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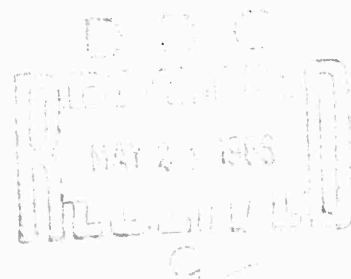
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TRENDS
IN USAGE OF
SILVER

MATERIALS ADVISORY BOARD



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TRENDS IN USAGE OF SILVER

Prepared by

THE COMMITTEE ON TECHNICAL ASPECTS OF CRITICAL & STRATEGIC MATERIALS

MATERIALS ADVISORY BOARD

Division of Engineering - National Research Council

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FOREWORD

The intent of this report is to assess the changing applications of one of a group of materials (together with supply prospects), in a manner to be of assistance to a number of government agencies concerned with the adequacy of materials for critical military and civilian requirements. The focus is on changing technical requirements. From the conclusions reached, actions by the government such as the acquisition or disposal of government stockpiles might follow, but such decisions are necessarily influenced by other considerations, such as the economics of the situation. This report aims to answer the questions to only one part of the problem--prospective changes in use. Decisions on what to substitute for a scarce material are based on factors such as cost, production schedule, fabricability, and availability of property data as well as on purely technical considerations. Therefore, only limited comments could be made on substitutability.

Beyond the limitation noted above, a finite ability to predict the future should be appreciated. A worrisome aspect of materials management lies in the totally unexpected invention which generates a new requirement or renders an old one obsolete. Just as a committee cannot invent, neither can it foresee true invention. The best that can be hoped for are extrapolations based on recent discoveries and on technical and commercial trends. This is what is contained in the report that follows.

For the sources of data on material availability, principal credit is due the Bureau of Mines. These data have been augmented by input from metal producers who were asked to help, and from information available to the Committee members.

The report received the benefit of review by the entire Committee, by the sources of input from industry and by commodity specialists at the Bureau of Mines. Committee members were asked to serve as technical experts, and not as representatives of their company. This, together with the variety of inputs and reviews has made possible what are believed to be balanced presentations.

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ABSTRACT

This report is one in a series of five (the others being beryllium, molybdenum, platinum, and tantalum), in which the influence on applications of changing technology is explored.

Little concern is expressed regarding present stockpile specifications, but it is noted that much Treasury silver is of low grade and unusable for many applications without refining. A possibly inadequate domestic refinery capacity may limit the rate at which this metal can be used.

The future supply of silver appears to be inadequate. While no significant new applications are known, despite price increases, consumption continues to climb.

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Introduction

Silver has been known and prized since prehistoric times. "No one ever yet has had so much silver as not to desire more; and if people have a superabundance, they hoard it and are not less delighted with so doing than with putting it to use." - Xenophon C. 353 BC. It would appear that this is no less so today, despite the fact that monetary and aesthetic uses have been surpassed by industrial uses. Silver coinage and silver tableware, and other decorative objects of the metal, are so prominent in the minds and the eyes of most lay people as to obscure the overriding importance of silver as an industrial commodity of critical technical importance. The traditional uses have outshone the technical ones, both literally and figuratively.

Photography, not only of the lay kind but of the strategic and industrial kind, is totally dependent on silver as the light-sensitive component of the film. Practically the whole flow of the nation's electrical energy is controlled and switched through electrical contacts made of silver. Silver batteries power our torpedoes, rocket missiles, aircraft and spacecraft, and silver brazing alloys or solders join many of the metal parts of these and of civilian hard goods such as refrigerators, air conditioners, auto parts, and the like.

The fact that new production of silver, worldwide, fails to cover current world industrial consumption has been widely known and given much publicity of late. The reality of the shortage hardly needs detailed documentation here. A few statistics may serve to refocus the reader's attention in that direction.

