A preliminary draft of this report was found in the National Archives. The archivist at the National Academy of Sciences provided a copy of the final draft. Although the report offers a look at the thinking that went into the response to the tin crisis at the beginning of WWII, because the Bell System still had scrapped telephone equipment as a source of tin, the report probably does not give the final word on the lead and tin content of Bell System solder. Scrapped telephone equipment was sent to Western Electric's smelter on Long Island where it was melted down and usable metals extracted and reused. What arrangement the Bell System had with the Office of War Production for the System to keep any or all of this reclaimed metal, as opposed to relinquishing it to others for the war effort, is not known. However it is likely that at least some tin was retained by the System for reuse. For that reason it is unlikely that Bell System solder exactly followed the guidelines for solder composition set forth by this document.

NATIONAL ACADEMY OF SCIENCES

NATIONAL RESEARCH COUNCIL

ADVISORY COMMITTEE ON METALS & MINERALS

June 12, 1941

505 King Avenue
Columbus, Ohio

Memorandum

To: Dr. Frank B. Jewett, President, National Academy of Sciences.

From: The Advisory Committee on Metals & Minerals - Metals Conservation & Substitution Group.

Subject: Report No. 10 to the Office of Production Management.

Report on Tin

The attached report was prepared at the request of Dr. C. K. Leith. It reviews the present status of Tin together with suggestions for conservation and substitution.

The committee will be glad to undertake studies and submit reports if specific problems arise with respect to the conservation of, or substitution for, Tin.

Respectfully submitted,

Advisory Committee on Metals & Minerals

By Clyde Williams
Chairman

Encl.

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL
ADVISORY COMMITTEE ON METALS & MINERALS

505 King Avenue
June 4, 1941

Mr. Clyde E. Williams
Advisory Committee on Metals & Minerals
National Research Council
2101 Constitution Avenue
Washington, D. C.

Dear Mr. Williams:

REPORT ON TIN

The Office of Production Management in Washington has asked for a report on tin, especially with reference to conservation and substitution. The matter was referred to the Metals Conservation & Substitution Group. Dr. H. W. Gillett, to whom the task of preparing the report was assigned, prepared a preliminary draft and submitted it to all members of the Metals Group. The following contains not only the substance of the preliminary, but it also reflects the suggestions of various members of the Committee. Dr. Gillett's final draft follows verbatim:

INTRODUCTION

In the use of any expensive material, the amount employed is balanced against the difficulty in control of quality and the lower rate of production occurring when a smaller amount is used. The cost of the excess beyond that which would serve under more strict control and supervision is insuranoe against rejects on inspection. It is a sort of factor of safety. Under normal economic conditions a sudden increase in price of the material operates to reduce the magnitude of the factor of safety employed. Such reduction may also be applied as a conservation measure. This conservation entails no substitution and can be brought about without altering processes, installing new machinery or teaching new methods to workmen. Some degree of such conservation is relatively painless.

In an acute shortage of the raw material substitution becomes necessary. Substitution demands changes in design, processes and methods, revamping or installation of new equipment and the teaching of new skills to the employees. "Bugs" crop up that have to be eliminated, both in the behavior of the substitute in the hands of the user, and in the production line of the plant itself. Substitution is seldom painless and is difficult to accomplish satisfactorily unless previous research, development, and pilot plant manufacture have given a clear picture of the factors involved and have put some of the substitute product into the hands of the ultimate user for final appraisal. Carrying the study of substitutes through an adequate pilot plant development is costly and only the far-seeing persist to a sufficient degree to amass the needed technical information when the substitute product appears likely to be more expensive under normal economic conditions.

In an entire lack of the raw material, all ordinary cost factors go by the board. The problem is to make usable goods without it at whatever cost.

The consideration of substitutes for most strategic metals envisages the painless conservation and the slightly painful partial substitution that is obviously feasible on the basis of research already carried out. It ordinarily stops there, because of the availability of low grade domestic ore which can be processed to usable metal at an increased cost, but with a lesser over-all cost than would result from radical changes in processes and equipment to use substitute materials. Seldom is it necessary to face the possibility of a complete lack of domestic supply and a consequent condition of "all-out" substitution.

In the case of tin, all gradations of conservation and substitution have to be considered because of the entire lack of domestic tin ore (x), and the importance of establishing the degree of seriousness that would result through a complete absence of imports over long sea lanes. The ability to make the choice to protect or not to protect shipping over those lanes without entirely disrupting defense and other industry production in the latter case is useful to naval strategists. Beside the problem of shipping, the condition might have to be faced that no ore was being mined whether it could be shipped or not.

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x See Progress Report on Exploration of Tin Deposits. I.C. 7154 U.S. Bureau of Mines, March, 1941.

SUPPLY AND CONSUMPTION IN THE PAST

Data from Metal Statistics, 1940, published by American Metal Market show the following balance among the major uses of tin in some earlier years.

	U.S. Consumption- long tons (Primary + Secondary)	Per Cent of Total in Tin & Terne Plate	Solder	Babbitt	Collap. Tubes & Foil	Bronze
1917	76260	35	20	14	5	6
1925	80000	34	25	12½	9½	6
1927	68200	35	20	11	8	7
1928	74370	36	18	11	10	6
1930	65450	42	17½	8	10	5½
1935	71170	43½	25	7½	7½	6½
1936	83050	42	22½	8	6½	7½
1937	90130	45	22	7½	5½	7
1938	58275	42	22	7	9½	6½

The rate of importation - i.e. visible stocks in warehouse and landing at New York at the end of each month, from 1930 to 1939, inclusive, varied from 1400 to 7900 long tons. In 1939 the range was 3400 to 5800 averaging 4100, against tho year's use of 70400 long tons virgin tin. That is, only a few weeks' supply has been kept on hand.

The normal supplies of Chinese tin - 1936-1939 averaged about 10,000 tons but fell almost to zeroduring the last three months of 1939. The normal availability of tin from the countries covered by the "International Tin Control" is seen from the "Standard tonnages for 1940" as follows

Belgian Congo	14035
Bolivia	46027
French Indo China	3000
Malaya	77335
Dutch East Indies	39055
Nigeria	10890
Siam	18628

Except for Boliva, all these sources involve long sea lanes upon which traffic might be interrupted.

Uses

The uses for tin, their relative importance, and some approximation to the amount of tin that would be used, were it available in any desired quantity, in a year of active defense and industrial production, may be gained from the statistics for 1937, a fairly active year, but one in which the maximum need for tin was far from being reached, since finished steel production, a useful index of industrial activity, was but 57 million net tons of ingot, etc. against over 90 million planned for 1941 and the years following. However, the need for tin does not expand directly with the steel production index, because people eat whether times are good or bad, hence the canning industry runs more nearly at a constant level from year to year and the resultant tin plate industry, from month to month, than almost any other industry that can be named. The need for more canned goods due to feeding soldiers at cantonments instead of in private homes, materially increases the need for tin plate, and will require operating steadily at full capacity in 1941 and later years.

The automobile industry is a considerable user of tin and while the 1941-42 auto and truck production for private use is to be limited to not more than about 4-l/4 million vehicles against 4-3/4 million in 1937, the total of automotive products will be greatly increased by the army tanks, trucks, scout oars, etc.

As a first approach, it may be estimated that despite the introduction of all possible conservation of the painless type, the total tin requirement for 1941 and later years will be greater than in 1937. The relative tonnages required for the different uses of tin will shift somewhat from the 1937 proportions, but the relative order of magnitude will probably show no great deviation, until considerable substitution is initiated, so the data for 1937 should indicate the order of importance of the uses for which substitutes are sought.

THE USES OF TIN

The 1937 figures were as follows:

LONG TONS OF TIN USED IN 1937

	Primary	Secondary	Total
Tin plate	39,221	-	39,221
Terne plate	382	1,015	1,397
Solder	12,026	7,832	19,858
Babbitt	4,501	2,272	6,773
Bronze	3,712	2,784	6,496
Tinning (Wire, milk cans, etc.)	2,585	67	2,652
Solid tin tubing	1,278	18	1,296*
Collapsible tubes	3,571	-	3,571
Foil	1,456	4	1,460
Type metals	221	1,140	1,361
Chemicals	171	1,331	1,502
Tin oxide	793	411	1,204
Galvanizing	997		997
Bar tin	652	174	826 (Chiefly destined for tinning and soldering)
Pewter and other white metals	374	33	401
Misc. Alloys	482	24	506
Other Misc. uses	506	97	603
	72,928	17,202	90,130

* 1937 figures show this item; later figures are lumped with tinning.

