424	1,074	1,149
Cast iron	NAp	NAp	NAp
Clay	NAp	NAp	NAp
Copper	542e	1,275e	1,910
Steel, carbon ...	602	1,334	2,460
Steel, stainless ..	2,537	5,223	6,896

e Estimate.
NAp Not applicable.
[1]Installation costs are based upon a survey of contractors in the Denver, Colorado, area for 1988. Previous years are calculated from these estimates.

NOTE.—Information derived from tables 13, 16.

Table 20.—Material and installation costs of a 2-inch residential sprinkler system

(actual dollars)[1]

Material	1967	1979	1988
PVC	2,671	6,389	6,134
Cast iron	NAp	NAp	NAp
Clay	NAp	NAp	NAp
Copper	2,743e	6,358e	12,432e
Steel, carbon	2,629	6,320	12,304
Steel, stainless	13,399	29,865	39,205

e Estimate.

NAp Not applicable.

[1]Installation costs are based upon a survey of contractors in the Denver, Colorado, area for 1988. Previous years are calculated from these estimates.

NOTE.—Information derived from tables 14, 17.

Table 21.—Material and installation costs of a 6-inch residential drain/waste line

(actual dollars)[1]

Material	1967	1979	1988
PVC	1,245	2,696	2,026
Cast iron	831	1,959	11,327
Clay	672e	1,497e	2,344
Copper	3,311e	7,041e	9,391
Steel, carbon	828	2,170	4,178
Steel, stainless	4,308	10,534	13,768

e Estimate.

NAp Not applicable.

[1]Installation costs are based upon a survey of contractors in the Denver, Colorado, area for 1988. Previous years are calculated from these estimates.

NOTE.—Information derived from tables 15, 18.

UTILITY/MAINTENANCE COSTS

Once the material and installation costs have been considered, the engineer must think about utility costs. In the case of piping, these are the maintenance costs as well as the estimated life of the piping system. Historically, the engineer has often neglected these costs, feeling that the responsibility ends with the installation of the new piping system. This is particularly true in the residential building and construction industry where the homeowner bears the maintenance costs.

Tables 22 and 23 show the utility/maintenance requirements and costs for each piping system. These costs are minimal as most piping systems require little maintenance. In fact, maintenance costs tend to be a function of how well the system was installed. Usually, the only reason a piping system requires repair is because the line is plugged or there is a leak. Most leaks occur at joints or because of a failure of a pipe wall. The drain/waste line is most likely to need repair due to root penetration and/or freeze-thaw problems.

Maintenance cost estimates for the three systems are based on the assumption that the pipe was properly installed and that one leak will occur in the life of the system. Repair of this leak will require removal and replacement of a standard length of pipe. Removal of a standard length of pipe requires the breaking of two joints, one on each end. A new section of pipe must be laid and the two ends rejoined. It was also assumed that the old length of pipe would be sold to a scrap dealer where possible; if not, it was to be disposed of in a landfill. This is a typical practice in the construction industry.

Tables 22 and 23 detail some of the unit costs which may be required in fixing a leak in 1988. Backhoes are necessary when the pipe is installed below the ground and must be dug up for repairs. The estimated costs for fixing a leak in each of the three systems is shown in table 23 and detailed in tables 27, 28, and 29. These tables summarize the entire lifecycle costs for each application system and will be discussed in depth later in the report.

Table 22 shows that PVC is the least expensive material in terms of repair cost for the 3/4-inch and 2-inch systems. Clay is least expensive to repair in the 6-inch system, with PVC being the second cheapest. This information compares well with that found in the installation cost section where PVC was the least expensive material in all situations. Material costs and jointing costs for clay are less than PVC in the 6-inch system, giving clay the slightly lower cost. The useful life of all materials is long with respect to replacement concerns and it is possible that the materials will outlive the life of the project. For this reason, no economic analysis is done for replacement costs.

