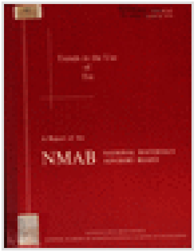

Trends in the Use of Tin (1970)

Pages
65

Size
8.5 x 10

ISBN
0309344840

Panel on Tin; Committee on Technical Aspects of Critical and Strategic Material; National Materials Advisory Board; Division of Engineering; National Research Council

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TRENDS IN THE USE OF TIN

REPORT
of the
PANEL ON TIN

COMMITTEE ON TECHNICAL ASPECTS OF
CRITICAL AND STRATEGIC MATERIALS

NATIONAL MATERIALS ADVISORY BOARD
DIVISION OF ENGINEERING--NATIONAL RESEARCH COUNCIL

Publication NMAB-265

National Academy of Sciences - National Academy of Engineering
Washington, D. C.
March 1970

This report is one of a series in a study undertaken by the National Materials Advisory Board for the National Academy of Sciences and the National Academy of Engineering in partial execution of work under Contract No. GS-00-DS-(P)-94008 with the General Services Administration on behalf of the General Services Administration, the Office of Emergency Preparedness, and the Department of Commerce. Partial financial support of this contract was provided by the U.S. Bureau of Mines.

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I. CONCLUSIONS

The estimated future consumption of tin in the United States for 1970 and 1977 compared to 1968 is shown in Table 13. A slight drop in consumption in 1969 and 1970 may be expected, but a modest rise of 5% or 6% is indicated by 1977. Even this is subject to some doubt because of the possible adoption of aluminum automobile radiators.

These calculations are based on presently-known trends and impending developments. It must be stressed that research developments presently unforeseen could change the picture rather sharply to either increase or decrease tin usage.

At the existing rate of consumption, tin reserves, which are minable deposits under existing conditions, appear to be adequate for at least 20 to 40 years.

Tin resources, which are tin deposits not currently minable but which could become minable due to improved exploration, mining, milling and economic conditions, appear to be adequate for an additional 40 to 50 years.

II. INTRODUCTION

Tin has been known and valued since the Bronze Age. It is a soft and very ductile metal that can be readily cold-worked, as by rolling to foil, extruded into collapsible tubes, or (when hardened by alloying) spun into pewter ware. Tin's low melting point of 232°C and ease of handling without oxidation have been assets in making soft solders and low melting alloys. Tin lacks the mechanical strength and melts at too low a temperature for general use as a structural material. However, it serves admirably as an attractive, protective, and nontoxic coating on steel and other metals, as a constituent of many alloys, and for many applications where the metal or its compounds offer economic or technical advantages.

Unfortunately, tin production in North America is inconsequential, except for the recovery of secondary metal from scrap. This has necessitated maintenance of an emergency stockpile. Due to concern over continuation of an adequate supply of the metal from Southeastern Asia and Africa in the future, substitute materials and procedures have been developed to reduce dependence on imports. A prime purpose of this report is to investigate the status of tin and the degree to which recent or potential technical developments will influence our future needs for it.

III. SOURCES OF SUPPLY AND RESOURCES

The dependence of the United States upon imported primary tin is well known. Less than 0.1% of the tin used comes from tin mined in Alaska, California, and Colorado, and most of this is a by-product from mining other metals. Likewise, production in Canada and in Mexico is very small, amounting to only a few hundred tons per year each. The Texas City tin smelter [1] has been producing a few thousand tons of tin yearly from some domestic secondary tin residues, but recently this production has dropped to a rate of less than a thousand long tons per year. In early 1970, however, a contract was signed between the Texas City smelter and Bolivia to increase the tin metal production to over 5,000 long tons annually. Of course, potential capacity is far greater. In 1946, for example, over 42,500 long tons of Grade A metal were produced there from a mixture of high grade alluvial and medium grade Bolivian concentrates. With adequate tin smelters situated in or near countries producing tin, there is little incentive to export concentrates to the United States except under unusual political conditions.

A new tin smelter was constructed and put into operation in July of this year in Liverpool, England. A modern tin smelter facility is being installed outside of Oruro, Bolivia, and is expected to be in operation in mid-1970.

In recent years, new smelting plants have been installed in Indonesia, Thailand, and Brazil so that today there is a surplus of smelting capacity.

In 1968, 72% of the tin metal imported came from Malaysia, 21.5% from Thailand, 2.5% from the United Kingdom, and the remaining 4% largely from Nigeria and the Netherlands. These countries represent smelter locations, not ore deposits.

An estimate of 1968 production of tin in concentrates from the principal non-Communist tin-producing countries is given in Table 1. Among the minor

TABLE 1. TIN RESOURCES OF THE WORLD, THOUSANDS OF LONG TONS OF TIN IN CONCENTRATES (Exclusive of the USSR and China)

Country	Production (2) in 1968 (Estimated)	Presently Minable Reserves, Robertson**	Potential Resources, Sainsbury USGS*
United States			43
Canada			40
Mexico			5
			88
Bolivia	29.1	485	1000
Brazil		100***	1074
Argentina			7
			2081
England		37	94
Portugal and Spain			150
France			4
East Germany and Czecholslovakia			50
			298
Indonesia	16.6	550	540
Malaysia	75.1	600	1000
Thailand	23.6	1402	1120
Burma		60***	250
Vietnam and Laos			75
Japan			16
			3001
Nigeria	9.6	86	138
Dem. Rep. Congo	7.4	155	1000
Rep. S. Africa			22
S. W. Africa			100
Southern Rhodesia			60
Other areas in Africa			70
			1390
Australia	6.8	81	250
Other	14.6	65	
Total	182.8	approx. 3600	7100

*Reference 3. Tin in deposits not currently minable because of factors such as low price, low grade, and beneficiation problems. As geologic knowledge increases and as prices rise, new sources of tin will become classifiable as resources.

**Reference 4. Estimate for 1970 at a price of $1.40 per pound in 1960 ($1.60 per pound in 1968).

***Robertson (4) showed no reserves for this country. These data are based on Reference 3.

sources, the most important is Australia because of its 1968 production of 6,800 tons and its currently growing rate of production.

A. Resources

Some estimates on tin resources in the non-Communist world are given in Table 1. These are not directly comparable since they are made from different bases. Thus, Robertson's estimates have been made from official projected reserve calculations and refer to tin in deposits that are minable under present conditions and price levels. Estimates by Sainsbury include submarginal and probably undiscovered resources. It must be borne in mind that new deposits of minerals, including tin, are constantly being found; therefore, estimates of reserves must be recalculated at intervals. Reserves of many minerals are as great or greater now than they were known to be 50 years ago, but the grade of ore may be much lower.

These estimates indicate existence of some 3,500,000 to 7,100,000 long tons of tin foreseeable at this time. This is sufficient to maintain the present rate of production (which roughly equals the rate of consumption) for 20 to 40 years.

Data on tin production and resources of Communist countries are largely lacking. However, an estimate is given of 45,160 long tons of tin produced in 1968 from Communist countries other than Yugoslavia.[(2)] Sainsbury's[(3)] educated guess is that the USSR and China have about 710,000 long tons in measured and indicated reserves, about 1,420,000 tons inferred, and 4,260,000 in submarginal resources. The distribution between the USSR and China can be found in Table 1-A. This would indicate that the tin resources of these two countries are far greater in proportion to their current consumption than is the case with the rest of the world.

The improved recovery of tin has been brought about by new developments in off-shore exploration and mining, greater efficiencies in the milling operations (particularly by the flotation of cassiterite and other minerals), the application of tin volatilization to low grade concentrates and residues, and the reclaiming of tin from scrap materials. The United States Government stockpile still remains as a major potential supplier of future tin.

TABLE 1-A

ESTIMATED TIN RESERVES AND RESOURCES OF THE USSR AND CHINA (IN THOUSANDS OF LONG TONS) (3)

	Measured Plus Indicated	Inferred	Submarginal Resources
USSR	210	420	1260
CHINA	500	1000	3000
Total	710	1420	4260

This obviously cannot represent the total tin that will be available eventually to industry. As geologic knowledge increases, and as prices rise, new sources of tin will become classifiable as resources.

B. Secondary Tin

An important source of tin is that recovered from scrap. In the past six years, U.S. yearly production of tin from this source has been an average of 23,500 long tons. Of tin consumed over this period, 29.3% has been from secondary sources.

From 13% to 15% of the production of secondary tin comes from detinning plants operating on clean unused tin plate scrap. This is largely from can-making plants, and at present represents 11% of the tin used in making tin plate. Most of this production from detinning plants, or about 85%, is recovered as high-purity electrolytic tin; the remaining 500-600 long tons yearly are recovered as tin compounds. Although some attempt has been made at times to recover tin from used cans, as during war-time conditions, this has been unsuccessful in the U.S. The cost of collection, cleaning, shredding, and processing has been prohibitive, and the quality of steel scrap obtained has been low. Since an average of only about 9.5 pounds of tin per long ton of tin plate scrap is presently recovered, the value of the steel after detinning is normally much greater than that of the tin recovered. A satisfactory high recovery of tin is made by an alkali-chemical process from clean, unused tin plate scrap and the resultant bundled steel scrap is high grade. In treating old cans, however, the recovery of tin is less efficient and the quality of scrap poor because of lead (in solder) and residual tin in the side seams of the cans. Also, the cans (unless well shredded) retain large amounts of leaching solution which withstands effective washing. This results in excessive loss of dissolved tin.