The figures given above for 1937, used in preliminary studios, are those given on page 685 of Minerals Yearbook 1940, U.S. Bureau of Mines The figures differ from those givon on page 107 of the 1940 Year-book of the Am. Bureau of Metal Statistics whose data are quoted below:

PRIMARY TIN CONSUMPTION AND STOCKS OF THE UNITED STATES

(Tons of 2240 lb.)

	1935	1936	1937	1938	1939	1940	
Stock at beginning (by difference)	10,600	7,700	7,700	13,300	13,300	14,200	
Deliveries	59,110	74,005	83,665	50,660	69,899[a]	112,844[a]	
Total. supply	69,710	81,705	91,365	63,960	83,199	127,044	
Consumption	61,942	74,012	78,152	50,624	69,041	74,114	
Stock at end (by difference)	7,700	7,700	13,300	13,300	14,200	52,930	%
Analysis of Consumption							
Tin and terne plate	28,942	35,442	41,012	24,314	38,321	38,964	52½
Babbitt	3,700	5,000	4,500	2,810	3,760	4,120	5½
Solder	11,480	11,080	11,780	7,820	10,090	11,430	15½
Bronze	3,600	4,800	5,000	3,000	3,960	5,530	7½
Tubes and foil	4,300	5,500	5,000	4,000	3,910	5,370	7
Other uses	9,920	11,390	10,860	8,680	9,000	8,700	12
Totals	61,942	74,012	78,152	50,624	69,041	74,114[b]	

[a] Minus re-exports of 1,997 tons in 1939 and 2,653 tons in 1940.
[b] World production, 1940, estimated, ore in terms of metal, 236,600.

"The above table is based on the reported deliveries of foreign tin and the estimated industrial use as reported by us monthly with subsequent annual revisions , The invisible stock is consequently computed by difference. The industrial use unclassified comprises torne plate, block tin tube and pipe, galvanizing, tinning, oxide, pewter and britannia metal, typemetal, and other alloys and sundries , most of such uses being of relatively small magnitude," "According to the above computation there was indicated an invisible stock of about 53,000 tons at the end of 1940, an increase of about 39,000 tons during 1940, Of this about 14,000 tons had been delivered to the Metals Reserve Co., while about 7,500 tons had been delivered to other governmental branches. It is indicated therefore that a substantial increase of stocks in the hands of consumers, or in warehouses otherwise, occurred during 1940."

"The production of secondary tin is not introduced into the computations for the reason that substantially all of it is derived, in one stage or the other, from tin plate manufacture and has already been charged to the manufacture of tin and terne plate. However, the production of secondary pig tin, outside of the tin plate mills (that is, by detinners) has been as follows, in tons of 2,240 lb,:

1935	900	1938	2,950
1936	2,740	1939	3,790
1937	2,900	1940	3,830 "

The computations herein before do not include the large quantity of tin that has gone into use as solder and is reclaimed as solder, largely from old automobile radiators. The use of solder in the manufacture of motor vehicles in 1940 was about 17,500 tons, chiefly in the radiators. The manufacturers of tin cans and other tinware may have used something like 7,500 tons.

The bulk of the tin plate and a good deal of the terne plate were for cans, and some 3,500 to 4,000 tons of the solder listed (on p.5) was used in joining the side seams of tin cans. The can industry uses approximately half the new tin required by industry. Solder, babbitt, bronze, various coatings of pure tin, tubes, foil, galvanizing and tin oxide follow in about that order as users of new tin.

INDIVIDUAL USES FOR TIN

The uses in the list may be considered in reverse order of importance.

Pewter

Pewter is chiefly used for articles of aesthetic rather than industrial importance and can be considered as almost wholly substitutable.

Galvanizing

The primary use of tin in galvanizing is for the appearance of the spangle. Its inclusion is thought by some to injure the corrosion resistance of the zinc coating. The use of tin to produce spangle could be dispensed with. One commentator says that the use of tin favors the production of "tight", i.e. more formable, zinc coatings, so that inability to use tin might work hardship. An aluminum addition also serves in making a "tight coating." Some authorities think that the presence of tin leads to a heavier rather than a lighter coat of zinc. Whether any improvement in the zinc coating is balanced by the expenditure of tin or aluminum would be affected by the relative availability of the three metals. The evidence on the value of tin in a galvanizing bath is quite conflicting.

Tin Oxide

The chief use of tin oxide is as opacifier in vitreous enamels. This use has fallen off from a previous much higher level, because the oxides of antimony, titanium, and zirconium have been developed to do a satisfactory job more cheaply. This use for tin oxide could be practically eliminated without material hardship. Tin oxide and other chemical compounds of tin come almost entirely from secondary sources, as does the tin used in keeping type metals up to the desired composition during many remeltings.

Type Metals

There is a large amount of tin already tied up in type metals, but this is a revolving fund. The composition of type metals may be varied within reasonable limits. The amount of tin required could be somewhat reduced by such variations in tin content.

Foil

"Tin" foil is very often not pure tin, but lead foil with a tin surface. With few exceptions its uses could be served by aluminum foil or zinc foil, but under the present condition of scarcity of aluminum and zinc this substitution is not immediately feasible. In the long run they are feasible substitutes. Temporarily, the use of waxed paper, cellophane, and the like will handle the packaging uses. Lead foil, or PbSn foil with low Sn, might be made to serve for electrical condensers. This particular use needs rather close examination. On the whole, nearly all uses of tin foil may be considered as replaceable by substitutes. Erekson* reports that two transparent materials equal or superior to tin foil are available for packaging of cheese and are cheaper.

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* Erekson, A. B. Proc. 1st Food Conf., Inst. Food Tech. 1940, pp. 185-188.

Collapsible Tubes

In collapsible tubes the situation is not so simple. These are usually, like foil, made of pure tin, or in some cases of lead with a tin surface, the tin being used sometimes for its bright appearance, sometimes for its resistance to corrosion by the material packaged. The purest grade of aluminum would serve for the majority of tooth paste and other tubes, though some shaving creams corrode aluminum. However, as in the case of foil, this substitution is not feasible at the moment, and it is said that aluminum tubes smaller than one inch diameter are not readily made. Zinc tubes can be made and would handle some needs, but zinc, like aluminum, is momentarily not available for this use. Some salves and the like could be packed in Pb or Pb-Sb tubes. Quite a variety of products could be packed in large lead tubes.

Considerable effort has been put on making tubes of plastics and of rubber hydrochloride, and, despite some difficulties, such materials appear to be possible of satisfactory development. Pending the perfection of non-metallic substitutes, it would be possible to use shaving sticks instead of shaving creams, tooth powder instead of tooth paste, and with less convenience to the user, and with alteration of the packaging technique, to pack in glass some of the products now packed in tubes. In less than "all out" substitution, some of the present uses for collapsible tin tubes would deserve continuation while substitutes are being perfected, or until aluminum again becomes available. Some of the cheaper tubes are duplex, i.e. made of lead with a pure tin coating amounting to 5% of the total weight; more expensive types of duplex tubes carry up to 10% with an average of say 7%. Reworking of plant scrap requires remelting of the duplex material, whereby the tin, originally on the surface, is taken into the body, which was originally (when made from virgin metal) pure lead. This goes on until the body becomes an alloy of about 85 Pb 15 Sn. With the 10% pure tin coating this means that the regular product contains 25% tin. To give equivalent strength such a tube has to be twice as heavy as a pure tin tube. The total saving in tin by means of "10%" coated tube is therefore 50%.

By the use of other alloying elements beside some 15% tin, in the lead body, to strengthen it, the tube need not be as heavy, and it is alleged that by suitable choice of alloying elements a corrosion resistance equal to that of a pure tin coating of the usual "7% grade" can be built up against quite a variety of the materials to be packaged, thus saving about 2/3 of the tin required in a pure tin tube, against one of about 1/2 in a coated,duplex tube.

Because of the tin content of even the duplex or the alloy tube, reclamation of used tubes would deserve organized effort.