The sum of material, installation, and utility/maintenance costs are shown in table 24. Values are given solely for 1988. The reason for this is that the table is meant to serve for comparison purposes only. As can be seen, the comparison of the sum of the three cost components shows that nothing has changed in terms of which material is least expensive. PVC is still the material of choice when material, installation, and utility/maintenance costs are considered. Further, the addition of utility/maintenance costs has not changed the economic ordering of material choices. This would tend to indicate, that for a properly installed system, the utility/maintenance costs are not important in the selection process. The only other component of the cost comparison analysis that may effect the selection process is the cost of material disposal.

Table 22.—Utility/Maintenance

Material	Maintenance requirements	Repair requirements	Maintenance and repair Equipment costs	 Labor costs	Useful life
PVC	Little or none. Visual inspection.	Plastic pipe cutter and solvent cement. In below ground applications heavy equipment is required for access only.	Backhoe $100-150/d.	Pipe fitter $20-25/man·h with benefits. (Assembly will take 30-35% less time.)	Unknown. Some pipe has been in service since the 1940's.
Asbestos cement	Little or none. Visual inspection by walking if pipe is large enough or inspection by computerized probe for small diameter pipes.	Well trained, knowledgeable personnel needed to make repairs. Heavy equipment needed to access and move pipe. If repairing holes, cement must be of the same proportions as the original mix and the repair must be shaped to correspond to the original pipe. Care must be taken when moving or cutting pipe so as not to release any asbestos particles.	Backhoe $100-150/d.	Pipe fitter $20-25/man·h with benefits.	+100 years
Cast iron	Little or none. When problem arises repair is made.	Well trained personnel need to make repairs. Heavy equipment needed to access and to move pipe.	Backhoe $100-150/d.	Pipe fitter $20-25/man·h with benefits.	+150 years
Clay	Little or none. When problems arises repair is made. Maintenance in areas of tree growth is relatively high.	Well trained, knowledgeable personnel. Heavy equipment needed for access and to move pipe.	Backhoe $100-150/d.	Pipe fitter $20-25/man·h with benefits.	+100 years
Copper	Little or none. Visual inspection.	Skilled pipe fitter. Soldering or threading equipment.		Pipe fitter $20-25/man·h with benefits.	20-25 years
Steel	Visual inspection. When problem arises repair is made.	Skilled pipe fitter. Welding or threading equipment. If large or long pipe segments are used heavy equipment is needed to move pipe.	Backhoe $100-150/d. Crane $50/h plus $200 setup fee.	Pipe fitter $20-25/man·h with benefits.	20-30 years

Table 23.—Utility/maintenance costs

(1988 dollars)

Material	Pipe size (nominal diameter)		
	3/4-inch	2-inch	6-inch
PVC	85	148	524
Cast iron	NAp	NAp	1,790
Clay	NAp	NAp	294
Copper	109	204	1,341
Steel, carbon	159	302	912
Steel, stainless	388	708	2,136

NAp Not applicable.

NOTE.—Costs are based upon information found in table 22.

Table 24.—Material, installation, and utility/maintenance costs

(1988 dollars)

Material	Pipe size (nominal diameter)		
	3/4-inch	2-inch	6-inch
PVC	1,234	6,282	2,550
Cast iron	NAp	NAp	13,117
Clay	NAp	NAp	2,638
Copper	2,019	12,636e	10,732
Steel, carbon	2,619	12,606	5,090
Steel, stainless	7,284	39,913	15,904

e Estimate.
NAp Not applicable.

NOTE.—Costs are based upon information found in tables 19, 20, 21, and 23.

PIPE RECYCLE AND DISPOSAL COSTS

Disposal of material must be considered in two ways. First, that the material is without value and is to be thrown away. Second, that the material does have some value and should be recycled. Simply because it is possible to recycle a material does not mean the material will in fact be recycled. Collection, separation, and reprocessing all affect the recyclability of a material. Today, pipes can often be recycled and sent back to the market place as used parts. Cast iron has a long history of this. Typically, a used pipe, irrespective of material, can be resold for approximately 40% of its current list price. However, the pipe must be fairly clean and corrosion free. The used pipe market is interested only in long lengths of used pipe and there is a great demand for larger diameter pipe such as sewer and waste lines. Cast iron, stainless steel, carbon steel, and copper pipe are often reused. Clay pipe, however, is not generally sold for reuse since it is usually destroyed during removal. The demand for used PVC pipe is low because it is relatively inexpensive to purchase new. Table 25 details information about pipe recycling and/or disposal.