From the standpoint of conservation and landscape pollution, it is highly desirable to collect and treat old cans effectively, since over half of the imported or primary tin is used in can making. Unfortunately, there seems to be no possible way to make this economically feasible. The trend has been toward cans containing less tin, or even no tin. Hence, the average amount of tin per can is diminishing, as discussed later under Tin Plate. In the future, to some extent, this may be counterbalanced by the trend toward welded and solderless cans which would enhance the value of the steel scrap. A dilution factor from aluminum and other nonsteel cans may be minimized by magnetic sorting. However, for many years ahead, there appears to be no economical way to collect and treat used cans for tin recovery. In an extreme emergency, it could be done when cost is no consideration; but the labor involved, transportation, and new plant capacity needed at such a time makes this means unattractive. If solderless cans become predominant and the average tin content continues to decrease, it is more likely that old cans would become usable steel scrap directly, i.e., without removal of tin. In the proportions now present, lead in the solder is generally considered to be a more harmful contaminant of steel scrap than tin.

The 86% to 87% of secondary tin from sources other than unused tin plate scrap is recovered in alloys and compounds, as indicated in the following tabulation:*

	Long Tons of Tin Content		
	1966	1967	1968
Bronze and brass	12,297	11,268	11,895
Solder	5,777	4,775	4,215
Type metal	1,714	1,604	1,604
Babbitt	1,121	912	838
Antimonial lead	318	386	400
Chemical compounds	826	506	524
Miscellaneous	58	40	41
Total	22,111	19,491	19,517

*U.S. Bureau of Mines, Minerals Yearbook, 1967, 1968

Scrap sources for these products are largely automobile radiators, brass and bronze scrap, railroad car babbitt, type metal for reprocessing, and dross and residues from lead-base and tin-base scrap delivered to secondary metal plants. (A small amount of primary tin in skims and drosses from primary lead refineries is included.) Recovery of tin (from the scrap received) at the refineries is generally satisfactory with little opportunity for significant improvement. However, slightly less than 40% of the tin going into applications other than tin plate, is recovered because of the impracticality of collecting scrap that contains minor amounts of tin.

Future production of scrap from these miscellaneous sources will vary, of course, with the amount of tin consumed in uses other than tin plate. Greater efficiency in recovering scrap or getting it to the secondary smelter is possible, as in more complete dismantling of old automobiles, but little improvement in the percentage of tin recovered as secondary metal can be expected under normal economic conditions. This holds, also, for emergency conditions (with tin scarcity) because of the probable greater need for labor to do work other than dismantling old equipment and collecting and sorting the scrap.

C. Stockpiles

Accumulation of tin in inventories and stockpiles does not increase the world's total supply, but these inventories and stockpiles act as stabilizing influences in marketing and are visible supplies.

The most important stockpile, of course, is that of the United States Government which was initiated just prior to World War II. Since June 1962, when a program to dispose of tin in excess of potential needs was started, over 90,000 long tons have been sold and nearly 25,000 tons are still authorized to be sold.

From time to time, in the past, through agreements by participating tin-producing countries, international tin controls have attempted to stabilize the supply-demand position. The current Third International Tin Agreement came into operation July 1, 1966, and extends to June 30,1971. It represents six tin-producing and nineteen tin-consuming countries. (The United States is not a member.) Production is curtailed by agreement when it definitely exceeds the expected rate of consumption. A buffer stock has been established with a definite schedule whereby sales are made when the price exceeds a certain price and purchases are made at a lower figure. On November 1, 1969, this buffer stock was estimated to be of the order of 8,000 long tons of tin (price $1.69/lb.).

U.S. industry stocks of tin at plants, in process, or in transit to the U.S. usually are in the range of 30,000 to 40,000 long tons.

IV. GENERAL USAGE DISTRIBUTION

Present uses of tin are shown diagramatically in Figure 1. Quantitative distribution by general use categories is shown in Table 2. For convenience in discussion of trends and future needs, these uses have been divided into three main divisions of tin plate, solder, and miscellaneous.

A. Tin Plate

During 1968, the base year for this discussion, approximately 67,000,000 pounds (30,000 long tons)* of tin were consumed for domestically-produced tin plate for all applications, including packaging and other products which utilize tin plate. About 90 percent of all tin plate produced is used in can making.

It should be recognized that 1968 was, in essence, an abnormally high year for tin consumption. This was caused mainly by large tin plate inventories

*Figures from Can Manufacturers' Institute adjusted for American Iron and Steel Institute reported shipments and for differences in mill inventories.

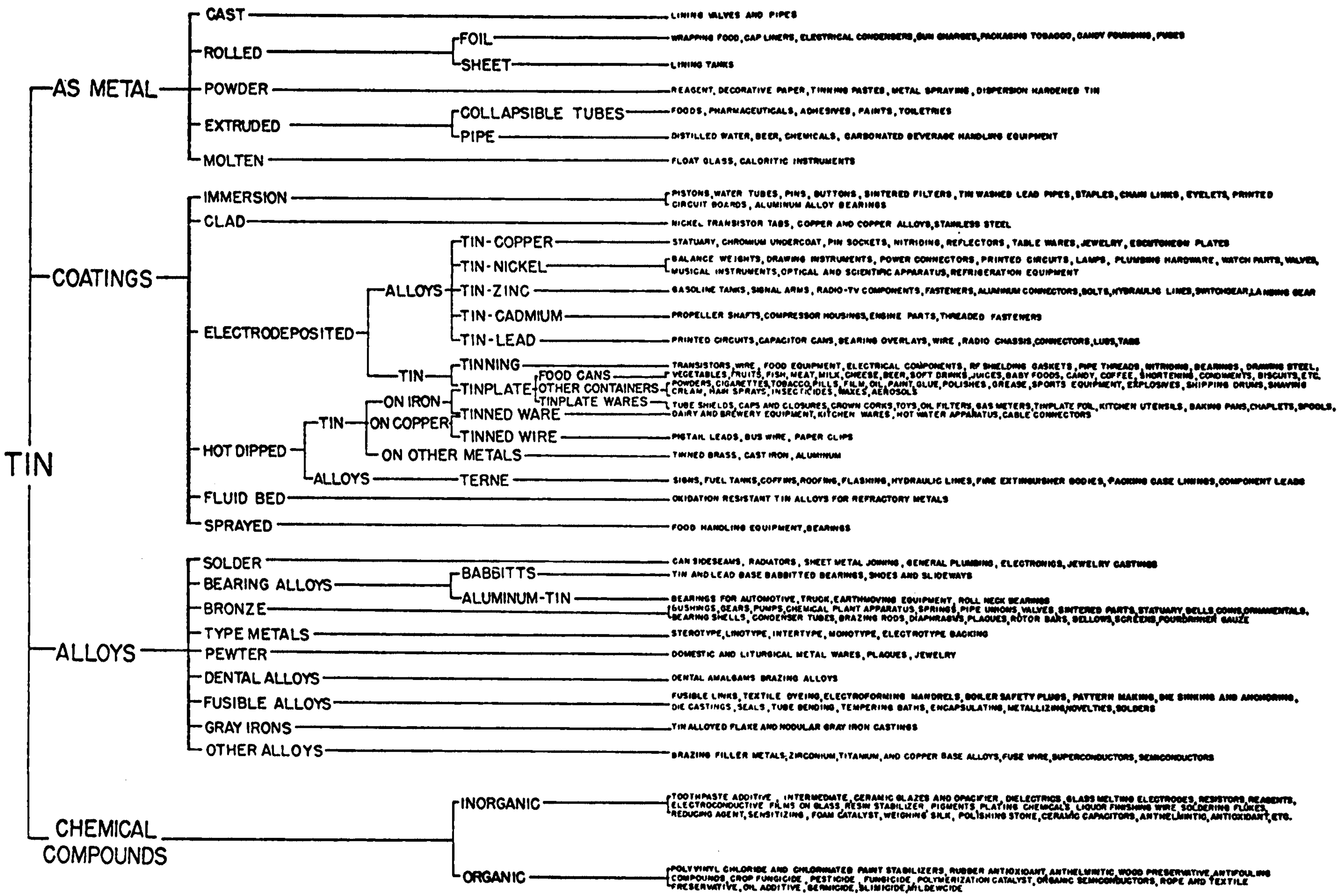

FIGURE 1. TIN AND ITS USES

TIN RESEARCH INSTITUTE, INC.
AUGUST, 1965

TABLE 2. CONSUMPTION OF TIN IN THE UNITED STATES, BY FINISHED PRODUCTS (LONG TONS OF CONTAINED TIN)

	1967			1968		
	Primary	Secondary	Total	Primary	Secondary	Total
Tin plate*	29,552	-	29,552	28,839	-	28,839
Solder	14,052	6,070	20,122	14,685	6,685	21,370
Bronze and brass	4,350	12,110	16,460	3,851	11,631	15,482
Babbitt	1,662	1,159	2,821	2,143	1,440	3,583
Chemicals, including tin oxide	937	1,837	2,774	1,774	1,423	3,167
Tinning	2,551	58	2,609	2,105	55	2,160
White metal**	1,094	70	1,164	1,330	66	1,396
Type metal	100	1,019	1,119	108	1,109	1,217
Collapsible tubes and foil	1,071	38	1,109	1,114	55	1,169
Tin powder	924	19	943	1,103	53	1,156
Bar tin	854	21	875	970	115	1,085
Terne metal	264	179	443	295	185	480
Pipe and tubing	53	14	67	53	37	90
Alloys (miscellaneous)	310	142	452	442	182	624
Other	74	54	128	77	66	143
Total	57,848	22,790	80,638	58,859	23,102	81,961

*Includes secondary pig tin acquired in chemicals.