Tinned Articles

Tinned steel articles such as kitchen equipment (e.g. potato mashers) and large cans used for milk collection are difficult of satisfactory substitution on account of the sanitary factors. Tinned copper vessels and tubing find use in the milk and food industries. Aluminum, stainless steel, or nickel alloy,, and sometimes heavily electroplated silver-coated utensils, vessels and tubing will serve the great bulk of these uses, usually at considerably greater expense, but aluminum and nickel are already scarce and chromium may become so. In fact, tinned articles are temporarily serving as substitutes for uses in which some of these other materials are normally employed. Ice cube trays for refrigerators are an example. A copper-tin electroplate of speculum metal is being considered in the place of the nickel undercoat beneath chromium plating. In the tinning of copper wire for electrical conductors to prevent attack of the copper by the sulphur in rubber insulation, a thinner coat ~~of~~ tin, deposited electrolytically can probably be used to replace thicker hot-dipped coatings. The problem may also be attacked by the use of glass fiber and other chemically inert insulating coatings. In some important applications of tinned copper pipe, an immersion coating, using only 5 to 10% as much tin as a hot-dipped coating, is now being applied. Other methods for making thinner coatings are being developed.

Solid Tin Tubing

The "block tin pipes" are used for distilled water in the laboratory and for various uses in the beverage industries. In some of these uses aluminum has been satisfactorily substituted, and in view of the relative weights of these solid tubes, such substitution would probably be advantageous even in the light of the scarcity of aluminum. Tin lined rather than solid tubing, glass tubing, etc. might sometimes be used. Bendability without danger of fracture of a tube or of an interior coating is a desirable feature of the solid tin pipe, but by correct engineering materials not capable of bending could sometimes be substituted. In some of the most crucial cases, the use of silver tubing might be considered.

Bronze

Only a little over half the tin used in bronze is new tin, the balance is secondary, largely as secondary ingot made from scrap collected and sorted by secondary metal dealers. That source of supply would not dry up entirely for some years, and the ordinary cast red bronze of commerce - 85 Cu 5 Sn 5 Zn 5 Pb and modifications thereof could, for many uses, be made without need for much new tin. The 85-three fives-may itself be substituted by 82 Cu 3 Sn 5 Pb 10 Zn, for many uses, with a resultant increase in the suitable scrap supply. These secondary alloys could be applied with reasonably good service results for many of the corrosion resistant castings for which bronze of higher tin content is ordinarily specified, and for quite a proportion of the bronze bearings. There are, however, many important bearings made of 80 Cu 10 Sn 10 Pb, or of alloys of closely similar composition, in which the required amount of Sn is large and the tolerance for other elements is not large enough to avoid the necessity of using some metallic tin, new or secondary, in the mixture.

Pulverized 80:10:10 is being applied to steel backs by powder metallurgy technique, the clad back being then curved up into bearings. Hence the amount of bronze required is greatly decreased from that for a solid bearing. Such bearings are new, so their range of applicability is not yet certain.

Were nickel available, the 10% Sn in 80:10:10 might be changed to 5% Sn 5% Ni, and the alloy still be applicable for many bearings, but that is not feasible at the moment. However, the tin content could ordinarily be cut to 8% without greatly altering the properties. Some English and German specifications for this type of alloy allow 8 Sn 12 Pb. Ball or roller bearings could often be used in place of bearing bronzes, but at an increase in cost and with the necessity for a complete redesign to give room for the more bulky bearings. In rolling mills, roller bearings and water lubricated bearings of plastic-impregnated fiber are used where grease lubricated bronze bearings were formerly used, but some precision mills are equipped with very large, very precisely machined bronze bearings using oil under pressure that it may not be wise to attempt to replace with other bearings.

Railway freight car bearing backs are made of high lead, low tin bronzes, the raw material being primarily old bearings sent in for remelting. The linings are Pb-Sb-Sn alloys with around 4 to 10% Sn. Tin-free linings or those with only around 2% Sn could be substituted. Pb bearings hardened with Na, Ca, and Li of the "Bahnmetall" type have been used in Germany and the analogous "Satco" metal in U. S. There is a question whether these are as suitable as the usual Pb-Sb-Sn lining for rolling stock operated at high speeds, but in spite of various drawbacks, Satco metal could be resorted to in an emergency.

New passenger cars can use roller bearings. Certain locomotive bearings require tin and substitution in this relatively small tonnage is probably inadvisable.

The uses of bronze other than for bearings can be almost wholly substituted by other copper base alloys having equal strength and corrosion resistance, but which are usually somewhat more difficult to handle in the foundry. Were aluminum available for use in aluminum bronze, that tin-free alloy, in the hands of a foundry accustomed to the precautions necessary in gating and pouring, would serve many purposes equally as well as the tin-bronzes. Much the same can be said for the silicon bronzes. These are Cu-Si alloys with small amounts of Fe, Mn, or Zn. As wrought metal they can replace phosphor bronze in a great variety of uses. As casting alloys they require care and experience in melting, since they are gas-sensitive. However, these foundry troubles and those with aluminum bronze are not considered to be too difficult to control once a moderate amount of development is put on the problem by the foundry. A specially useful alloy giving high yield strength, silicon brass, carrying say 10 to 14 Zn, 4 to 5 Si, balance Cu, except for a fraction of one per cent of Mn, might be the first choice when Zn becomes available again. There should be no permanent shortage of Si.

The strength and corrosion resistance of well-made aluminum or silicon bronze castings and wrought products are entirely satisfactory. Their chief drawbacks are their incompatibility with lead, so that it is not now feasible to introduce enough lead to make these alloys machine as well as the leaded tin bronzes, although the dispersion of sufficient lead is not necessarily hopeless and deserves further study. This substitution therefore, means, for the present, a reduction in production of the machine shop. The incompatibility with lead explains why these bronzes are not substitutable for leaded tin bronze bearings, or for leaded brass screw stock. A tin-less bronze that is compatable with lead would be a very welcome help in the solution of this phase of the substitution problem. One reader of the preliminary draft of this report considers that this statement deserves strong emphasis.

At the expense of slower machining, almost all uses of tin-bronze other than bearings can be quite easily substituted for, and bronze bearings can often be substituted by roller bearings at the expense of redesign.

Considerable painless substitution can be made, but "all out" substitution would not be painless. The cases where substitution would entail great difficulty can ordinarily be handled with bronzes made from secondary metals, as long as they are available.

Babbitt

Bronze is used for many purposes beside bearings and the other uses are definitely substitutable. On the other hand, babbitt's only use is as bearing metal, and, in ordinary practice, a smaller proportion of old babbitt comes back for reclaiming than is the case with old bronze. Babbitt stands third on the list of uses for new tin.

There are two types of babbitt bearings, tin-base and lead-base. The tin-base babbitts ordinarily contain some 85 to 90% Sn, the balance being Sb and Cu. The lead-base babbitts contain 5 to 15% Sb with 5 to 10% Sn, balance Pb. Much more lead-base than tin-base babbitt is employed.

Babbitts can be poured into a bearing around a mandrel, or cast centrifugally against a previously tinned steel or bronze back, or they may be spread upon a flat steel strip and the coated strip be bent up into a "thin backed, snap-in" bearing. The automobile industry employs the thin backed bearing to a very large extent. The babbitt coating is extremely thin. The thinner the soft lining the more it is supported by the strong back and the more severe duty the bearing will stand. With modern thin backs lead-base babbitt is adequate for most present motors. If aluminum pistons are displaced by cast iron pistons, the increased bearing load might call for a return to tin babbitt. The lead-base babbitt needs 2 to 4% Sn to improve corrosion resistance against acid oil. Dropping to this content of Sn from the 85% Sn of a tin base babbitt has already allowed marked conservation of tin in the automobile industry.

In the thicker bearings used in most other applications of babbitt, tin-base babbitt is preferred to lead-base for severe service. The ordinary lead-base babbitt loses strength at bearing temperatures. It is possible to make a lead-base babbitt whose commonly measured room and elevated temperature properties are practically identical, but that does not insure that the behavior as a bearing will be the same.