For the case studies of the residential plumbing, sprinkler, and drain/waste systems, it was assumed that 30% of the cast iron, stainless steel, carbon steel, and copper would be suitable for reuse and could be sold as is. Because of the smaller market demand for used PVC pipe, approximately 20% of the original piping run was deemed salvageable and sold. All pipe was sold at 40% of its current, 1988, market price.

The pipe which is not recycled has to be disposed of or scrapped. Copper, cast iron, carbon steel, and stainless steel are usually taken care of through a scrap dealer on a weight basis. These pipes are eventually melted down for reuse. The scrap values are listed in table 25. These values are based on the assumption that the scrap dealer must provide a driver and trailer to haul away the material. The prices paid for scrap metal would be higher if the customer were willing and able to haul the debris to the scrap dealer's place of business. Very little if any of this pipe is carried to landfills for disposal. For this study, all metal pipe is assumed to be either reused or recycled.

Unlike the metal pipes, clay is not reusable and must be disposed of in a landfill. However, the clay pipe is degradable and thus does not provide all of the problems inherent in the disposal of nondegradable materials such as plastics. PVC pipe is frequently sent to landfills as the material costs are so low that recycling does not occur. PVC additionally can not currently be sold to a scrap dealer as in the case of the metal pipes. Very little PVC is thus reused or recycled. This is largely due to the degradation of its virgin properties upon reprocessing as well as the lack of a plastic collection network.

Because PVC pipe is not often recycled and is not currently processed to any great extent for reuse, the general practice is to dispose of PVC in landfills with other construction debris. Disposal costs are based on a volume of waste times a tip fee (cost per unit volume). The Midwest presently charges anywhere from \$2.50/yd^3 to \$3.30/yd^3 for the privilege of dumping material in a landfill. However, with the decreasing availability of landfills, this cost is likely to increase. (Some estimates indicate that landfill costs are increasing at an annual compounded rate of over 25%.) East coast states are already facing this problem and landfill costs are much higher.

Recyclable scrap metal credits, reuse credits, and disposal costs have been calculated for each of the materials selected for the residential plumbing, sprinkler, and drain/waste line case studies. A summary of the recycle and disposal costs are shown in table 26. Values are for comparison purposes only and are given for 1988. From this information it can be seen that most of the values are negative. This means that money collected from recycle and reuse will offset costs. The metal pipes are the easiest to reuse or recycle and thus have the largest negative values. PVC is not recycled or reused effectively and, consequently, its negative cost values are relatively low. Clay is not recyclable or reusable and is the only material with a positive cost. Now that the final component of the cost comparison analysis has been looked at, a comparison involving all of the costs is needed. This comparison is done as a lifecycle cost analysis.

Table 25.—Recycle and disposal

Material	Recycle	Scrap value		Disposal	Disposal cost
		$/st	$/lb		$/yd^3
PVC	At present very little pipe is recycled. In areas where significant amounts of PVC pipe are being discarded, longer pieces are being salvaged and reused. Until recently there was no market for plastic scrap. At the end of 1987, a method of turning "plastic scrap into a material that replicates wood" (6) was introduced into the U.S. The wood feedstock can withstand up to 40% PVC.	0 When recycling becomes standard practice, the scrap value of PVC could be significant.	0	At present PVC is buried in landfills with other construction debris. Studies now indicate that "No statistical relationship has been found between the amount of polyvinyl chloride in garbage and levels of dioxin or furon after incineration under proper combustion conditions." (7)	[3]2.95
Cast iron	Cast iron pipe has a distinctive record of reuse as cast iron pipe.	[1]44	0.022	Landfill	[2]2.95
Clay	None	0	0	Landfill if removed from ground.	[3]2.95
Copper	Some longer sections of pipe are reused if in good condition.	1,500	[2]0.75	Landfill	[3]2.95
Steel, carbon	Some longer sections are reused if in good condition.	[1]45	0.023	Landfill	[3]2.95
Steel, stainless	Some longer sections are reused if in good condition.	600	[2]0.30	Landfill	[3]2.95

[1]Iron & Metals, Inc., Denver, CO.
[2]Fagan Iron & Metal Corp., Denver, CO.
[3]RPS Landfill, Goden, CO.