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From the 1966 Minerals Year Book - U. S. Bureau of Mines

	<u>Millions of Troy Oz.</u>					
	<u>1961</u>	<u>1962</u>	<u>1963</u>	<u>1964</u>	<u>1965</u>	<u>1966</u>
World Mine Production	236.9	245.5	249.7	246.6	254.1	253.0
Free World Industrial Use	239.5	247.8	257.2	290.9	333.6	390.2
Free World Coinage	137.1	127.1	167.0	264.5	374.7	107.7
U.S. Mine Production	34.7	36.8	35.2	36.3	39.8	43.7
U.S. Industrial Use	105.5	110.4	110.0	123.0	137.0	183.7
U.S. Coinage	55.9	77.4	111.5	203	320.3	53.8

From the 1966 Review of the Silver Market - Handy & Harman

	<u>1962</u>	<u>1963</u>	<u>1964</u>	<u>1965</u>	<u>1966</u>
World Production					
Ex. Communist	208.6	215.4	217.2	223.2	231.0
World Industrial Use					
Ex. Communist	258.5	260.7	304.2	346.6	356.5
Coinage	127.4	166.4	267.1	375.6	107.4
U.S. Production	36.3	35.0	37.0	39.0	42.0
U. S. Industrial Use	110.0	110.0	123.0	137.0	150.0
North American Prod.	108.2	107.6	109.2	111.2	117.0
North American Use	118.1	117.8	132.1	147.0	160.6

Note the sharp decline in coinage use in 1966.

"World industrial consumption over the past ten years has increased at an average annual rate of about 6 percent. If we project this same rate of increase over the next ten years, a figure of about 590,000,000 ounces will be reached by 1975. The recent coinage change by our government will undoubtedly be carefully studied by other countries still

using silver in their coins, and it seems probable that coinage uses by these countries will decline in the future. In 1965 coinage requirements outside the United States amounted to about 54,400,000 ounces. For the sake of calculation, an estimate of 30,000,000 ounces by 1975 is perhaps reasonable. On the basis of these estimates, total world consumption for 1975, both industrial and coinage combined, would amount of 620,000,000 ounces. This does not include United States coinage demand, although the present law provides for a silver half-dollar containing 40 percent silver. It is assumed either that Treasury stocks will be adequate to provide silver for the half-dollar for the indefinite future, or that a non-silver material will ultimately be adopted.

"New production over the past ten years increased at an average rate of only about 1 percent per year. However, higher price levels should stimulate more production in the future."¹

Many people knowledgeable about the production of silver hesitate to estimate the amount of increased production that various price increases might bring about. All are quick to point out that the bulk of the world's silver is produced as a by-product of base metal mining and smelting. The degree to which silver production in the U.S. is inelastically geared to base metal production may be seen in Table 1.

J. Kalliokoski and R. A. Whitaker² point out that roughly 25 percent of the free-world supply of silver comes from ores in which silver accounts for more than half the value. Detailed documentation of this information is in the Committee's hands; it has been summarized in the table on page 4.

J. Convey and N. S. Spence of the Department of Energy, Mines and Resources, of Canada, join Kalliokoski and others in the opinion that increased prices for silver will fail to stimulate increased silver production in proportions anything like that of the price increases.

"If we assume for the purpose of this discussion that new production will increase at the rate of 3 percent a year over the next ten years,

TABLE 1. UNITED STATES MINE PRODUCTION OF SILVER, ACCORDING TO RECOVERABLE VALUE OF ORE*
(Excludes Mines with Annual Production Below 100,000 Oz)

Class of Ore (Percentage of Total Value Con- tributed by Silver)	Percentage of U.S. Total				Silver Produced (oz)	By Classes	Percentage of U.S. Total			
	By Classes	Cumulative Per Cent		By Classes			Cumulative Per Cent			
		0 to 100	100 to 0				0 to 100	100 to 0		
			1963				1962			
0 to 10	10,190,763	30.40	30.40	100.00	12,229,104	34.77	34.77	100.00		
10 to 20	6,958,367	20.76	51.16	69.60	7,017,505	19.95	54.72	65.23		
20 to 30	1,924,452	5.75	56.91	48.84	865,827	2.46	57.18	45.28		
30 to 40	252,555	0.75	57.66	43.09	280,107	0.80	57.98	42.82		
40 to 50	3,586,952	10.70	68.36	42.34	3,775,741	10.74	68.72	42.02		
50 to 60	...	...	68.36	31.64	...	...	68.72	31.28		
60 to 70	...	...	68.36	31.64	207,912	0.59	69.31	31.28		
70 to 80	267,853	0.80	69.16	31.64	...	...	69.31	30.69		
80 to 90	9,841,311	29.36	98.52	30.84	9,936,182	28.25	97.56	30.69		
90 to 100	494,827	1.48	100.00	1.48	856,130	2.44	100.00	2.44		
0 to 100	33,517,080	100.00	...	...	35,168,508	100.00	...	...		