In order to produce a lead-base babbitt whose high temperature strength is more like that of the tin-base babbitts, von Schwarz* advocates

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* von Schwarz, M. F. Neue Blei und Aluminium Lagermetalle-Giesserei, 27, 1940, pp. 137-144. Ger. Pat. 688,858 March 4, 1940, Brit. Pat. 500,236 Feb. 6, 1939.

dropping Sb and adding large amounts of As, one of his compositions is 86 Pb 8 Sb 6 As. Phillips* suggests 83-3/4 Pb 12½ Sb 3 As 3/4 Sn, and presents data showing its similarity of behavior to that of tin-base babbitt. C. E. Swartz** prefers an alloy of about 82½ Pb 15 Sb 0.90-1.25 Sn 1 Sb 0.40-0.50 Cu as preferable to the higher Sb composition because of better bondability, and having satisfactory behavior under the usual General Motor's bearing machine test. The present A.S.T.M. specifications for lead-base babbitt (B23-26) permit only 0.20-0.25% As, probably through fear of brittleness and injury to bonding properties, but S.A.E. specifications allow 0.60%.

Another lead-base babbitt with about 15% Sb, 1/4% Cu, 2% Sn, and 2½% Ag, developed*** to duplicate the hardness-temperature properties of medium grade tin-base babbitt, to have the corrosion resistance conferred by the tin content, and the soldering or bonding power of the Pb-Ag alloys has also shown good behavior on the General Motor's bearing test and on the basis of tests by an outside firm has been appraised by it as a possible substitute in case of a tin shortage.

Such babbitts may serve, not only on thin snap-in bearings, but also for the rebabbitting of old bearings originally made with tin-base babbitt, but all the suggested compositions need the test of actual service under a variety of conditions to evaluate their applicability. It is to be hoped that a large number of users will try and report upon the behavior of these compositions or others aimed to duplicate the properties of tin-base babbitts.

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* Phillips, A. J. et.al. / The properties of certain lead-base bearing alloys - to be presented at A.S.T.M. meeting June 1941 - U.S. Pat. 2,232,185, Feb. 18, 1941. Compare also Automotive Industries, May 15, 1941, p. 520 on use of this alloy in die casting.

** Swartz, C. E. Private communication to Dr. Z. Jeffries, May 6, 1941.

*** At Battelle Memorial Institute.

Other possibilities have been suggested[x].

An Ordnance Department reader comments that broadening of government and industrial specifications to allow greater use of secondary metal would be desirable.

For heavy duty trucks, buses, Diesel engines and the like, a bearing that is stronger at operating temperature and that will stand higher operating temperatures than even tin-base babbitt is in demand. Large aircraft engines also need something beyond the babbitt class. Bearing metals whose properties are improved over babbitts in these respects, but which, in the harder grades, do not have as good embeddability for grit as the babbitts and which need harder shafts, have been produced from a cadmium base, from alkali-hardened lead (Satco type) and from "copper lead," (alloys with 20-35% Pb balance Cu sometimes with a little Sn or a little Ag). All these are more prone to corrosion by active oil at high bearing temperatures than tin-base babbitt. The need for shafts with harder surface is not insuperable, since flame hardening and induction hardening are already coming into wide use.

The cadmium babbitts are excellent but are already in use to the full extent that the supply of cadmium will allow. Cadmium production occurs only as a by-product of the production of zinc. Its production cannot be increased at will. Some 3000 tons of metallic Cd, a record amount, was used in 1940. The demand was so great that prompt deliveries carried a large premium.

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x Bearing metals from the point of view of strategic materials. Metals & Alloys, v. 12, Sept-Dec. 1940, pp. 274, 455, 629, 749.

The alkali hardened bearing metals are rather complex alloys containing small but precise amounts of the easily oxidizable metals Ca, Na, and Li so that their control in melting is difficult and needs experience. The average shop would have much difficulty with them. Little experience has been had with them in engines and the like, although their status as linings for freight car bearings is better understood. Some part of the field now occupied by tin-base babbitt might ultimately find replacement in these alloys, but the alkali-leads can hardly be relied upon for wholesale replacement, though some authorities consider that they deserve more attention than they have heretofore been given.

The Cu-Pb alloys would serve for a considerable proportion of the uses now employing babbitt but would require harder shafts. There is a large production of Cu-Pb for aircraft use, but the manufacture of good Cu-Pb bearings is an art. Rejections are usually so numerous that the final cost of a good Cu-Pb bearing is much higher than that of a good tin-base babbitt bearing. Although it is possible to line a bearing with Cu-Pb without using a removable backed bearing, it is very difficult and substitution of Cu-Pb in the repair of machines previously babbitted with thick tin base linings would be impractical.

Silver linings are used in some severe duty aircraft bearings and probably cost no more than a really good Cu-Pb bearing. While silver is relatively non-seizing, the seizure behavior of silver bearings is improved by a coating of electroplated lead or electroplated silver-lead alloy. The plated silver-lead alloy could be used on "snap-in" bearings in place of either tin-base or lead-base babbitt, for quite a range of service. Gold has fair bearing properties, and gold-plated bearings are a possibility. The stock of gold in the U. S. would make a vast quantity of bearings.

Thus it is not feasible to make a sweeping substitution of tin-base babbitt by any single substitute, each bearing problem has to be considered on its own merits. Through changes in design, practically anything now using tin-base babbitt could be revised to allow the substitution of some tin-free or very low tin ubstitute. Repair of old bearings designed to use tin babbitt may still require that material, though in many cases a lead-base babbitt would serve.

Solder

Substitution for tin solders is more simple than for tin-base babbitts, since solder does not have to meet so many and so varied requirements as a bearing does. Conservation of tin in solder by the use of a composition low in tin and high in lead is seldom feasible. The pressure of ordinary economic factors has already led to the use of nearly the lowest practical tin content in most tonnage uses, though reexamination of the situation may sometimes still show further reduction feasible. The thickness of the solder film tends to increase with decrease in tin, so reduction of tin content below some fixed point results in the use of more pounds of tin. Since the strength of a solder film is the better, the thinner the film, i.e. the greater the support it gets, joint quality is reduced at too low tin content, Some shops that could use solders of various tin contents may be using only one high-tin solder to avoid the bother of keeping different grades separate, but outside of such rare cases, attempts to lower the tin content are likely to defeat their purpose.

Good solders are produced by substituting part of the tin by cadmium, and cadmium-zinc alloys are in use as solders to stand higher temperatures than lead-tin solders, but the normal scarcity of cadmium and the temporary scarcity of zinc make such substitution only of academic interest.

There is no present substitute solder with the low melting point and good wetting power of the lead solders high in tin. The adoption of a higher operating temperature in order to use substitutes requires a slight modification in soldering practice and sometimes the higher temperature may affect the metals being joined. Both these difficulties can usually be gotten around.

The largest item in the total annual consumption of solder is in dip-soldering of automobile radiators, which takes about 2 lbs. Sn per car. Radiators for glycol-cooled aircraft engines operate at such a temperature than Pb-Sn solder is too weak. A solder of 94-95 Pb, 5-6 Ag is used on these radiators, This solder is covered by S.A.E. Aircraft Materials Specification 4755. The Army Air Service and the National Bureau of Standards find that this solder is not impractical to handle and the joints are superior in strength to those made with Pb-Sn solder, The lead-silver solder solidifies at 580° F. and dip soldering, is done at about 850° F. instead of the 700° F. used with ordinary solder. This increase in temperature tends to soften cold worked copper of ordinary commercial grade. The strength conferred by cold working can be retained, if the annealing temperature of the copper is raised by addition to the copper of a fraction of a per cent of silver, chromium, columbium or various other metals that serve this purpose. Thus certain types of radiators might require the production of a special grade of copper to be amenable to dip soldering with Pb-Ag.

For many purposes it is unnecessary to use as much as 5 to 6% Ag, since a solder of 97½ Pb, 2½ Ag or 97½ Pb, 2½ Ag, ¼ Cu has nearly the same wetting power. This is a well-known solder for joints in electrical machinery in which accidental overheating would loosen joints of Pb-Sn solder.