Table 26.—Recycle and disposal costs

(1988 dollars)

Material	Pipe size (nominal diameter)		
	3/4-inch	2-inch	6-inch
PVC	-8	-109	-34
Cast iron	NAp	NAp	-1,263
Clay	NAp	NAp	4
Copper	-235	-2,362	-1,999
Steel, carbon	-139	-795	-318
Steel, stainless	-574	-4,485	-2,059

NAp Not applicable.

NOTE.—Negative values indicate a credit against costs.
NOTE.—Costs are based upon information found in table 25.

LIFECYCLE COST ANALYSIS

This paper has stressed the importance of considering all of the costs (material installation, utility/maintenance, and recycle and disposal) when selecting a material for a piping or construction project. This compilation of costs is called the lifecycle cost. Tables 27, 28, and 29 detail the components of costs for each portion of the lifecycle for residential plumbing, sprinkler system, and drain/waste piping case studies. All values are calculated in 1988 dollars. Material and installation costs were calculated for 1988, the year they occur. All other values were recomputed as net present values by a combination of assumed inflation and discount rates. Maintenance/repair costs were assumed to occur in 1998. In order to reflect the time value of money, wages, material, scrap metal credits, and backhoe costs were inflated 5% per year and discounted 10% per year over the ten year period. Maintenance disposal costs were assumed to increase 25% per year and were discounted 10% per year for the ten years. All reuse credits and final disposal costs were presumed to take place in 2008, the useful life of copper and carbon steel. Reuse credit and recyclable scrap metal credits were inflated 5% per year and discounted 10% per year over the 20 year period. Landfill disposal costs were assumed to increase 25% per year and were discounted 10% per year for the 20 years. Estimates of the man-hours required for installation and maintenance are given along with the dollar estimates of costs and credits.

Table 27.—Lifecycle costs for a 500-foot 3/4-inch residental plumbing system

(1988 dollars)

	PVC	Copper	Carbon steel	Stainless steel
Material costs	98	560	1,191	3,951
Installation costs				
Labor hours[1]	46.7	60	56.4	130.9
Wages	1,051	1,350	1,269	2,945
Maintenance/repair costs				
Labor hours	3.6	4.3	5.2	10.8
Wages	50	60	72	149
Material	2	14	26	93
Disposal	0.05	0	0	0
Scrap metal credit	0	-6	-0.61	-4
Reuse credit	-3	-25	-49	-171
Disposal costs				
Landfill disposal of nonmetals	8	0	0	0
Recyclable scrap metal credit	0	-63	-3	-45
Total cost	1,206.05	1,890	2,505.39	6,918
Ranking	1	2	3	4

[1]Labor hours estimated from Plant Design and Economics for Chemical Engineers, first, second, and third editions. Hours include receiving, transportation, distribution, site preparation, cutting, fitting, threading, cementing, welding, field assembly, alignment, testing, backfilling.

Table 28.—Lifecycle costs for a 1,500-foot 2-inch residential sprinkler system

(1988 dollars)

	PVC	Copper	Carbon steel	Stainless steel
Material costs	959	6,222	6,026	28,000
Installation costs				
Labor hours[1]	230	276	279	498
Wages	5,175	6,210	6,278	11,205
Maintenance/repair costs				
Labor hours	6	7.2	10	16
Wages	83	99	138	221
Material	8	50	49	227
Disposal	0.36	0	0	0
Scrap metal credit	0	-25	-1	-14
Reuse credit	-43	-279	-267	-1,257
Disposal costs				
Landfill disposal of nonmetals	104	0	0	0
Recyclable scrap metal credit	0	-611	-32	-433
Total costs	6,286.36	11,666	12,191	37,949
Ranking	1	2	3	4

[1]Labor hours estimated from Plant Design and Economics for Chemical Engineers, first, second, and third editions. Hours include receiving, transportation, distribution, site preparation, cutting, fitting, threading, cementing, welding, field assembly, alignment, testing, backfilling.