*United States Bureau of Mines Information Circular 8257, 1965.

Free World Production by Classes of Ore

	<u>Ag Million Oz.</u>	<u>% of Tabulation</u>
Copper Ores	18.814	10.82
Copper-Zinc Ores	3.641	2.09
Copper-Lead Zinc Ores	30.109	17.32
Gold Ores	5.119	2.94
Copper-Nickel Ores	1.818	1.05
Lead-Zinc Ores	62.617	36.02
Tin Ores	4.5	2.59
Silver Ores	<u>47.238</u>	<u>27.17</u>
TOTAL	199.395	

then our estimate of world production of silver by 1975 will amount to approximately 300,000,000 ounces. This would leave a deficit of 320,000,000 ounces between total demand and new production by 1975. If we accept this as a reasonable estimate of the scope of the supply problem in the years ahead, future price levels will be determined by the extent to which the growing annual deficit can be filled from secondary sources."¹

Increased prices are most likely to cause these effects in the order listed:

1. Bring out offerings from existing hoards.
2. Restrict usage to the availability supply (current production plus hoard offers).
3. Increased new production (amount debatable).

The figures for industrial usage or consumption are net after deducting current scrap recoveries. Thus silver shipments to tableware producers exceed their net consumption by the amount of process scrap they return for remelting. However, old silverware that is gathered from users for melting is termed "salvage" or secondary silver and constitutes a source that helps make up the deficit between net consumption as just defined and newly mined production. The same rationale is applied to the other categories of use. Often, whether a particular lot of returned

silver is counted as salvage or as recycled scrap is an arbitrary matter, sometimes depending on whether the particular processor happens to be a salvager or a manufacturer. All of the data are, therefore, somewhat ambiguous.

Industrial usage has exceeded new production only since about 1958. Before that time, ever since industrial consumption was first reckoned with, the reverse had been the case. For years the unused silver went into monetary stocks or coins and into private hoards. Relatively little of the world's silver has ever been really lost; however, the rate of loss today is probably higher than heretofore. It is these hoards and monetary stocks that will be looked to in order to compensate for much of the deficit between new production and use. There are some 1,900,000,000 ounces in the U.S. subsidiary coin and 370,000,000 ounces in silver dollars outstanding and there were 592 million ounces of silver in the Treasury, including 437 million ounces backing silver certificates, as of December 31, 1966. Besides the U.S. sources of secondary silver, there are other nations' coinages yet to be demonetized. Canada has just announced the change of 10¢, 25¢, and 50¢ coins from 80 percent silver to pure nickel. Recent usage of silver in these coins has been about 20 million ounces per year. The total silver in circulation in Canadian coins is about 150 million ounces.

I. Consumption by Application

The principal uses of silver in the U.S. are:

<u>Category</u>	(a) Percent of Total	(b)
Photography	32	26
Electrical and Electronic (including batteries)	31	25
Silverware and Jewelry	17	30
Brazing Alloys and Solders	13	10
All Other	<u>7</u> 100	<u>9</u> 100

(a) Ratios derived from information submitted to the House Subcommittee on Mines & Mining, June 6, 1965, by the U.S. Department of Commerce.

(b) U.S. Bureau of Mines, November 1967.

A. Photography

This principal consumer of silver is, as far as is known, without anything approaching a satisfactory substitute. It is true that certain copying processes, such as Xerography, Thermofax, etc., do not use silver, but their potential to save large amounts of silver seems limited. It is known that intensive work on silver substitution is being done. Most of the present candidates are too slow for ordinary photography. One authority said: "We've got two or three lines of investigation that look promising and in the course of time we'll expect that some photographic uses will be supplied with materials other than silver." Another authority within the same organization was queried directly and replied that if silver became scarce: "It seems likely that there would be a corresponding reduction in our output of photosensitive materials with production concentrated in those items of greatest importance at the time of the emergency." The preeminence of silver salts as photographic receptors is not the result of any unusual primary sensitivity to illumination, but is due to the fact that they undergo an unusual secondary amplification process called development which may multiply by about 10^{11} the effect produced by the original light exposure.