Preliminary experiments by three of the largest can-makers indicate that either the 5% or the 2 1/2% Ag solders be successfully used to solder the side seams of cans made from the present type of tin plate, in the automatic can-making lines. One maker states that the corrosion angle would need further investigation before Pb-Ag could be adopted, Some 10% as much tin is used in can-soldering as in the tin coating on the cans themselves, The apparent suitability of Pb Ag solders for the exacting task of automatic can soldering indicates that they should serve almost every soldering use. One limitation may be in applications where the soldering flux is not easily removed, since active fluxes that are corrosive appear to be needed, whereas non-corrosive ones may be used with Pb-Sn solders. For such cases it may be necessary to turn to the high melting point, "silver solders," high in Ag. Pretinning with a very small amount of Sn before applying the Pb-Ag solder is sometimes desirable.

The opportunity for widespread substitution of Pb-Sn solders by Pb-Ag solders makes it advisable to discuss the oost of the latter and the availability of Ag. The replacement ratio, 40 to 50 lbs. of Sn by 2½ to 5 lb, of silver, is attractive. Cost plots are given by Addicks* for various prices of Sn and Ag. These are on a cost per pound basis and to reduce them to cost per unit volume the data for Pb-Ag should be revised upwards by about 15% due to the higher specific gravity of the high lead alloys. However, at present prices for Sn and for industrial Ag, the raw material cost of 2½% Ag solder is practically identical in cost per volume with a 45 Sn 55 Pb. A 6% Ag solder would cost about

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* Addicks, L. Silver in Industry, 1940, p. 85.

40% more for raw materials. Actual present prices of the Ag solders, however, appear to be considerably more above those of Pb-Sn solders than this raw material cost comparison indicates, which may be because of the relatively small production of Pb-Ag solders so far.

If 20,000 long tons of Sn in solder per year, averaging say 40% Sn, is to be substituted by Pb-Ag solder, the 110,000,000 lbs. of Pb-Sn would, on account of difference in specific gravity, correspond to some 125,000,000 lbs. of Pb-Ag solder. At 5% Ag this means 6,250,000 av. lbs, or 88,000,000 troy oz. of Ag, or at 2½% Ag, 44,000,000 troy oz.

Since 2½% Ag will serve for most solder substitution, on estimate half way between the amount required by that composition and that for the 5% Ag composition, i.e., 66,000,000 oz. should be sufficient for "all out" substitution of Sn in solder.

In 1940 the U, S. and Canada used industrially 41,000,000 oz. and the U. S. Treasury purchased about 5 times that much, i.e. 203,000,000 oz., raising the accumulated Treasury holdings to 3,135,000,000. That is, in 1940 the Treasury laid in silver over and above present industrial requirements, sufficient for 3 years supply of solder. Devoting 1/3 of the Treasury holdings to such use would give enough for 15 years supply. (The availability of silver is also pertinent to its use in bearings to replace those now using tin.)

One large use for solder, in which Pb Sn solder is of relatively low Sn content but which takes 1/2 to 1/3 lb. Sn per car, is in "body solder", used to even up dents and smooth over welded joints before lacquering the car body, One of the "big three" makes of low priced cars uses no body solder, smoothing the body in other ways, If 3,000,000 cars are made in the 1941-1942 season that do use body solder, this would take about 500 tons of Sn. Use of other methods of smoothing or the application of a Pb Ag solder could certainly be applied, if it were necessary to conserve that amount of tin.

The two drops of solder on the base of electric light bulbs, used to favor good electrical contact with the socket, take around 100 tons of tin annually. The requirements are not such that a tin base solder is needed.

One reader of the preliminary draft states that experiments now in hand, but not sufficiently completed to allow full appraisal, indicate that there will be several combinations in addition to the lead-silver alloys that may prove useful as substitutes for lead-tin solders.

At first sight, replacement of "wiping solder" used for making joints in electrical cable and in lead pipe for plumbing, seems difficult because of the peculiar properties demanded in a wiping solder, met only by solders with either 38% Sn or 23 Sn 9Cd. However, Willard* points out that lead-burning technique can be applied and tin wholly eliminated in these joints,

Mention should also be made that copper brazing or brazing with phosphor copper, silver solders, etc. in controlled atmospheres affords an economical method, applicable to large production, for joining parts that were formerly soldered, and that, of course, welding may likewise often be substituted for soldering.

Thus in a great many of the present applications for solder substitution could be made painlessly, in others after some change in technique, but "all out" substitution for tin in solder could be accomplished with relatively little difficulty.

Tin Cans

The lion's share of the new tin goes into tin plate and of this about ¾ goes into food packaging. Hence it is in the can and canning industry that the major reduction in tin consumption should be looked for.

It is obvious that in the entire absence of tin, many food products could and would be packed in glass. The proportion of the total pack put up in glass has increased in recent years**. Ceramic containers are on the increase in Britain***.

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* Willard, F.W. Tin Plate and Solder - Metals & Alloys, v. 3, Feb, 1941 p. 174.

** Western Canner & Packer, March, 1941 p. 25. Canning Age, April, 1941 p. 248.

*** Canner, April 12, 1941 p. 18.

The glass industry could increase its production of containers considerably without having to install more melting furnaces, forming equipment and lehrs, but it would take time for it to equip to carry the whole burden.

The permanent practical difficulty with glass containers is their weight and the cost of freight in shipping both empty and filled containers. Another difficulty is the poorer thermal conductivity of glass, which slows down the heating for sterilization and the cooling after it, so that production is likely to be decreased. Also, glass may break under these thermal shocks or rough handling, so that wastage of both container and contents may occur. The effect of light may bring the destruction of vitamins, so that dark glass or light-proof wrapping may need to be used. A temporary difficulty is that canners' equipment for filling, sterilizing and conveying is designed to take tin cans, and in some cases would require changes and considerable increase in mechanical equipment to handle entirely glass instead of tin, or to greatly increase the proportion of the present pack that goes into glass. It would probably be difficult to displace the type of cans ordinarily used for canned milk, by glass, and it is obviously important to utilize the present equipment for canning milk rather than to displace it all by other equipment.

Utilization of present can filling and can making equipment, which is balanced with the present needs of the canners, to the greatest possible degree, will hamper the ultimate object, the canning of sufficient food, the least.

Present can making equipment is designed to make can bodies from tin plate by soldering the side seams at a very high rate of production and with a percentage of rejects that is remarkably low for any industrial product. Every bit of this high rate of production is needed to provide the cans for the canned goods needed by the Army and Navy, and the civilian population. Until added equipment can be provided to make up for any decrease in productive capacity entailed by any kind of substitution, such substitution cannot be introduced.

The tin stock pile is aimed to bridge such gaps between present practice and the employment of substitutes. The stockpile needs to be large, or the gaps small.

The really vital primary purpose of the tin coating on tin plate is to allow satisfactory automatic soldering of the side seam. The other primary functions can perhaps be met in other ways. In about 5% of the total pack a heavy tin coating is required to protect the can from corrosion by its contents, or the contents from contamination. This "class 1" type of products includes baby food, sauerkraut, cherries and a few other acid fruits. Obviously, the "class 1" products could be packed in glass, replacing the cans for which a heavy tin coating is still allowed, and thus striking at a use in which no conservation is now being applied. Some food products (and many industrial products) could be packed in uncoated, properly cleaned and preheated, black plate coated with one or more coats of various lacquers analogous to that used in beer cans. In the present state of knowledge, these lacquers have been developed for application over a tinned surface, and some difficulties are met in securing perfect adhesion over even well cleaned, preheated black plate, so that it is scarcely feasible at the moment to go completely to lacquer-coated black plate. The thin electroplated coatings will, however, provide for the needed adhesion. Nevertheless, it seems unlikely that the researches in progress on coating black plate will fail to solve this problem. Many tin cans for food already carry a lacquer coating over the tin.

Without doubt methods for use of black plate with suitable priming coats and lacquers are in use in Germany. Reports of the Consul General, Frankfort on the Main, for 4-27-40 and 8-7-40 discuss the use there of welded, phosphate and lacquer coated tinless cans for food containers, and other methods adopted or on trial. However, it is reported, National Provisioner, Jan. 18, 1941, p. 34, that the tinless containers have proven entirely satisfactory only for alkaline-reacting foodstuffs.

The tin coating protects the tin plate from rusting in shipment or storage between the steel mill and the can factory, helps somewhat in protecting the outside of a filled can from rusting, and gives the shiny appearance the public is used to. No commercial tin coating is free from microscopic pin holes, but if a lacquer coating itself has pin holes not all of these pin holes come on top of pin holes in the tin coat, so the presence of tin somewhat lightens the task of making the lacquer protect the steel. Putting on a really protective lacquer probably involves coating the completed can body and carefully controlling the drying or baking process, so that production would be slowed down compared with present methods of applying lacquers.