**Includes pewter (britannia metal) and jewelers' metal.

Source: U.S. Bureau of Mines, Minerals Yearbook 1968.

stocked by can manufacturers in anticipation of a work stoppage in the steel industry, and unusually large vegetable packs, especially tomatoes. Although 1968 represents a peak year in tin consumption, such peaks should be kept in mind when planning for future tin needs during emergency periods. Emergency periods will also tend to reflect peak conditions because of requirements for feeding our armed forces and allies.

1. Factors affecting tin consumption of tin plate

Under normal conditions, the major factors that bear on tin consumption for tin plate in the 1970-1977 period are:

a. Continuing rapid conversion of beer and soft drink containers to tin-free steel (TFS)[5, 6] and aluminum. Although total beverage-can production will increase from 50,000,000 BB* in 1968 to an estimated 114,000,000 BB in 1977, by 1973 the majority will be produced from TFS and aluminum.

b. Projected increased imports of tin plate into the United States will reduce the tin requirement for domestic needs.

c. Projected rapid decline of some traditional tin plate packs, such as canned milk that is being converted to powdered milk.

d. A relatively slow growth is projected in BB consumption for packaging fruits, vegetables, and other food products. By and large, the tin coating weights, which will prevail in these packs, will be the

* BB stands for base box, a unit commonly used in the tin plate industry, which is equal to 31,360 in.^{2} of plate (62,720 in.^{2} of total surface area). It is used here because it is more closely related to tin consumption than is a tonnage figure because of the variety of steel base thicknesses produced as tin plate.

same as presently applied. However, a sizable portion of the ends used will be converted to TFS, thus holding tin consumption for these packs relatively constant.

e. The number of nonfood containers will also increase gradually over the period in question, but increased use of TFS and black plate will limit the increase in tin consumption.

Other factors which could affect tin plate usage in containers in the future are:

a. In the case of tomato products and certain other vegetables where rapid detinning has recently become a problem, there may be a shift from plain or enameled No. 75-25, or No. 100-25 cans to the HTF (high tin fillet) can [(7)] which utilizes enameled No. 25 plate throughout and pure tin solder to provide a sacrificial tin anode at the solder fillet. Such a change would reduce the tin requirement in tin plate. However, this reduction would be offset by the increase in tin needed in the solder. The net effect would depend upon the can sizes involved and the quantities of each size.

b. A breakthrough in the development of plastic materials (or combinations of materials) with low permeability and absorptive properties could result in a significant penetration of plastic containers for packaging food and beverages. Many companies are funding large research efforts to solve these problems. The major impact on tin requirements would be in the food packaging area since most beer and soft drink cans are already projected to convert to TFS and aluminum.

c. Successful development of composite containers for shortening, coffee, and other nonheat process applications could also have a substantial effect on tin plate consumption.

d. Future developments in tin plate containers are anticipated which should tend to slow the trend away from tin plate, but these will not have major impact before the end of the 1970-1977 period.

e. An increase in tin usage is a possibility in future tin plate packs which do not exist today in any substantial form, namely sterilized dairy products as substitutes for fresh milk, canned potatoes and potato products as substitutes for fresh and frozen potatoes, and food aerosol products on a much more extensive basis than at present.

2. Trends in tin coating weights

The percentage of tin in tin plate (wt. basis) produced in the United States has decreased steadily since the introduction of electrolytic tinning in the late thirties. Representative figures are as follows:

1940	1.68% tin
1943	1.20% "
1950	0.87% "
1959	0.62% "
1968	0.53% "

Actually, the figure 0.53% for 1968 is not indicative of the true decrease in tin coating weights. After 1959, the rapid trend to lighter basis weight with the introduction of double-reduced plate has resulted in more base boxes per ton of plate than in prior years.

The average tin coating weight is a better indicator of the efficiency with which tin is used. In 1940, the average tin coating weight was about 1.50 lb/BB, and in 1968, it was approximately .36 lb/BB (nominal). The 1968 figure represents approximately 65% with No. 25 (.25 lb) tin coating (both sides) and 35%, a mixture of "heavily coated" plate* with at least one side No. 50 or heavier.

Since 1952, substantial reductions in tin consumption for "heavily coated" plate have resulted from identification of factors responsible for variations in corrosion resistance and development of tests to measure these properties[8, 9] and changes in tin mill processing to provide improved corrosion resistance.[10] These improvements, along with differentially coated plate and the use of improved enamels over the tin in some applications, have made it possible in 1968 to utilize "heavily coated" electrolytic tin plate with average nominal tin coating of 0.50 lb/BB in place of 1.25 lb/BB common coke hot-dipped plate required previously. Additional improvements to permit further reductions in tin coating weights in "heavily coated" plate are not anticipated.

Attempts to substitute No. 10 tin coating for No. 25 have not been successful. The No. 10 coating weight has been unsatisfactory because of dull spots from complete alloying of the light tin coating during flow brightening, and because of insufficient unalloyed tin for ease of soldering. The amount of No. 10 produced is so small that the effect on tin consumption is insignificant.

3. <u>Substitutes for tin plate</u>

The most important substitute for tin plate is TFS, which is used widely in beer and soft drink containers. The TFS concept was first introduced in 1965 as the result of new developments in container processes.

*"Heavily coated" refers to No. 50, No. 75, or No. 100 electrolytic tin plate bearing average tin coatings of 0.50, 0.75, and 1.00#/BB, respectively, or differentially coated No. 50-25, No. 75-25, No. 100-25, No. 100-50, or No. 135-25, which have the heavy coating on one side and a lighter coating on the other.

Despite extensive R&D efforts over the years with various materials and side seam joining techniques, prior to 1965, no process was available for making heat processable, hermetic containers which could compete economically or in quality with soldered tin plate. The introduction by American Can Company in 1965 of the MiraSeam process for adhesively bonding can side seams made possible the first extensive use of tin-free materials in high speed manufacture of hermetic containers. The process was first introduced for producing 3-piece aluminum beer cans but was soon changed over to TFS because of economics. In 1966, the Conoweld process for welding TFS was introduced by Continental Can Company as a second method for producing high-strength, heat processable containers without the need for tin to permit soldering.

The first TFS used commercially in beer cans was an electrolytic chromate-phosphate treated steel of the type developed in the 1950's. It was far superior to the cleaned and oiled black plate then being used for a number of nonfood container applications and served to get the TFS beer can program under way. With commercial experience, however, deficiencies became apparent which prompted the cooperative efforts by the can manufacturer and the steel companies that led to the development of a new material designated TFS-CT (tin-free steel-chromium type).[11]

The TFS-CT produced in the United States consists of steel electroplated with 0.3 to 0.5 microinch of metallic chromium which, in turn, is covered by a stable film of chromium oxide. Total chromium amounts to approximately 6 mg./ft^2 of plate surface, or 2.6 g/BB. This is similar to chromium-plated steels produced earlier in Japan, but metallic chromium thickness has been reduced to give good performance in beer and soft drink containers and to make it compatible with high speed strip plating. Oxide levels have also been modified to give optimum performance for beer, soft drinks, and food products.

The TFS-CT materials are far superior to other tin-free steels. They are now used extensively in beer and carbonated beverage cans, estimated to account for between 3 and 4 billion 12 oz. cans in 1969. Usage is expected to spread to crowns and closures and to a fair portion of the ends for process food cans. Use in bodies for food cans is not expected in the near future because of economic considerations involving both the pricing of the TFS basis weights required and the cost of converting to adhesive bonding or welding, and because some tin is required to retain quality of a number of food products.