Table 29.—Lifecycle costs for a 150-foot 6-inch drain/waste line

(1988 dollars)

	PVC	Cast iron	Clay	Copper	Carbon steel	Stainless steel
Material costs	563	9,836	476	7,478	2,603	10,730
Installation costs						
Labor hours[1]	65	66	83	85	70	135
Wages	1,463	1,491	1,868	1,913	1,575	3,038
Maintenance/repair costs						
Labor hours	16	17.6	8	20	22	36
Wages	221	243	111	276	304	497
Material	38	801	9	580	200	823
Backhoe	61	61	61	61	61	61
Disposal	3	0	0	0	0	0
Scrap metal credit	0	-7	0	-94	-6	-70
Reuse credit	-14	-442	0	-320	-96	-455
Disposal costs						
Landfill disposal of nonmetals	101	0	110	0	0	0
Recyclable scrap metal credit	0	-34	0	-433	-24	-321
Total costs	2,436	11,949	2,635	9,461	4,617	14,303
Ranking	1	5	2	4	3	6

[1]Labor hours estimated from Plant Design and Economics for Chemical Engineers, first, second, and third editions. Hours include receiving, transporation, distribution, site preparation, cutting, fitting, threading, cementing, welding, field assembly, alignment, testing, backfilling.

The analysis indicates that PVC is the most economical material for all three piping systems when the full lifecycle costs are taken into account. With the single exception of clay in the 6-inch system, PVC has a cost advantage over all the other materials at every stage of the costing procedure except recycling and disposal. In general, PVC is cheaper in terms of cost of material, cost of installation, and cost of maintenance. All of the metals have a substantial reuse credit and/or scrap value while PVC has a small credit for reuse and a cost for disposal. However, in no case are the scrap and reuse credits large enough to offset the cost advantage PVC has in terms of materials and installation. A break-even analysis for total cost of PVC versus the closest competing material is shown in terms of disposal costs in table 30. Values for disposal costs in table 30 are calculated such that PVC would be equal in total cost to the next closest competing material for the specific piping system.

As can be seen from table 30, all disposal costs would have to be greatly increased over the $2.95/yd^3 value used in the lifecycle analysis before the cost advantage of PVC would be lost. Only in the 6-inch line is the disposal cost plausible. This is because clay does compete with PVC in this market.

Table 30.—Disposal cost for break-even analysis for PVC against closest competing material in 3/4-inch, 2-inch, and 6-inch applications

(1988 dollars)

Nominal pipe diameter, in	Disposal cost $/yd^3	Competing material
3/4	5,144	Copper
2	3,002	Copper
6	95	Clay

NOTE.—Values derived from tables 27, 28, and 29.

Reviewing, it can be seen that in 1988 PVC is the material of choice on an economic basis for the 3/4-inch plumbing, the 2-inch sprinkler, and the 6-inch drain/waste systems. The advantages of PVC are shown to be in all aspects of the lifecycle cost analysis except the recycle and disposal component. Even a substantial increase in the disposal cost would not remove the cost advantage that PVC holds over the other materials. Only in the 6-inch drain/waste line does PVC have serious competition from clay pipe.

SUMMARY

Throughout the history of man, pipes and piping systems have played a role in the development of civilization. Piping systems have provided utilities such as water and gas and have removed waste for our homes and cities. Crude clay and pottery were the first materials used for pipe, followed by wood and lead. As systems became more complex and temperature and pressure requirements increased, better materials and construction techniques were needed for piping. The additional problem of health hazards caused by using some piping materials led to tin lined pipes, iron pipes, and finally plastic pipes. Germany was the first to use plastic pipe, producing PVC pipe in the mid-1930s. A variety of other plastic materials were used for piping applications in the 1940s, 1950s, and 1960s. This practice continues today, although the plastics used have been changed or modified in many cases.