In the case of certain foods it is thought that a bare tin interior can surface helps in preservation of the contents by reaction of the tin coating with oxygen in the contents, so that for these cases, a bare tin coating is preferable to a lacquer coating. Such cases might be handled by addition of some harmless material to react with the oxygen, but such addition would have to be approved by the Food and Drug Administration. Since only the surface is active to absorb oxygen, a very thin flash of electrolytic tin might serve as well as a dipped coating.

In spite of these factors, well joined can bodies made of black plate or of very thinly coated tin plate, can be made to serve for some proportion of the food pack, yet to be exactly determined, and for a vast majority of non-food products.

An obvious suggestion is to "stop-off" the balance of the area of the sheet from which cans are to be made, and tin only the areas that form the side seam and take the solder. This is probably being done to some extent in Germany and has been given some thought here.* Under normal economic conditions it has been considered cheaper to tin the whole plate than to accept the drawbacks attendant on trying to develop a stop-off for hot tinning.

It is an axiom in soldering that the metal surfaces to be soldered must be extraordinarily clean, free from even the adsorbed air film taken up on exposure to the air. Hence the surface is fluxed to bare clean metal and immediately coated. It is often necessary to scrub the surface underneath a layer of molten solder or of a

* Compare Canad. Pat. 389,847 July 9, 1940 to Champlain Corp.

constituent of the solder, to provide mechanical as well as chemical cleaning. This preliminary coating of the surface prior to use of ordinary solder is usually done with pure tin or a high tin solder, and the operation is termed "tinning" even when a metal other than tin is used. With such a layer of easily fusible metal on the tinned surface, the face of the metal beneath the layer is maintained in a clean condition, ready to be joined in the later soldering operation without much difficulty in fluxing.

Molten tin applied to steel attacks the steel and forms an iron-tin alloy that is not readily fusible. Outside of this alloy layer is a thin fusible layer of pure tin. It is this pure tin layer that serves to protect the surface and keep it prepared for soldering. Only a small fraction of the tin applied enters this vital layer when the total amount of tin applied is small.

If the pure tin layer is too thin, through being wiped too closely, on reheating the frozen coating, it tends to draw up into droplets instead of staying as a complete layer. This phenomenon is known as "de-wetting". If de-wetting occurs, a poor solder joint is likely to result. Hence the production of tin plate that carries an unbroken film of molten tin without de-wetting, after wiping, gives reasonable assurance that that tin plate will solder satisfactorily.

The thickness of the tin coating on tin plate is described in terms of lbs. Sn per base box of tin plate. A relatively thin coating averages perhaps 1.3 to 1.5 lb/base box on the basis of the total tin consumed in making the coating. But if the coating is not evenly distributed, it is likely to vary in individual locations on the sheet from say 1.8 to 0.7 lb/base box, "spot test". This means that the spot carrying only 0.7 lb/base box is commercially solderable, it does not de-wet, and also means that for all save "class 1" products, a can with 0.7 lb./base box spots in it is usable from the corrosion aspect. Accordingly, tin plate for cans does not need more than 0.7 lb/base box anywhere, so if means could be found to apply that weight of coating uniformly, with no still thinner spots, the total tin in the coating could be reduced almost by half. No means is known for accomplishing this by hot-dipping.

It is, however, entirely feasible to apply a coating of that or of still lower average thinness in very uniform fashion by electroplating. However, great care is needed in cleaning the steel before plating, since an apparently adherent coating will be produced, but on attempting to solder it, the tin coating over insufficient cleaned steel de-wets on melting and does not solder properly. If the electrodeposited coat is brought to the melting point, as by dipping in hot palm oil, a coating that will de-wet can be detected, and the poor portions scrapped. This results in what amounts to 100% inspection as to solderability. Of course, with close control of cleaning and plating and with adequate inspection, the unmelted thin plated coating will behave similarly to the melted one when it is melted in the soldering operation. Active development of thin electroplated tin coatings is going on. When the solderability is satisfactory, so that the can can be made at all, the behavior of coatings even as thin as 0.50 lb/base box as to interior corrosion is promising, though atmospheric corrosion of the exterior is not so well prevented, and protective coatings of other types might need to be applied to the outside.

Much of the effort on the utilization of electroplated sheet has been put on trying to utilize it under the exact processes used with heavy hot-dipped coatings, such as soldering of pre-enameled or lithographed blanks, instead of working out modified processes to evade the difficulties that are met. Even so, it is plain that a good many non-food products and quite a proportion of food products could be packaged in cans made from electrolytically coated plate carrying less than half the normal amount of tin. It has been suggested that even though the protection afforded by present substitute coatings may not be as permanent as that consumers are used to, a system of dating cans and planning for consumption within a certain period, like photographic films, might be applied.

Another suggestion has been silver plating instead of tin coating, a matter that has been given much publicity, but is appraised as of no commercial interest for cans to be discarded, when very thin silver coatings are applied, though for returnable containers of other types very heavy silver coatings have promise.

Hot dipping with aluminum instead of tin can be made to produce somewhat protective coatings, but the lack of solderability and the questions as to corrosion resistance render these of no immediate interest, especially in view of the present scarcity of aluminum. Experiments with nickel plating, nickel plating with a flash of chromium, and with tin plated over nickel have not so far been promising from the can-makers' point of view and need no discussion in view of the present nickel scarcity. For replacement of hot dipped tin coatings in other uses, there may be possibilities in a thin electroplate of nickel covered by another thin electroplate of tin, when nickel again becomes available.

A complete avoidance of tin could be brought about, in cans that need tin only for solderability, by the use of seamless or welded can bodies in place of soldered ones. Deep drawn cans are being stamped out of steel plate of suitable drawability by one can maker, thus providing both the body and one end.

Another can maker has made bodies by welding a steel strip turned up into a tube, a difficult process with such thin stock, but one that appears feasible. Suitably lacquered cans made entirely from black plate without any tin have been packed and put into consumers' hands. The possible production rate by this welding method appears greater than with multiple spot welding of a lap joint, a method that has also been experimentally applied.

There is much in favor, from the point of view of tin conservation, of putting development effort on the stamped, or welded, lacquered can in preference to that on utilization of very lightly coated tin plate.

The difficulties in the way of employing thin electroplated coatings with a saving of half or more of the tin now used, or of lacquered plate with entire avoidance of tin, are not entirely in the present lack of perfection of the processes for producing and utilizing such products and the slowing down of can making while introducing unfamiliar methods. Great difficulties lie in the cost and delay involved in the installation of new plating or welding equipment to deal with the large tonnages involved. The use of materials and man hours in the making of these installations at this time could be justified, and indeed would be imperative, were a severe shortage of tin certain in the near future. But until that shortage is imminent, a slower, but steady, development of the techniques involving radically different practices, so that the most satisfactory ones may be chosen when "all out" displacement is required, is the saner course. However, such development needs acceleration.

A certain degree of painless conservation, without substitution, is being accomplished by the can makers. The possibilities in this line were discussed at a meeting April 16th called by the O.P.M. Division of Conservation and Substitution.

Reduction of the weight of tin coating on cans for food products (except the 5% of class 1 products) by about 10% was considered feasible by the can makers and has now been ordered by O.P.M., though it will slow up tin pot production somewhat and require some increase in the number of tin pots. This reduction to an average thinness of 1.35 lb/base box, stack, corresponding to 1.25 lb/base box, spot test, is within the coating tolerance with which can makers are already familiar. A greater reduction in coating weight of hot-dipped plate was appraised as slowing tin pot production to an excessive degree, and probably leading to much soldering difficulty, though no trouble is anticipated in respect to preservation of the canned food. However, with more experience in the large use of coatings on the low side of present practice, a further small reduction may be possible as a result of experiments now under way.

Packing foods in large cans rather than small ones would require less tin per pound of food packed, and the large cans would be even more convenient for the Army, but neither the canners nor the can makers have equipment to use or to produce a greatly increased proportion of large cans. Full use of what large can equipment exists, and expansion of such equipment rather than that for smaller cans, are obviously steps in the right direction.