Bethlehem Steel, National Steel, United States Steel, and Youngstown Sheet and Tube are presently producing TFS-CT commercially, with total capacity estimated to be more than 15,000,000 BB/per year. Additional lines are scheduled to go into production in the near future. Requirements are projected to reach 60,000,000 BB by 1973 and could approach 90,000,000 BB by 1977, on the basis of current technology and competitive conditions.

Aluminum is the second largest substitute for tin plate and, like TFS, has made its greatest penetration in beer and soft drink containers. Nearly all beer cans and a fair percentage of soft drink cans have an easy-open aluminum top end. A large number of TFS easy-open ends are also used for soft drinks, but, in either case, tin plate has been replaced by a substitute material. Two-piece drawn and ironed aluminum cans have gained acceptance for beer and soft drinks and will account for more than 15% of the total beverage can production. However, the rate is not projected to be as great as that of TFS containers. Again, regardless of whether the growth is in aluminum or TFS, it will be at the expense of tin plate usage.

Aluminum is also being used in a number of food can applications. Drawn cans with easy-open ends are produced for potted meat, Vienna sausage, sardines, and some premium soups, and aluminum easy-open ends are used on tin plate bodies for dry food products. Easy-open, all-aluminum cans with adhesively bonded side seams are being produced in volume for processed luncheon meat and premixed cocktails. In such uses, the easy-open feature and improved container performance obtained with aluminum justify the higher material cost and the expense of converting to the bonded side-seam process.

Composite containers produced with fiber—aluminum foil bodies and metal ends now account for the major part of cans for motor oil and frozen citrus juices. Considerable effort has been, and is being, expended on development of composite cans for beverages, coffee, and shortening, but none has achieved commercial status to date. Only in the case of coffee and shortening would this affect tin plate usage.

Plastic bottles have displaced chemically treated steel cans for liquid detergents, but this had no effect on tin plate consumption. A breakthrough in plastics technology will be required for any significant displacement of containers now made from tin plate.

Nonreturnable glass bottles for beer and carbonated beverages have increased, but the main effect has been to replace the returnable bottle. Consequently, tin plate consumption has not been affected.

4. Significance of substitute materials to tin requirements

It is interesting to compare the projected requirements for tin in the 1970-77 period with what the requirements would be if No. 25 tin plate were to be used in place of the aluminum and TFS projected.

	1970	1977
Projected Tin Requirements	55,000,000 lb	49,000,000 lb
Equivalent of TFS and Aluminum		
Beverage	13,000,000 lb	33,000,000 lb
Food and Nonfood	2,000,000 lb	7,000,000 lb
	70,000,000 lb	89,000,000 lb

It is clear that the use of substitute materials greatly reduces the drain on the world tin supply. With expanded production of metal containers just getting a start in other countries, the use of substitute materials could become more important in future years if the growth follows a pattern similar to that in the United States.

It should also be kept in mind that substitution of TFS-CT and aluminum in place of tin plate places demands on the supply of chromium and aluminum. At 2.6 g. of chromium per BB of TFS-CT, chromium requirements would be approximately 170,000 lb in 1970, 340,000 lb in 1973, and 510,000 lb in 1977.

5. Outlook under emergency conditions

Under emergency conditions where tin would not be readily available, we are in a better position now than during World War II. At that time, to a fairly substantial extent, food packaging was converted to glass and untinned, chemically-treated steel. Because only zinc phosphate treated steel was available, the range of applications and performance obtainable were somewhat limited. Tin consumption in the United States dropped from 101,000,000 lbs in 1941 to 49,000,000 lbs in 1943, accomplished partly by substituting glass and chemically-treated steel for tin plate and partly by shifting to electrolytic tin plate in place of 1.25 lb hot dipped tin plate.

The recently developed TFS-CT is far superior to the chemically treated steels available during World War II and, therefore, could be utilized in a much wider range of applications. Its use would be governed mainly by the ability of the can-making industry to convert to adhesively bonded or welded side-seam processes required for manufacturing TFS-CT can bodies, instead of the soldering process used for tin plate. Both adhesive bonding and welding produce cans suitable for process foods. Expanded use of TFS-CT would also require sizable investments by the steel producers in additional TFS proeessing lines.

Aluminum could also be used for a number of applications, but converting to the manufacture of aluminum cans would present a greater problem than in the case of TFS. The adhesive-bonding process is applicable to aluminum, but presently available welding processes are not. Drawn, or drawn and ironed, aluminum cans would be satisfactory for a wide range of products. However, conversion to those processes would be more difficult and costly than conversion to adhesive-bonding or welding.

The use of these substitute materials would depend, of course, upon their availability in time of emergency. The relatively small total requirement for chromium to handle all metal can requirements, including that now in aluminum and presently imported tin plate, would be approximately 1,100,000 pounds in 1970, increasing to 1,300,000 pounds in 1973, and 1,500,000 pounds in 1977. Complete conversion to aluminum would require in excess of 7,000,000,000 pounds in 1970 and more than 9,600,000,000 pounds in 1977.

B. Application of Tin Plate Other than Can Manufacture

The approximately 10 percent of tin plate not used in making cans is used for many products that cannot be estimated quantitatively. Table 3 lists some of these products.

One of the important items in this category is oil filters for the automotive industry, where the good drawing characteristics of tin plate permits proper shaping. Another large application in the communications industry is for Stalpeth cable sheathing for ease of solderability. The use is growing rapidly; substituting another material in the complex manufacture of cable sheathing may be possible but would seem to involve a major design engineering and manufacturing change. Most, if not all, of the other items listed are made out of tin plate primarily for convenience, and substitutes (as black plate, tin free steel, cold rolled sheets or plastics) could be used in case of tin scarcity. Many of these products are presently made from second grade or "waste-waste" tin plate.

TABLE 3. TYPICAL PRODUCTS (OTHER THAN CANS) MADE FROM TIN PLATE

Automotive oil filters	Flashlight battery parts
Cable sheathing	Cannisters
Roller paint trays	Lipstick tubes (eyelet machines)
Gas tanks (example: lawn mowers)	Cutting edges for wax paper
Paint brush ferrules	Stove pads
Waste baskets	Portable file cases
Dust pans	Metal tags - - poultry
Thermos bottles	Shoe polish cans
Lunch boxes	Stamp-pad containers
	Toys

1. Summation

Considering the period 1970-77 under normal conditions, it is estimated that the use of tin for tin plate will decline at a compounded annual rate of approximately 1.5 percent per year. In 1970, approximately 55,000,000 lbs of tin will be required, diminishing to 49,000,000 lbs in 1977. This will occur in spite of continued rapid growth in beverage can shipments (particularly for soft drinks), and small but steady increases in over-all food and nonfood can shipments.

This forecast is based on the projection of presently known technology and market trends in the many areas where tin mill products are now utilized. It is recommended strongly that this analysis be updated at three-year intervals because of the rapidly changing technical and market conditions in the field of packaging, where the major portion of tin plate is now used.

C. The Use of Tin in Solders

Solder alloys account for the second largest use of tin in the United States. The consumption of tin in solder in the United States during the period from 1963 to 1967 increased slowly from 19,600 long tons in 1963 to 22,700 tons in 1966, dropped slightly to 19,800 tons in 1967, and was 21,400 tons in 1968. Of this amount, about one-third was from secondary sources.

Tin is the active constituent of the majority of solder alloys and promotes wetting to the metals that are being joined. Other metals such as antimony, indium, and silver have been employed as substitutes for part or all of the tin in solders but, generally, the solders have not performed as well. The use of tin in solders is typified by the following applications:

1. Electrical-electronic applications

Substantial amounts of tin-lead solders are utilized for connections of components and assemblies of communication, computer, television-radio, and aerospace equipment. Alloys containing 60 to 63 weight percent tin, balance lead, are used for wave-soldering and hand-soldering of components to printed wiring boards. The lower melting temperatures, flow characteristics, wetting ability, and surface appearance (inspectability) are reasons for the employment of these solders. Alloys containing 45 to 50 percent tin are used for hermetic seals, while alloys with tin contents ranging from 30 to 60 percent are used for hand-soldering of point-to-point wiring. Solder alloys containing 34.5 percent tin are used for wiped joints at splices in lead-sheathed telephone cable. Stalpeth communication cables utilize a corrugated tin plate wrap with a soldered seam. The solder presently used contains 3 percent tin, 2.25 antimony, balance lead, as compared to the 30-tin-70-lead solder formerly used.

While the trend in the electronics industry has been toward miniature and integrated circuits that eliminate many soldered interconnections, solder joints continue to be required for connections to these circuits. The present use of tin in solders is not expected to decrease but rather to show a modest increase as a result of growth in the electronics industry. Recent developments of coaxial cable for communications have produced a new type of cable that uses less copper and has superior characteristics but employs a soldered seam. The solder used in this application contains 60 percent tin to provide the necessary mechanical properties and sufficiently low soldering temperatures.