The copying processes just mentioned do not rely on this kind of chemical amplification; the bulk of the work is done by a rather drastic primary exposure. Nor do these processes match the photographic capability of storing about 10^8 bits of information per square centimeter.

A more immediately fruitful effort than trying to find a silver substitute might be to extend the use of known and practical means of recovering photographic silver. Much of the silver in black and white film and most of the silver from colored pictures turns up in the hypo solution after development. Recoveries from this source, and from the burning of photographic film and from the processing of emulsions stripped from film now yields in the order of several million ounces of silver per year. Some of this is deducted in determining net photographic usage, and some appears as salvage or secondary silver in the statistics. As silver prices rise, there will be an economic stimulus to extend this activity.

Silver nitrate is the starting chemical compound for photographic preparations and there is no present difficulty in obtaining silver of suitable purity for the photographic grade of silver nitrate. At one time, a specially refined grade of bullion, low in bismuth and a few other heavy elements--the so-called "Nitrate Grade"--was in regular use at a small price premium. This is no longer the case since silver nitrate producers have learned to remove these objectionable impurities by processes involving photo reduction, precipitation and absorption. However, any gross amount of impurity in the silver supply would impose added costs and inconvenience upon the nitrate producer. Thus, if coins were to be used in the production of nitrate, without intermediate refining, the 10 percent copper content would not be welcome, but probably could be coped with.

B. Electrical

The next, and almost as important user of silver, is the electrical industry including batteries. Batteries should be considered apart from other electrical uses as they share no common technology; they will be discussed separately.

Silver and silver alloys are almost universally used for the contact surfaces that make and break intermediate and heavy electric currents. Generally, a silver button or a silver rivet is attached to a copper or other base metal switch arm or conductor. The use of silver is preeminent because of its corrosion resistance in combination with high electrical conductivity. The conductivity is the highest known, some 2 to 6 percent better than the copper standard, depending on the purity, temper, etc., of the silver. The importance of this marginal superiority is often exaggerated; the crucial characteristic is the ability to resist oxidation, even at elevated temperatures. The conductivity of copper, for instance, is adequate, but were it used instead of silver, switch life and reliability, i.e., surety of making a contact, would take a drastic drop as the copper surface oxidized. An oxidized contact interface increases resistance which increases heating which accelerates oxidation, and so on to destruction.

If a real pinch on silver occurred, some use of silver in very light current contacts, and in "dry"* circuits, that should be of noble metal (gold, platinum, palladium, or rhodium) or of thin coatings of these metals, could be eliminated by directive. The use is not believed to be substantial. Some silver contacts could be designed with copper, tungsten, molybdenum, or carbon, taking such necessary steps as increasing the size and adding a heat sink or by provision for cooling, increasing contact force and providing wiping action to abrade away oxide films. These alternate procedures and materials are usually costly and less satisfactory in performance.

A more practical approach is to extend the use of bimetals, i.e., base metal--noble metal composites, reserving the use of silver only for those places where it is functionally required. A substantial amount of this is done now, and economics dictate the extent of the use. A working surface of sufficient depth to outlast the anticipated wear and arc erosion is all that is needed. A high copper base substrate could replace more silver whenever either price or availability so dictates. In normal times the cost of the silver saved must be more than the extra cost of making the bimetal.

Two large representative manufacturers of electrical contacts were queried directly about what would be the consequences of a severe curtailment of silver over a three-year period. One estimated that up to 15 percent, and the other up to 25 percent of silver usage could be saved by redesign without serious consequences to the quality of the devices. However, this would be accomplished only with a very large expenditure of engineering effort. A 50 percent curtailment would have a severe impact on the industry, requiring extensive redesign, de-rating, and probably curtailment of the output of new devices. For most devices, there appears

* A "dry" circuit is one carrying a very low voltage micro-current, frequently idle for long periods, hence particularly susceptible to failure by tarnish films on the contacts.

to be no good substitute for silver, and economic pressures have already brought about its frugal use and conservation. A ninety percent reduction would be unmanageable.