A further saving in tin, and one already being put into practice voluntarily, comes from making cans for non-food products from terne plate rather than tin plate. Terne plate contains some 18 - 25% Sn, perhaps more for the lighter coatings, and the coating thickness is generally less for tin plate. Most of the cans for paint, etc, are already made of terne, and, except for white and very light paints, the terne coating is as satisfactory. Ends for oil cans can be made of black plate. What cans were still made of tin plate that could serve as well if made from terne have now been shifted to terne.

Use of waxed paper and plastic impregnated paper containers for dry products is, of course, feasible for a variety of such products now packed in cans, and that type of container is applicable to the frozen food industry, a development that could be increased with a resultant considerable saving in tin.

By the painless processes of using a slightly decreased weight of tin coating and shifting to terne a total percentage conservation of 15% in the tin required by can makers is being brought about. This percentage decrease, however, is insufficient to make up for the increased need for cans, so that the total tin needed by can makers will probably not fall below the 1937 level.

The suggestion that, since beer was formerly packed in bottles, the tin beer can being a recent innovation, beer cans could be considered replaceable and the brewers could all go back to bottles, was not cordially received by can makers. They pointed out that some of the brewers who have adopted the can have dismantled all or part of their bottling line and that it would be a hardship upon this one class of can users to forbid them cans. Hence shifting back to beer bottles was not classed as a painless substitution by the can makers. However, it is stated* that only about 9% of the beer is packed in cans so the changeover has occurred only in a few instances. These few, however, use some 3/4 of a billion tin cans.

The comments by readers of a preliminary draft of this report included the following: "In a shortage of tin, the use of tin cans for packaging beer seems unwarranted, particularly in view of the fact that the glass industry is supposed to be very much overdeveloped. If a shortage of tin appears imminent, beer cans should go to the foot of the priorities list."

The can makers' attitude in vigorously planning to retain their beer can business as long as possible argues well for their will and ability to keep in the business of making usable cans, even if their supply of tin is stringently reduced, or even if they are forced to resort to black plate with lacquer coatings. The surplus capacity of the glass industry might well be utilized to relieve some of the

* Glass Packer - March, 1941.

pressure on the can makers in a shortage of tin, but the can makers can be counted upon to keep some sort of steel can in the running, even in the event of entire failure of the tin supply.

Some opposition even to feasible substitution, unless substitution is made compulsory, is to be expected, in view of the flat statement alleged * to have been made before the National Canners Association.

> "There is no substitute for tin. They have some substitute metal cans in Germany, and that may be all right for Germany, but you couldn't get Americans to eat out of them."

On the same page with this quotation is a statement taken from "Steel", that U. S. tin plate makers who are expanding their facilities contemplate using existing equipment, even if not conveniently located, rather than install new equipment in their own plants because of uncertainty as to tin supply and "the possibility of the development of lacquers and coatings which might supplant tin."

A middle view is taken in the statement of one large can maker in discussing the preliminary draft of this report. This says -

> "Unless the American public is willing to put up with containers by no means acceptable to the military forces, uncoated black plate is out of the picture; the tremendous difficulties with atmospheric corrosion of the plate, both before and after packing, make it so. Furthermore, with uncoated or untreated black plate there is a great deal of corrosion trouble between the time the plate leaves the steel mill and the time it arrives at the can factory. Any black plate used will have to

* Sheet Metal Industries, March, 1941 - p. 325.

carry an organic coating. Organically coated black plate has proven acceptable for certain industrial products, particularly those containing no water, but here again we encounter trouble in securing the types of organic coatings that are necessary to give satisfactory results over black plate. Such coatings must of necessity be more gas and vapor impermeable than those which are ordinarily used on tin plate. In many instances this involves the use of phenol formaldehyde, urea formaldehyde, and alkyd resins, and at present the shortage of phthalic anhydrid and formaldehyde is rapidly eliminating the use of such materials, at least for the time being."

"Most of the tin plate used in can manufacture is not given an organic coating. All black plate used will have to carry an organic coating. It follows, therefore, that a great deal more coating and baking equipment will be required if black plate is substituted for tin plate to any extent."

"Another important factor in the use of black plate is the necessity for chemically pretreating the surface of the plate before an organic coating is applied. This is imperative for any food product which is sterilized in the can, and as our information develops it appears more and more that for really satisfactory results the same will have to be done on all black plate. As far as I know there is not a steel mill in the country as yet prepared to properly pretreat the surface of the plate."

"Another factor to consider is that a great many products containing water which give absolutely no trouble from perforations or hydrogen swells in tin cans, even with light weight coatings, exhibit a marked corrosive action when packed in black iron. The trouble begins the moment the electrochemical protection afforded by tin is removed. We observe this corrosive action even when the cans have been carefully hand coated with a multiplicity of coatings. It must be borne in mind that there are not any organic coatings which are absolutely impervious at thicknesses compatible with can manufacture. I recently received some black iron cans from Germany packed with soup, sausage, and beans, and the condition of these on arrival well illustrates the corrosive effect of products not ordinarily considered corrosive when we think in terms of tin cans."

"The substitution of electrolytically coated tin plate appears somewhat simpler than the substitution of black plate, but here again the picture is not altogether rosy. Commercial usage has proven this plate satisfactory for a considerable number of industrial products containing very little or no water, and where any enamel or decorative coatings required do not have to be baked at a temperature exceeding 300°. With the unmelted coatings, however, we encounter difficulty where the enamel or decoration applied must be baked at temperatures in the neighborhood of 400°.

The difficulty arises in soldering. Furthermore, the light weight electrolytic coatings (0.5 lbs. per base box) do not offer the corrosion resistance that the present hot melt coatings do, unless an organic coating is applied over the tin coating. But, once it is necessary to apply organic coatings we encounter the difficulties from soldering, and the necessity for tremendously expanding enameling and baking facilities."

While this brings out the difficulties, it also indicates that, if steelmakers are instructed in the proper cleaning and pre-treatment of sheet at the steel mill; if suitable protection, as by hermetic sealing of packages of prepared plate, is given to the sheet in transit and in storage at the can plant; if supplies of materials for coatings are broadened, (which is a matter of chemical plant capacity rather than of ultimate raw materials) and if equipment for coating and baking the lacquers is provided at the can plants, it is not impossible to utilize un-tinned stock for a considerable proportion of cans, even though under normal economic conditions there is little incentive to take these steps.

It further shows that if electroplating facilities are extended, and coating and baking equipment supplied, thin electrolytic coatings can be made to serve for another considerable portion. The problem of "decorative" coatings may be disregarded, only protective coatings need be considered.

It is not impossible, though it would be awkward, to deposit a thin electrolytic tin coating inside a welded can body. Thus avoiding soldering difficulties and the use of solder.

And, for those applications where neither the un-tinned nor the lightly tinned steel container can be suitably developed in a suitable time, glass containers can be used.

Except where glass is substituted, avoidance of tin by the canning industry will be neither cheap nor painless, but by going to the necessary expense and trouble, a large measure of avoidance could be accomplished.

A representative of another can company comments that it might well be emphasized that the use of thin electrolytic coatings offers an "immediately practical method offering substantial conservation with minimum hardship."

Still another can company comments, however, that because of the limited production of electrolytic plate at present, this is not an immediate answer.

Reclamation of Tin From Used Tin Cans

Since a special report has been made on this topic, reference need only be made here to the sound conclusions of that report, that such reclamation is only feasible as a non-economic measure of last resort, which at best, could reclaim only a small tonnage, insufficient to improve the situation appreciably. All-out substitution would be invoked before such reclamation were resorted to, save in a few localities where conditions are not as unfavorable as those that generally obtain throughout the country.

Roofing Terne

Terne plate for roofing is very heavily coated sheet, the coating being 5 to 15 times as thick as that on terne for cans, so that while the tin content is only 20-25%, the total amount of tin is considerable. Experiments are under way on the cleaning of steel so that a tin-less, or very low tin lead costing will adhere. An adherent lead coating should serve practically as well as the terne coat for roofing, so such developments should be fostered. Use of a preliminary coating of ordinary terne followed by pure lead, has been suggested. Heavily lead-coated sheet would have special applicability as substitute for galvanized steel while the zinc shortage lasts,

SUMMARY

Summing up the situation, painless conservation such as has been introduced by the can makers will reduce the need for new tin by 10 or 15% of the 50 to 60% of the total likely to be used for cans in 1941 - i.e. 5% to 9% on a percentage basis.