In the case of critical tin shortages, the use of lower tin (30%) content solders for hand-soldering of wiring could be instituted. These measures would involve greater manufacturing costs and some reduction in quality.

It is unlikely that appreciable decreases could be made in the tin content of solders for wave-soldering of printed wiring boards. The use of solders containing 50 to 55 percent tin for these applications might be possible with development of suitable manufacturing processes.

2. Tin requirements for soldered cans

Tin requirements in solders for soldered cans during the period 1970-77 are estimated as follows:

	Tin Requirement, pounds		
	1970	1973	1977
Pure Tin Solders (includes 99.6 Sn/0.4 Ag)	4,440,000	4,900,000	5,370,000
"High Tin" Solders (Mainly 30 Sn/70 Pb)	660,000	690,000	770,000
Low Tin Solder (2 Sn/98 Pb)	1,320,000	1,080,000	770,000
Total tin	6,420,000	6,670,000	6,910,000

These estimates are based on 1968 consumption and projected can production for the 1970-77 period that was used for projecting tin requirements for tin plate.

Solder consumption for cans in 1968 is estimated at approximately 78,710,000 pounds with an average tin content of about 8 percent. This required 6,340,000 pounds of tin.

Pure tin and 99.6 tin/0.4 silver solders accounted for around 4,240,000 pounds of tin. Applications such as aerosol cans, antifreeze and insecticide cans, and high tin fillet (HTF) cans for detinning vegetables consumed the major part of these very high tin solders.

High tin solders, mainly 30 tin/70 lead, accounted for approximately 650,000 pounds of tin. These were used mainly for nonfood containers. Low tin solder, 2 tin/98 lead, required a total of 1,446,000 lbs of tin for 72,300,000 lbs of solder. Approximately 58 percent of this was used in soldered beer and soft drink cans, with the remainder used for various food and nonfood applications.

During the period 1970-77, a total increase of only 7.6 percent is projected. An increase of almost 1,000,000 pounds, or 21 percent, in pure tin or tin-silver solders is anticipated, mainly as a result of expanding production of aerosol containers. An increase of almost 17 percent is expected for tin in high tin solders. A decrease of about 42 percent in consumption of low tin solder holds the over-all increase to the relatively low level.

Actually, the consumption of low tin solder for can applications, other than beer and soft drinks, should increase a total of approximately 15 percent during the 1970-77 period. However, almost complete conversion of beverage cans to adhesive bonding, welding, or drawing and ironing would bring about a decrease in consumption which would overshadow by far the increase for other applications. Interestingly, if the 57 billion beverage cans projected for 1977 were made from soldered tin plate, the tin required for solder in cans would be approximately 2,300,000 pounds greater than shown in the above projections.

The projected increase in amount of solder for pressure cans is somewhat less than the increase in pressure can production expected for the same period. The reason for this is that a significant part of the increased production will be in drawn and ironed tin plate, welded TFS, or drawn and ironed or impact-extruded aluminum, not one of which involves the use of solder.

As mentioned earlier in the section on tin mill products, there is a good possibility that use of pure tin solder in HTF (high tin fillet) cans for detinning vegetables will increase markedly in the next few years because of sporadic high corrosivity of a number of products, particularly tomatoes. This would increase sharply the amount of tin required in solders for cans. However, since the HTF can uses No. 25 tin plate instead of "heavily coated" No. 75-25, No. 100-25, or No. 135-25, the reduction in tin required for tin plate would offset the increase in tin for solder. Thus, the net effect on over-all tin requirements would be of little consequence.

There are some new developments in solders containing antimony. Solder containing 95 tin/5 antimony is a possible replacement for 99.6 tin/0.4 silver solder now used extensively in pressure cans. The maximum effect on the tin requirements for 1977 would be a decrease of only 180,000 pounds. There is also some work with 0.5 tin/1.5 antimony/98 lead solder as a replacement for the 2 tin/98 lead low tin solder now used very widely in cans; however, rapid conversion is not expected.

As in the case of tin requirements for tin mill products, the requirements for solders should also be reviewed at three-year intervals to keep up with the rapidly changing technology in the field of packaging.

3. Miscellaneous solder applications

The use of solders is so widespread that it is difficult to enumerate all the applications and impossible to list the amount of tin used in each. Table 4 lists some applications qualitatively according to the general type of solder used. Average tin content of solder in the past few years has been 20-22%.

TABLE 4. APPLICATIONS FOR TIN IN SOLDER ALLOYS

Tin Lead Alloys (2-10% Sn)	Can soldering, coating metals and wire, terne, body solder, electric lamp manufacture
Tin-Lead Alloys (10-40% Sn)	For coating and joining metals, electronics, auto radiators, air coolers, refrigerators, can soldering
Tin-Lead Alloys (40-70% Sn)	Wiping solder for lead pipes, radio, TV electronics, motors generators, radiators, telephone and communications
Tin-Antimony	Solders for joining, solders for elevated temperature use, plumbing hot water systems, commutators, armatures, binding wires
Tin-Silver	High temperature solders, aircraft air coolers, fine instrument assemblies
Tin-Zinc	Aluminum soldering

Aside from the electrical-electronic field of application, which is considered to be the largest consumer of tin in solder, the most important present consumption is in automotive radiators. Solder in the cores is 15-20% tin; that for the tanks and connections is about 40%. Since over 24,000 short tons of solder are currently used yearly for radiators,[12] the total amount of tin for this general application is estimated at nearly 6000 long tons per year. Much of this is recovered as secondary metal. The amount of tin per radiator has reached a reasonably stable level; the total amount for this application currently follows the general production trend in automobile and truck production. Substitute materials, such as aluminum radiators, that may use no solder, , are a strong possibility for changing this situation in the next few years since much research has gone into this and is continuing to the point of commercial usage on a rather large trial basis. The effort here has been more to avoid using copper than to substitute for tin, and the current high price of copper is favorable for more widespread adoption of the aluminum radiator.

Auto body solder, at one time a large consumer of tin, is now only a minor application. The tin content of the solder now is only 2 or 3 percent, and changes in design and welding practice have reduced the amount of solder needed for new cars. Consequently, less than 0.2 lb of tin per body are involved in this application. Plastic body "solder" is used in some repair shops.

A recent announcement has been made of galvanized steel tubing or pipe for water lines that can be joined by soldering. This may extend the use of solder in the construction somewhat, but as the use of soldered steel is an alternate to soldered copper and both suffer by use of plastic tubing, the effect on solder consumption is expected to be minor.

Tin-lead solder, in general, has been such a convenient, readily applied, joining material for metals that its use for a multitude of applications, other than those that have been discussed, has seemed to be almost indispensable. Other means of joining can be used in an emergency for most of these applications, such as mechanical, brazing, welding, or joining with various organic adhesives. However, it would take an emergency to force even mild curtailment in the use of tin in solders for those many minor applications where it is well established and shows advantages from a convenience and economic standpoint. Growth in these minor applications is expected to be normal, that is, parallel with general business activity.

D. Miscellaneous Applications of Tin

Although the tin used in tin plate and solder accounts for over 60 percent of current U. S. consumption of tin, there remains a number of products which can be conveniently discussed as miscellaneous applications.

1. Tin in alloys other than solder

Bronze and Brass. Most of the brasses and bronzes containing tin are well known, some going back to ancient times, and the tendency in recent years has been toward replacement with new materials or alloy compositions. Thus, rather than following normal industrial growth in the U. S., the tin consumed in these alloys has remained comparatively constant. In the past two years, consumption has decreased slightly when demand for most metals has been expanding. At the present level of 15,500 long tons of tin per year for brass and bronze, three-fourths has come from secondary metal. The diversity of applications is shown in Table 5.

Active research programs are in progress by the copper industry to regain and retain some of this market. Also, the Tin Research Institute has developed a 5% tin-containing, age-hardening bronze that has high strength, good electrical conductivity, and corrosion resistance. Such activity may help to counterbalance the tendency to use materials other than tin-bearing bronzes and brasses, but it does not appear likely that the rate of tin consumption for this field will change markedly in the U. S. in the next decade. In other countries, as in Japan where shipbuilding, power equipment, and machinery needs are expanding rapidly, the demand for tin-bearing bronzes and brasses is expected to continue to increase moderately in the next few years.