Salvage of electrical contacts, once they are installed in electrical equipment, is a fairly long cycle proposition. Where the scrap goes to the copper smelters, silver salvage follows. If it goes into steel, the silver will be lost (as will the tramp copper).

Current quality of newly refined silver is adequate for the electrical contact business. Some coin silver could be used directly, but most would have to be refined. Some of the Treasury stocks have a lead content that is objectionable.

The miscellaneous electrical, electronic, or noncontact uses are so diverse as to make much generalization impossible. Many of these uses require a grade of silver more pure than standard commercial grades. Few of them could be substituted by a base metal, and gold or platinum group substitutes might not be as available as silver, even if they would work as well which, in many cases, they would not.

Solid state switching with controlled silicon rectifiers or power transistors eventually will replace many silver contacts; their effect is already being felt and could be accelerated if need be. Their construction usually requires gold for attachment. However, the use of silver contacts has grown in the face of increasing acceptance of solid state devices. The five-year estimated growth rate is about 4.7 percent per year.

C. Electric Batteries

The conductivity and corrosion resistance of silver and the negative heat of formation of silver oxide make silver and its oxide ideal cathodes and cathode depolarizers respectively. The result is a larger energy storage capacity per unit weight or per unit volume than any other present practical system.

COMPARISON OF SECONDARY BATTERY SYSTEMS^(a)

	<u>Watt-Hours per pound</u>	<u>Watt-Hours per cu. in.</u>	<u>Maximum Life (years)</u>	<u>Cost (arbitrary units)</u>
Lead Acid (industrial type)	10.0	1.2	7.0	1.0
Nickel-iron	11.0	0.7	11.0	1.7
Nickel-cadmium	14.0	1.3	10.0	3.0
Silver-zinc	40.0	3.2	1.5	5.0
Silver-cadmium	27.0	2.3	2.5	5.5

(a) Values must be considered approximations, because precise values depend on battery design and usage.

The short life and the cost preclude the use of silver in most applications except military and aerospace. About 90 percent of the silver battery output is bought by the military. It is assumed that no restrictions would be put on this use and that silver use would be restricted elsewhere to make the metal available for batteries.

Present newly refined silver is satisfactory. Coinage would require prerefining as would some old Treasury silver with high lead. The salvage of silver from the battery industry is high, but would deteriorate in a war situation.

Public information is inadequate to estimate changes in silver consumption in batteries. It was estimated to be 10,000,000 ounces in 1965.

D. Silverware and Jewelry

Much of the functional and aesthetic value of solid or sterling silver could be achieved with silver electroplate or bimetal like Sheffield plate. However, there is a "status" attached to sterling that would stand in the way of the willing acceptance of plate at this time.

It must be assumed that as a practical matter, the people could be fed from stainless steel tableware, and that if need be, much of that silver could be made available for nonsubstitutable uses. However, many

people make their living in this field and the dislocations could be serious if a suitable alternate material were not available.

Much silverware production could use coin for direct melting provided that enough fine silver could be added to raise the silver content from 90.0 to 92.5 percent; and also provided that the coins are well enough sorted to keep out any sensible amount of the new cupro nickel clad coins. Some Treasury stocks have objectionable lead content for this use. Silverware production is likely to follow disposable income. The five-year estimated growth rate of 4.2 percent per year.

E. Brazing Alloys

Some silver could be saved out of current brazing alloy usage. Some alloys of high silver content, established long ago, continue to be used - unnecessarily - mostly because of inertia. They work, and the cost of establishing the reliability of a new alloy outweighs prospective saving from a lower silver alternative. To fully realize this saving would probably require some fiat by a regulating authority.

If too much silver is squeezed out of brazing alloys, the consequences are higher working temperatures, increased processing costs for many classes of hard goods, and spoiled work. About 10 to 15 percent of silver use could be saved if users would accept the resulting higher working temperatures and the collateral higher costs. Higher prices will tend to bring this about. However, in an emergency much brazing alloy is used by the military and leading consumer uses are severely curtailed, i.e., refrigerators, air conditioning, and other consumer durables.