Some 16% of the new tin is now taken by solder, almost all of which could be rather painlessly substituted by Pb Ag, possibly by other solders, much of this without too great increase in cost.

Tin-base babbitt is more difficultly replaceable in that good engineering and, of ten, considerable redesign are required to utilize other types of babbitt, bearing metals, or bearings.

Tin bronze is substitutable in almost every application, with the exception of the leaded bearing bronzes of the 80 Cu 10 Sn 10 Pb type.

Considerable conservation and some substitution can be made in the case of articles of copper and of steel (aside from tin plate) tin coated by hot-dipping, but the applications are so numerous that no sweeping statement can be made.

Solid tin tubing, collapsible tubes and foil likewise have a wide range of uses. In most of these, other materials are substitutable but in a few cases the specific properties of tin are needed and substitution would work a hardship. Reclamation of used tin and lead-tin collapsible tubes is advisable.

Tin oxide as opacifier is replaceable, tin in galvanizing probably unnecessary, and pewter can be classed as non-essential.

The U. S. Bureau of Mines* has estimated that a 25% reduction in total tin consumption could be brought about without particular hardship. Indeed, the two items, the present reduction in tin for can making purposes plus the large replacement of PbSn solders by Pb Ag solders, which appears feasible , alone amount to about that reduction in new tin.

By all-out substitution in every possible line, which would require construction of much special equipment, and at least temporary hardship, it is believed that at least three-quarters of the tin ordinarily used could be replaced.

This means that the domestic smelting of Bolivian ores will supply most of the irreducible minimum, The stock pile needs to be brought to such size that the inevitable delays in building new equipment and adopting new techniques may be bridged over. The stock pile situation was dealt with in the reports of the Tin Sub-Committee

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* Info, Circ 7154, March, 1941.

to the Mineral Advisory Committee of the Army and Navy Munitions Board, dated April 26, 1939 and December 11, 1939. The application of conservation and substitution may be necessary, in advance of actual emergency, in order to build the stock pile rapidly to the recommended height. The belated adoption of the stock-piling idea may thus be somewhat made up for.

It is noteworthy that, useful as tin is, the properties for which it is used are not, in general, as specific as is the case with manganese to control sulphur and make steel rollable, or with chromium in conferring resistance to corrosion upon steel. Those materials themselves, in the present state of knowledge, have to be used, no other materials are effective substitutes.

In the case of tin, our lack of domestic supply, coupled with its cost, have led to steady consideration of and experimentation with substitutes so that a large background of research information is at hand on them, In some cases this background is already nearly sufficient, as in the case of solder, to warrant full assurance of feasibility of substitution. In others , continued and amplified effort is needed before that stage can be reached.

Among the problems whose solution would be most fruitful in allowing conservation or substitution of tin are:

Development of solderable, pore-free, very thin electrolytic tin coatings and the use of such plate in the can making industry.

Development of stamping end welding of can bodies and of lacquer coatings to allow the use of black plate in cans, rather than of half-way measure s.

Development of a tin-less bronze compatible with lead, for machinability and especially to replace 80 Cu 10 Sn 10 Pb bearing bronze, incidentally to replace leaded brass screw stock during a zinc short age.

Development of tin-free or low-tin babbitt for replacement of tin-base babbitt, especially in repair of thickly-lined bearings on present machinery.

Continued development of tin-less substitutes for solid tubes, collapsible tubes and foil.

Development of pure lead or low tin lead coating of roofing terne.

On the whole, tin is somewhat more replaceable and less indispensable than is commonly supposed. Large industries have been built around the use of tin, and a, change to a tin-less economy would scrap much equipment and require installation of much new equipment. Never-the-less, even in a tin-less economy, we could sti11 can foodstuffs, make bearings suitable for engines and machines, and join materials that are now soldered mith Pb Sn solder. Strong , corrosion resistant, tin-less bronze castings and wrought products would be available. Once the adjustments were made and the new equipment and techniques provided and used, a lack of tin would then be more irritating than serious.

From the comments received from members of the Metals group, can makers, and others, on a preliminary draft of this report, the compiler concludes that, on the basis of the engineering functions served by tin as a coating or in alloys, the most ready means to bring about further conservation and substitution of tin, in actual emergency, or in order to facilitate the accumulation of an adequate stock pile would be:

1. Drastically, but progressively, and with care to give a reasonable time for acquiring skill in the use of higher melting solders and in other joining methods, decrease the amount of tin allowed for solder, This substitution involves a minimum of equipment modifications. Complete abandonment of PbSn auto body solder could be made promptly. The solder problem is so much more readily solved than those of the other major uses for tin, that a general ban upon use of PbSn solder, to be raised in specific cases only upon a showing of engineering necessity, might well be contemplated. Secondary tin till serve for the exceptions, so new tin might ultimately be completely barred. Large steps toward this could be taken promptly, Many users of solder are already accustomed to some use of the PbAg solders. Other users should acquire this familiarity promptly.

2. Expand the use of glass containers where feasible, with beer and "Class 1" food products as examples. Official bans upon a few such selected uses may be justifiable. In general, official bans would be less likely to pick the correct applications of substitutes than would action by the industry itself, as brought out just below. However, it should not be forgotten that substitution of glass for tin cans saves steel as well as tin.

3. Progressively decrease the total amount of tin allotted to the can-making industry, thus forcing, but giving time for, an orderly development in, the substitution of thin electrolytic tin plate and of black plate for cans. The can-makers and the National Canners Association know the particular products which are most amenable to packing in containers made with less tin, out of the hundreds of products now packed in the usual tin can, and are doing much research on such

replacement. A greater increase in such research and especially in its practical application would be expected under the spur of necessity than if the matter is allowed to drift. The time to get experience in the making and actual use of cans with little tin and with no tin, and for accurate evaluation of their applicability is now rather than after a sudden shortage has developed. It requires so much detailed knowledge to determine the applicability of substitution in a specific case that instead of ordering substitution in specific cases, limitation of total supply, leaving its distribution among specific canning applications to those with most information, seems preferable. Because of the need for new equipment, this sort of substitution cannot be made over-night, but because of the time lag in building equipment it is important that the **other time lag**, in finding out what equipment would be needed, should be cut down by very active work right now. The 1939 report to the Army and Navy Munition Board stated "any program of substitution should be worked out carefully in advance so that when an emergency arises the tin available can be used to the best possible advantage." This advance knowledge needs to be secured with the utmost promptness in view of 1941 conditions.

4. Restrict the use of new tin for cast or wrought bronze where silicon bronzes and the like are applicable. Locomotive bearings, some rolling mill bearings, 80 Cu 10 Sn 10 Pb bearings (or 80 Cu 8 Sn 12 Pb, the composition of the British and German analogs of 80-10-10) would be definite exceptions, and some other cases of like nature would crop up. Bronze substitution does not require new equipment.

5. Put emphasis upon adapting the design of bearings in new types of machinery and new models of old types to use lead-base rather than tin-base babbitt, to use thin rather than thick babbitt linings, or to use other than babbitt bearings.

6. Make drastic reduction in the amount of tin allowed for solid tin tubes, for collapsible tubes and invoke practically complete avoidance of tin-foil for wrapping purposes.

7. Arrange for almost complete elimination of use of tin oxide as opacifier, complete elimination of tin for pewter and probably in galvanizing.

8. Watch the use of tin in "tinning", i.e., applying protective coatings to other than tin plate, since this takes some 3000 tons of new tin. This, and some analogous applications, are so varied and some of them so difficultly replaceable that considerable care is needed in clamping down on these uses. Due to scarcity of other metals used as protective coatings, this use is likely to build up rather rapidly unless watched and held under some restraint, but such uses, if balanced by adequate savings of tin in other applications, help to relieve other tight situations.

9. In all ways possible, foster early acquaintanceship of tin users with the intimate details of the behavior of substitutes so that when necessary, their utilization may be prompt. Stock piles of immediately applicable information will serve, in part, in lieu of a stock-pile of tin. The accumulation of stock-piles of knowledge should be hastened.

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