Since the 1930s, the use of plastics as a material for pipe has been growing. The most dominant plastic used for piping is PVC (77.4% of the U.S. market in 1987) and it is growing the fastest. Consumption in the U.S. has grown substantially, with an average growth rate of 8.5% between 1965 and 1987. The largest growth industry for PVC in the U.S. is the building and construction industry, with PVC pipe being the major component involved in this increase.

The growth of the PVC pipe market is dependent upon what the pipe can be used for. Use of PVC pipe is predicated upon its material properties, its low cost, its ability to meet national and local plumbing codes, and its ease of installation. PVC pipe is used most for pressure water, DWV, and sewer/drain applications. These applications take advantage of the properties of PVC pipe. Use of PVC pipe for pressure irrigation is declining because other plastics are more effective in this type of application.

Several materials that are commonly used in the pipe industry are clay, cast iron, copper, lead, asbestos cement, steel, and plastic. The use of the individual material is dependent on the material properties and cost of the material. Replacement for any one of these materials may occur if cost and/or material property needs change. Looking at the change in the use of the various materials shows what effect plastics are having on the other material markets. Due to the differences in density of the various materials, a comparison of growth and/or decline for these materials in the piping industry is best performed on a volume basis. The comparison shows, that over time, PVC has become a dominant material in the piping industry, taking a large share of the market away from the more conventional materials. The effect that using PVC has on these other material markets is important.

By the use of historical data and applying a set of assumptions, calculations were made which established a table of equivalent volumes of the conventional materials replaced by plastics for use in piping applications. The values calculated were in turn compared to the 1978 and 1986 values for the cast iron, clay, copper, and steel industries with the following results:

1. Plastics are replacing metals in the pipe industry to an amount that significantly effects the metal industries.
2. Plastics replacement for cast iron has risen threefold from 1978 to 1986 and now replaces a volume amount equivalent to approximately 27% of the total cast iron industry.
3. Plastics replacement for clay is not important since the portion of clay used for piping purposes is very small.
4. Plastics replacement for copper has risen from 5.66% of the total market for copper in 1978 to 9.42% in 1986. This represents a significant portion of the total copper industry.
5. Plastics replacement for steel comprises as yet only a small percentage of the total steel industry (2.62% in 1978 and 4.93% in 1986). However, due to the overall size of the industry, the replacement is significant. Also important is that plastic pipe used as a replacement material for steel pipe has risen to a level almost as large as the amount of steel pipe still being utilized.

The above results clearly indicate that plastics replacement of metals is not only a reality, but one of consequence. To understand the reason for this replacement and to determine if this is a cyclical situation or a permanent trend in the piping industry, one must look at how and why this replacement has occurred.

Replacement of one material by another is dependent on two main factors. These are the properties of the material and the relative cost of the competing materials. The material selection process is used to determine viable alternative materials for a given project based upon the properties needed for the application. The criteria that are considered include price, costs, availability of material, usable life, ease of handling, pressure rating, flexibility, temperature adaptability, corrosion, resistance to damage, environmental effects, and proven performance record. Selection by analysis of materials for these criteria yield a set of usable materials that must be compared on the basis of overall cost. The best technique of analyzing overall costs is a lifecycle cost analysis. This analysis considers the costs of material, installation, maintenance, and disposal.

Three example systems were analyzed on the basis of competing materials costs. The three systems were a 3/4-inch residential plumbing system, a 2-inch residential sprinkler system, and a 6-inch residential drain/waste system. The materials used in the analysis were those that would be reasonable for each application and included PVC, cast iron, clay, copper, carbon steel, and stainless steel.

After the lifecycle cost analysis was performed it was seen that in 1988 PVC was the material of choice on an economic basis for the 3/4-inch plumbing, the 2-inch sprinkler, and the 6-inch drain/waste systems. The advantages of PVC are shown to be in the material cost, the installation costs, and the maintenance costs. Only in the recycle and/or disposal portion of the lifecycle cost analysis was PVC not the most advantageous material. However, even a substantial increase in the disposal cost would not remove the relative cost advantage of PVC over the other materials. Only in the 6-inch drain/waste line does PVC have serious competition from clay pipe.

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