Bearing Alloys. The tin-base and lead-base bearing alloys, known as babbitt, require about 3,500 long tons of tin per year, of which about 40% is

TABLE 5. APPLICATIONS FOR BRONZE AND BRASSES

Cast	Wrought (Strip, Rod, Wire, Tubing)
Bearings and bushings	Relay springs
Pumps	Electrical contacts
Valves	Diaphragms
Pipe	Bellows
Gears	Clutch disks
Bells	Lock washers
Marine Engineering Parts	Chemical hardware
Propellers	Bearing plates
Shafts	Welding rod
Statuary	Bolts and nuts
Architectural ornaments	Snap fasteners
Railway Engineering parts	Cotter pins
Hydraulic Engineering parts	Wire rope
	Bourdon tubing
	Pinions
	Chime rods
	Heater bars
	Bridge and expansion plates
	Poleline hardware
	Flexible hose
	Hot forgings
	Signal wire
	Formed parts with punched holes
	Screw-machine products

from secondary metal. In the U.S., consumption rate for this application has been constant for the past 10 years. Alternate materials that have cut down on the average amount of tin per bearing have fully compensated for the normal increase in bearings and bushings used. This trend is likely to continue; in fact, in the future, a decrease in this use of tin in the U.S. is more likely than an increase. A popular connecting rod, main and camshaft bearing material in the United States is the steel-backed copper-lead bearing (30% Pb) with a tin-lead plated overlay. A 20% tin-aluminum bearing material can be used for the same purpose with better fatigue resistance at high loads. This latter type of bearing is used in 60% of European automobiles but has limited use in the United States at present. Trials have been in progress and the future may see extended use in the United States as a replacement for the copper-lead bearing. However, if a million tin-copper-lead bearings were replaced by 20% tin-aluminum bearings, less than 10 tons of tin would be involved.

The 6% tin-aluminum bearing alloys are used for heavy duty rolling mill bearings, and Diesel and tractor engines. No change in consumption level can be forecast.

A list of some of the applications of tin in bearing alloys, as well as in pewter, is given in Table 6.

Pewter. Statistics for "white metal" include pewter and jewelers metal. Britannia metal, the highest grade and most-used type of pewter in the U.S. is an alloy of 91-95% tin, balance antimony and copper. Present consumption of "white metal" tin-base alloys amounts to about 1400 long tons of tin, of which nearly all is primary metal.

Pewter manufacture in the U.S. has risen from zero, when use of tin was restricted, to several hundred tons of metal at present, and the trend is continuing. The high price of silver in the last three years, together with the

TABLE 6. APPLICATION FOR PEWTER AND BEARING ALLOYS

Pewter	Tankards, tea services, coffee pots, plates, trays, domestic utensils, candlesticks, plaquès, jewelry, trophies, ornaments, water jugs, communion cups
Tin-base and Lead base Bearing Alloys	Bearings for gasoline and diesel engines, electric motors and machinery of all kinds, counting mechanisms, railroad rolling stock, marine, propulsion, generators, household appliances, sewing machines, pump parts, journal bearings
Aluminum-Tin Bearing Alloys 20% Sn	Connecting rod, main and camshaft bearings for automobiles
Aluminum-Tin Bearing Alloys 6% Sn	Bushings and solid bearings for aircraft landing assemblies, floating bearings in gas turbine engines, diesel and tractor engines, rolling mill bearings

greater popularity of pewter, has attracted more silver manufacturers into the pewter market. With tin supplies freely available, the tin consumed in pewter probably will increase by 50% in 1973. Under restricted tin supplies, this nonessential application of tin probably would be curtailed again.

Miscellaneous Alloys. These are listed in Table 7.

Type metal is largely run-around* metal and only about 100 tons of primary tin are needed yearly to replace losses. This has been a steady demand However, with other means of printing and duplicating being developed, the use of type in the intermediate and far future is not assured. For the next few years, consumption of tin in type metal is expected to remain about the same or decrease moderately.

Fusible alloys have very specific uses as fuse links, safety devices for fire alarm and control systems, and for low-melting solders and seals. They are important uses, but little change is expected in their rate of consumption of tin.

Tin in cast iron is now a substantial use. The U.S. is estimated to consume 500-600 long tons of tin in this application and the trend is upward.

2. Tin in chemical compounds

The most important compounds of tin that are used in commerce, with their respective typical applications, are listed in Table 8.

Research developments in recent years are responsible for noticeably increasing the use of tin in organic chemicals. In the last ten years, tin in compounds has increased from about 1800 to nearly 3200 long tons. Much of this increase has been in primary tin since sources of secondary tin compounds, such as from detinning plants, have been limited.

*Type metal is melted after use and recast repeatedly. The dross and unusable type are processed at secondary metal plants and returned for reuse. Very little metal is consumed.

TABLE 7. APPLICATIONS FOR MISCELLANEOUS ALLOYS CONTAINING TIN*

Type Metal	Printing alloys
Fusible Alloys	Boiler safety plugs. Fire alarm and control devices. Fuse links
Tin in Cast Iron	For pearlitic and heat resistant iron (engine blocks, etc)
Dental Alloys	Silver-tin-mercury alloys (12% tin)
Zirconium-Tin	Structural material and uranium fuel elements, cladding for nuclear power plants. Chemical equipment handling strong HCl
Titanium-Tin	Chemical plant equipment, pumps, heat exchangers, structural materials for aircraft and space craft
Columbium-Tin	Superconducting solenoid magnets

*Above uses consumed 1571 tons in 1967 and 1841 tons in 1968.

(Uses other than those tabulated above consumed 128 tons in 1967 and 143 tons in 1968.)

TABLE 8. APPLICATIONS FOR TIN CHEMICALS

Inorganic	
Tin oxides	Vitreous enamel opacifier, marble polishing. Intermediate for other chemicals (SnO)
Tin chlorides	Electroplating baths, catalysts for silvering mirrors, chemical reducing agent, electrically conducting glass, food additive, perfume stabilizer, hardening glass surface. Intermediate for organic compounds ($SnCl_4$)
Tin sulfate	Electroplating baths, liquor finishing wire
Tin fluoride	Toothpaste additive
Tin pyrophosphate	Toothpaste additive
Tin bromide	Heavy media separations
Tin fluoborate	Electroplating baths
Organic	
Tin octoate	Catalyst for polyurethane foam manufacture
Monobutyltin	Stabilizers for plastics
Dibutyltin	Stabilizers for PVC plastics, veterinary uses, catalysis Intermediate chemicals, rodent repellant
Dioctyltin	Stabilizers for plastic bottles, waterpipe, wrappings, etc.
Tributyltin	Biocides, industrial fungicide, insecticides, disinfectants, anti-fouling paint additive, wood preservative, anti-fouling rubber coating for navigational aids (buoysite)
Triphenyltin	Agricultural fungicide and insecticide

Since tin oxide is included among the compounds, it is difficult to judge the true picture of growth for new and expanding uses such as in stabilizers and biocides. Predictions for the future, therefore, must rely more on recently published information covering new developments than on present statistics. The substantial use of organotin chemicals as biocides in countries outside the United States may be useful in predicting future U.S. markets.

In the last 15 years, 2000 tons of tin have been used in new developments for agricultural sprays, paint additives, fungicides, etc., but most of this use has been in Europe. Some hundreds of tons of tin have been used for fungus control on crops. The main use in the United States is as stabilizers, but a significant use of biocides has developed and future potential is enormous. New directives by the Food and Drug Administration have sanctioned the use of dioctyl stabilizers for PVC used to package foods and beverages and these compounds should have been in use in 1969. The annual rate of tin consumed in dioctyl compounds will probably be about 60 tons the first year. In the next five years, biocidal uses for tin compounds to control micro organisms may indeed use 1,000 tons annually for paints and for other uses.

Among pending items which may affect future use of organo tin compounds are new developments in using tributyltin in anti-fouling rubber coatings for navigational aids, such as buoys, which permit such aids to go 5 years without repainting. Small craft can be protected likewise. Tin-containing anti-fouling paints being tested by the Navy may develop into a large use. Tin products may be substituted to a greater extent for cadmium and barium stabilizers for thermoplastics (see Cadmium Panel Report).

The rise in total tin consumption for chemicals is expected to continue at a rate of 100 to 200 tons annually.

3. Tin as a coating other than tin plate

Tinning, both by hot-dipping and electrodeposition, has accounted for an average of about 2300 long tons of tin in the past decade. All but approximately 3% of this has been primary metal. Until 1966-1967, the trend had been for a slight yearly increase; then, in 1968, there was a marked decrease from 2600 to 2160 long tons.

Applications in hot-dip tinning, using commercial grades of pure tin, are listed in Table 9; those for electrodeposited tin and tin alloys are given in Table 10. Hot-dip tinning of copper and brass articles continues to be important and is so well established for many operations that it can be considered essential except where direct necessity would compel alternate methods of joining or coating. By electrodeposition, better control over thickness is attained for many products. There are no impending developments in tinning that are expected to drastically change this diversified use picture. Under normal conditions, tin consumption for tinning is estimated as 2500-2700 long tons in 1973. Under mildly restricted conditions, this would be below 2000 long tons.

Electrodeposited alloys of tin have attained considerable commercial importance, particularly tin-lead or solder coatings. Tin-nickel has some potential of increased use, but it is still a very minor consumer of tin.

Tin is coated by immersion or replacement from solutions of tin salts. This is a convenient procedure for thin coatings, i.e., coating aluminum pistons for automotive engines, outboard motors, and chain saws. A small but necessary use is that of coating copper tubing for assembly into water coolers and for hot and cold food dispensing machines. Such consumption of tin is included under tin in chemical compounds.