Coin can be melted directly into most brazing alloys. The lead content in some Treasury stock is objectionable.

The estimated growth rate is about 5.5 percent per year.

F. All Other

The relatively small usage and the wide variety would not justify study at this time. There is no emerging, large, new use for silver now in sight which is likely to upset the forecasts made above. Nuclear reactor

control rods of silver indium cadmium alloy (80% Ag) are of some growing importance, but there are other neutron absorbers available. The use is in the order of hundreds of thousands of ounces.

II. Secondary Metal and Domestic Refining Capacity

Let us now imagine that this year all foreign sources of silver are cut off, that Treasury stocks have been previously dissipated and that the deficit is to be filled first by melting silver coinage and secondly by dipping into an as yet undefined stockpile possibly derived from Treasury stock. Silver coinage could be used without refining for about 50 percent of the requirement for silverware, and perhaps 90 percent of the requirement for brazing alloys. We have estimated the usage of direct melted coin below the maximum possible for sterling so as to allow some pure silver for electroplate. Perhaps 10 percent of electrical contacts could be made direct from coin. Thus direct melted coinage would furnish about 30 million fine ounces. Newly mined and refined silver would provide about 40 million ounces. This makes 70 million ounces leaving about 70 million ounces to be derived from the refining of coins and other secondary sources and the stockpile. How much secondary refining capacity is available? This is not a rhetorical question. Refinery capacity should be ascertained as it would be pertinent to the determination of both the size and the makeup of the stockpile.

The amount of high-lead silver stocks left in the Treasury is not known to the Committee. Much of this should be avoided in the stockpile. It is axiomatic that the higher the purity of the stockpile, the more versatile its uses can be.

Much of the current supply of electrolytically refined silver is of very high purity as it comes from the cell. The Treasury might well consider getting rid of its high-lead stocks and exchanging some of its standard fineness stocks for higher fineness grades that are more widely usable.

Adequate ASTM specifications are either available or under preparation to cover both standard and high fineness grades. It is suggested that

appropriate government agencies should inquire about the availability of secondary refining capacity, the extent of high lead content Treasury stocks, and the amount, if any, of high fineness bullion on hand.

III. Substitutes

Substitutes as particularly related to each product have been discussed above. Apart from the aesthetic uses such as tableware and jewelry which could be functionally replaced by stainless steel (if available) there are no good substitutes for silver for any of the technical industrial applications. In the face of a severe silver shortage, photographic film production would simply be curtailed to fit the supply. Electrical contacts might do with 75 percent to 85 percent of the normal requirement, after which production would be curtailed. Brazing alloys might have 10 percent of the silver content squeezed out before production would have to be cut. Altogether about 25 or 30 percent of the total use might be substituted (depending somewhat on whose figures are preferred on page 6) at the very outside.

IV. Conclusion

Silver is of critical importance to our industrial well-being in both war and peace. Its current new production is far short of industrial usage, U.S. and worldwide, but less imbalanced on an all-North American basis. There is sufficient silver above ground in the U.S. in monetary and private hoards to take care of at least 14 years industrial use at the 1966 rate. There are, then, two problems: What to do about silver 20 or so years hence, which is not within the scope of this report; and what to do about silver in an early emergency. There are adequate statistical information and specifications to enable a good judgment to be made on the size and quality of a stockpile excepting for one aspect; we do not know that refining capacity could be devoted to the refining of coins, high-lead Treasury stocks, and other substandard grades of silver that will be drawn from hoards in both normal and emergency times.

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This report is one in a series of five (the others being beryllium, molybdenum, platinum, and tantalum), in which the influence on applications of changing technology is explored. Little concern is expressed regarding present stockpile specifications, but it is noted that much Treasury silver is of low grade and unusable for many applications without refining. A possibly inadequate domestic refinery capacity may limit the rate at which this metal can be used. The future supply of silver appears to be inadequate. While no significant new applications are known, despite price increases, consumption continues to climb.		

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