Metal-sprayed tin coatings, as applied by metal-spray guns, do not consume much tin.

TABLE 9. APPLICATIONS FOR HOT DIP TINNING BY FINISHED PRODUCT (COATINGS)

On Steel and/or Iron	On Copper or Brass	On Other Metals
Milk cans new	Food handling equipment	
Milk cans retinned	Pots (restaurant use)	
Dairy equipment	Pans (restaurant use)	Coatings on nickel, monel, and aluminum are limited
Brewing equipment	Electrical components	
Baking pans	Tags	
Kitchen ware	Terminal parts	
Pots	Eyelets	
Frypans	Tabs	
Mincers	Sheet for electronic use	
Spoons	Strip for electronic use	
Forks	Wire	
Bowls	Component leads	
Wire	Printed circuit boards	
Strainers	Fourdiner wire screens	
Tags	Electric coils	
Terminals	Armatures	
Eyelets	Commutator bars	
Terminal pins	Motor generators	
Fasteners	Water coolers	
Washers	Food dispensing machines	
Screws	Terminal pins	
Tubing		
Paper clips		
Staples		
Foundry chaplets		
Brackets		
Bearing shells		
Deep drawn steel articles		

TABLE 10. ELECTRODEPOSITED TIN AND TIN ALLOYS (APPLICATIONS)

Tin	Tin-Lead	Tin-Copper	Tin-Nickel
Copper wire*	Overlay on bearings	Nitriding stopoff	Decorative coating
Tags*	Radio-TV chassis*	Undercoat for tin	Surgical instrument
Terminal pins*	Radio-TV fittings*	Undercoat for	Drawing instruments
Eyelets*	Capacitor cans*	Ni-Cr plating	Watch parts
Fasteners*	Small electronic parts*	Trophies	Musical instruments
Washers*	Copper wire		Balance weights
Screws*	Printed circuit boards		Optical apparatus
Tubing*			Printed circuit board
Water coolers			Electrical switches
Aluminum bus bars			Electrical connectors
Switch parts*			Plumbing hardware
Circuit breaker parts*			
Chassis and parts*			
Overlay on bearings			
Copper and brass sheet			
Aid in drawing steel			

*Also applied by hot-dipping

4. Terne plate

The steel industry in the U.S. has the capacity to produce about 300,000 long tons of terne plate annually. This would require about 800 long tons of tin. However, Bureau of Mines statistics of the past few years indicate tin consumption in terne plate to be 450-500 long tons per year, of which 35-40% is secondary metal. About 75 to 85% of this is for gasoline tanks. Other applications are listed in Table 11. (This tabulation includes some applications of terne alloy other than terne plate.)

Although a 16% tin alloy is normally used for terne plate, particularly to meet a government specification of 15% minimum, both the amount of coating and tin content could be reduced to some extent with some loss in quality. Production of passenger cars probably would be curtailed in an emergency resulting in a smaller demand for gasoline tanks. In addition, development of plastic gasoline tanks has received considerable attention, although danger from greater ease in rupturing from collision is a strong deterrent to the use of plastics.

5. Unalloyed and slightly alloyed tin

Some of the applications of tin in the unalloyed or only slightly alloyed state are listed in Table 12.

Solid tin pipe and tubing have had a long history of use because of the ease of extrusion of tin and its lack of toxicity. Aside from solid tin tubing, tin-lined lead tubing is made. However, neither type is an important consumer of tin (60-90 tons annually in recent years) and can scarcely be considered essential. Moreover, tin sheet has minor applications that are presently useful but could be eliminated if the supply of tin were curtailed.

TABLE 11. APPLICATIONS FOR HOT DIP TIN-LEAD COATINGS

Terne Type Tin-Lead (12 to 15% tin)	Eutectic Type (Solder) Tin-Lead (60% tin)
Fuel tanks and piping	Printed circuit boards
Automotive	Component leads
Mowers	Radio-TV chassis
Outboard motors	Radio-TV fittings
Farm tractors	Capacitor cans
Coffin linings	Small electronic parts
Hydraulic line pipe	Copper wire
Roofing*	Fire extinguisher bodies
Fire extinguisher bodies	Coil leads for generators
Component leads	Armature windings
Packaging linings	
Advertising signs	
Copper wire	
Oil filter bodies	
Muffler bodies	
Furniture	
Automobile piston	
Piston ring (CI)	

*Roofing ternes or short ternes have a higher tin content

TABLE 12. USES FOR SOLID TIN

Form	Examples
Pipe	Handling distilled water, beer, carbonated beverages
Powder	Powder metal parts (iron and bronze), soldering pastes, decorative paper, chemical reagent
Foil	Cap liners, electrical condensers, packaging
Collapsible Tubes	Packaging pharmaceuticals (ointment) packaging paint coloring, foods
Sheet	Lining distilled water tanks
Wire	Fuse links
Liquid bath	Float glass
Bar tin	Anodes for plating. Lining brass pipe and valves for handling distilled water

Bar tin, consuming about 1000 long tons of tin annually, is important in producing anodes for electroplating and for miscellaneous and laboratory uses. Consumption of 800-1000 long tons per year is expected to continue.

Tin powder is a growing product development and amounted to 1156 long tons in 1968. This may increase by 1000 tons by 1973. It is used in powder metallurgy, for example, in making copper-tin products and in a newer-developing application with iron powder. Tin lowers the sintering temperature and time required in making powder metallurgy parts. Copper powder is not as effective, but can substitute for the tin powder when used with iron.

With competition from aluminum, lead, and plastics, the formerly very important use of tin in making collapsible tubes and foil has diminished to a minor but steady consumption of about 1100 long tons of tin annually. Collapsible tubes of tin are now used only where other materials fail to meet requirements of nontoxicity and extrudability. Tin foil probably will continue to be used for certain electrical condensers. With scarcity of tin, these areas of application probably would be reduced but not entirely eliminated. Almost all tin for foil and tubes is primary tin, hardened by slightly alloying with copper or antimony; some "tin foil" is a tin-lead alloy or solder.

Liquid baths of tin used by plate glass manufacturers for making "float glass" may hold 300 long tons per installation. The tin is not consumed, and the demand is only for new installations to replace or augment the older process of grinding and polishing. In the U. S., a maximum demand for possibly 600 tons per year may be encountered for this application in the next few years. Other developments in the glass industry may result in curtailing even this modest demand.

Organ pipes are frequently listed in this category of pure or slightly alloyed tin. However, at present, very little tin is used for this purpose and pipes that are made for this nonessential use are largely a 20-40 percent tin-lead alloy.

V. EMERGENCY CURTAILMENT IN USE OF TIN

Tin has attained the position of being a very useful, convenient, and economically-desirable metal for many applications, yet it can be replaced to a very large extent under emergency conditions. The extent, of course, depends upon the severity of the emergency.

As discussed under Tin Plate, almost complete elimination of tin in this application would be possible if unlimited substitution of tin-free steel, aluminum, glass, and plastics could be made. This would hardly be practical, since under emergency conditions, some of these alternate materials might be in short supply, and the time and manpower to convert lines to other container materials might be excessive in a period of stress. The rate at which nonfood containers and beverage cans are now being converted into tin-free cans could be accelerated, if conditions warranted such a move. Since adhesive-bonded and welded cans, as well as aluminum and glass, may be used for foods that require processing, the need for tin in this area could be minimized. Most of the 10% of tin plate production going into uses other than cans could be readily eliminated in favor of TFS-CT, lacquered steel, galvanized steel, aluminum, etc. Thus, under conditions when curtailment in the supply of primary tin is encountered, it would be possible to get along with less than half the 1968 consumption of tin for tin plate, but there would have to be sufficient incentive to convert can-making lines and steel mill tinning lines to tin-free materials and time to make the conversion. Extensive investments in new or modified equipment would be required.

With tin in solders, there is also the problem of balancing convenience and economic desirability with other known alternate methods of joining.

Adhesives, welding, brazing, and mechanical joining can be used to replace some of the soldering now being done, but at the cost of disruption of present methods, change in working skills, and usually at a sacrifice in quality and increased cost. Merely reducing the percentage of tin in the solder, particularly in electronics work and general hand soldering, usually results in lower quality workmanship and at times in a compensatingly higher amount of solder being used. (Effective reductions in tin content of auto body solders and can side-seam solders were made in the past.) As a general estimate, the primary tin now used in solders could not be reduced more than half without encountering an excessive amount of disruption in the metals joining field. Considerable secondary tin is recovered from solder; hence, a reduction in the use of primary tin would be modified because of this source of secondary tin.

As experienced in the past, tin in brass and bronze could be reduced appreciably with some loss in metal properties. Since three-fourths of the tin used in this area is secondary metal, it should be possible to get along for at least several years without the need for more primary tin. Likewise, with recovery of secondary metal and alternate materials, the need for primary tin in bearing alloys could be reduced to half that presently used without excessive disruption. Practically all the tin in pewter and jewelers' metal can be considered nonessential. Among miscellaneous tin-bearing alloys, at least half could be eliminated under emergency conditions. The same can be said of tin in tinning baths and in chemical compounds because of alternate materials and procedures. Although tin powder is growing in uses, copper powder and other materials could be used at some sacrifice in properties. Altogether, in case of necessity, about two-thirds of the 15,000 long tons of primary tin used in this miscellaneous grouping could be eliminated. Here again, of course, such reduction would be at the cost of disruption in many operations, economic loss, and, in many cases, some sacrifice in properties; but it could be done.

Summarizing, the United States is in a far better position to get along with less tin than it was during World War II. Tin is still extremely useful and, under normal conditions, will continue to be used at the same or slightly enhanced rate in the foreseeable future. However, it is not generally indispensable, and the amount of primary tin could be drastically reduced under emergency conditions by the use of known alternate materials and techniques. The GSA emergency stockpile of tin would be invaluable in making such a transition orderly and less costly.

VI. RESEARCH ON TIN

An intangible factor that should not be overlooked in considering future use of tin is that of discovery and development through research. This may be through many educational, industrial and research institutions in the course of their various activities. In addition, the Tin Research Institute has been established primarily to do research on tin-containing materials and to disseminate information on tin. Their laboratory is in England, and active information and service centers are maintained in the U.S.A., Belgium, France, Brazil, West Germany, Holland, Italy, and Japan. This Institute is supported by the tin-producing countries.

Although no quantitative measure can be placed on the amount of tin that may be needed for the applications likely to be developed by this and other organizations, the development of the use of tin in cast iron and the development of uses for tin chemicals (page 34) are prime examples of the effects of research in increasing tin consumption. Also, as examples of recent research developments, tin additions have been used (1) in developing high-strength titanium alloys with relatively good ductility and toughness, and (2) to aid in providing protection against surface oxidation of refractory metals in high-temperature service.

A. Tin as a Constituent of Titanium Alloys

Pure titanium undergoes a phase transformation at 882°C (1620°F) from low-temperature hcp alpha phase to high temperature bcc beta phase. Alloying additions, to improve strength, ductility, and workability, act either as alpha stabilizers or beta stabilizers. Tin additions to titanium are somewhat neutral in this respect augmenting either the alpha or beta stabilizing tendencies of alloying additions to titanium.

Numerous commercial titanium alloys have included tin in their formulations to take advantage of its beneficial alloying effects. Titanium alloys containing tin and the alloy class in which they belong are shown below.

Ti-5Al-2.5Sn (alpha)
Ti-5Al-5Sn-5Zr (alpha)
Ti-5Al-6Sn-2Zr-1Mo-.25Si (near-alpha)
Ti-6Al-2Sn-4Zr-2Mo (near-alpha)
Ti-2.3Al-11Zn-5Zr-1Mo-.2Si (near alpha)
Ti-4Al-2Sn-4Mo-.5Si (alpha-beta)
Ti-4Al-4Sn-4Mo-.5Si (alpha-beta)
Ti-6Al-2Sn-4Zr-6Mo (alpha-beta)
Ti-6Al-6V-2Sn (alpha-beta)
Ti-2.3Al-11Sn-4Mo-.2Si (alpha-beta)
Ti-11.5Mo-6Zr-4.5Sm (beta)

Alpha and near-alpha alloys are noted for their good creep properties at high temperatures. Alpha-beta and beta alloys are valuable for their workability and capability of heat-treatment to high strengths. Tin contributes to the alloy balance in each of these compositions to achieve not only the strength and ductility characteristics but metallurgical stability and oxidation resistance as well. Without tin, these alloys have been shown to be less stable, less workable, and shallower hardening. The utility of titanium alloys in the construction of aerospace airframe and engine components is considerably enhanced by inclusion of tin in alloy formulations. Consumption of tin, therefore, has a bright future in aerospace manufacturing programs in which titanium alloys are utilized. (See Table 13.)

B. Tin Additions for Surface Oxidation Protection

The technology of the space age makes more and more exacting demands on materials from the point of view of operating temperatures and reentry conditions. Many materials and designs are being studied to produce parts suitable for service at temperatures above 1100^{o}C (2010^{o}F). Among the materials being investigated are four refractory metals: tantalum, niobium, molybdenum, and tungsten. However, in the presence of oxygen they rapidly oxidize and decrease in strength. To date, intermetallic coatings such as aluminides and silicides, sometimes containing tin, have provided the best means of protection against surface oxidation of the refractory metals in high-temperature service. The tin-modified aluminide coating systems have compositions ranging from 33% to 75% tin; the tin-containing aluminide coating may be further modified with molybdenum, chromium, and titanium. A mixture of tin and aluminum powder (plus other modifiers, if necessary) in a lacquer base are applied as a slurry to the component. After drying, the components are diffusion treated in a vacuum furnace at 1040^{o}C (1900^{o}F) for half to one hour. A network of intermetallic compound formed by interaction of the aluminum with the substrate (e.g., $MoAl_3$, $TaAl_3$, WAl_3) results. This network retains a tin-rich Sn-Al alloy. On high temperature exposure, an aluminum oxide layer forms at the outer surface of the coating to offer oxidation resistance. The most important function of the tin-aluminum phase is to serve as a liquid carrier for aluminum, transporting it to

TABLE 13. ESTIMATED FUTURE CONSUMPTION OF TIN IN THE UNITED STATES, LONG TONS

	1968	1970	1977
Tinplate	30,000*	25,000	22,000
Solder	21,370	22,000	26,100
Cans	2,830	2,900	3,100
Auto Radiators	6,000	6,100 (5000)**	7,000 (1000)
Elect-Electronic and Miscellaneous	12,500	13,000	16,000
Miscellaneous	31,500	33,500	37,300
Bronze and Brass	15,500	16,000	17,000
Bearing Alloys	3,500	3,500	3,500
White Metal (Pewter, etc.)	1,400	1,700	1,900
Miscellaneous Tin Alloys	1,850	1,900	2,000
Chemical Compounds	3,100	3,400	4,500
Tinning	2,150	2,500	2,800
Terne Plate	500	500	600
Unalloyed and Slightly Alloyed	3,500	4,000	5,000
TOTAL	82,870	80,500 (79,400)	85,400 (79,400

* From Can Manufacturers Institute and AISI statistics; Bureau of Mines Reports 28,839 long tons. Remaining data for this column are from U.S. Bureau of Mines Reports, rounded figures.

** Figures in parentheses represent probable consumption if copper-base auto radiators are largely replaced by aluminum.

sites in the brittle, oxidation-resisting aluminide phase to effect self-healing of the coating as needed.

VII. STOCKPILE SPECIFICATIONS

The specifications for tin in the national stockpile were reviewed by the Committee. These specifications correspond with the ASTM Standard Classification of Pig Tin (B-339) which is under continued surveillance of Subcommittee II of ASTM Committee B-2. No changes are suggested at this time.

Since certain impurities in tin are undesirable for some applications but harmless for others, some deviation from the rigid maximum percentages of Grade A could be made without harm. Thus, copper in excess of 0.04% is entirely acceptable in making copper-base alloys; lead above 0.05% would do no harm in tin-lead solders and other lead-containing alloys. It may be an unnecessary economic penalty to require a smelter to refine tin to less than the presently allowed lead and copper maximums. However, to segregate special grades of tin would add complexity in marketing and should not be undertaken unless substantial offerings of such high-copper or high-lead metal are available.

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) National Materials Advisory Board, Committee on Critical & Strategic Materials, Panel on Tin	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

TRENDS IN THE USE OF TIN

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report of the Panel on Tin

5 AUTHOR(S) (First name, middle initial, last name)

NMAB Panel on Tin

6 REPORT DATE March 1970	7a. TOTAL NO. OF PAGES 60	7b. NO. OF REFS 12
8a. CONTRACT OR GRANT NO. GS-OO-(P)-94008 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NMAB-265 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) of Pr o assoc.	

10 DISTRIBUTION STATEMENT

org.
demi

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY

13 ABSTRACT

About half of the primary tin used in the United States has gone into making tin plate. With the development of adhesive and welded side seams for cans, a strong growth in the use of tin-free cans is expected. Under normal conditions, this development and other developments in substitute materials are expected to cause an annual decline of $1\frac{1}{2}$% annually during the 1970-1977 interval.

Moderately higher requirements for tin in solders and for miscellaneous applications as a whole are prognosticated. Total requirements indicate the need for slightly less tin in 1970 than in 1968, and a growth of about 5% between 1970 and 1977. Increasing industrialization in other non-Communist countries would normally indicate generally increased tin consumption, but this is compensated by the trend to use less tin per unit product. Consequently, overall growth in tin consumption to 1977 is considered to be similar to that of the United States. Reserves of tin appear to be adequate for at least twenty to forty years.

Unclassified
Security Classification

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ring 19