Technical Options for Conservation of Metals: Case Studies of Selected Metals and Products

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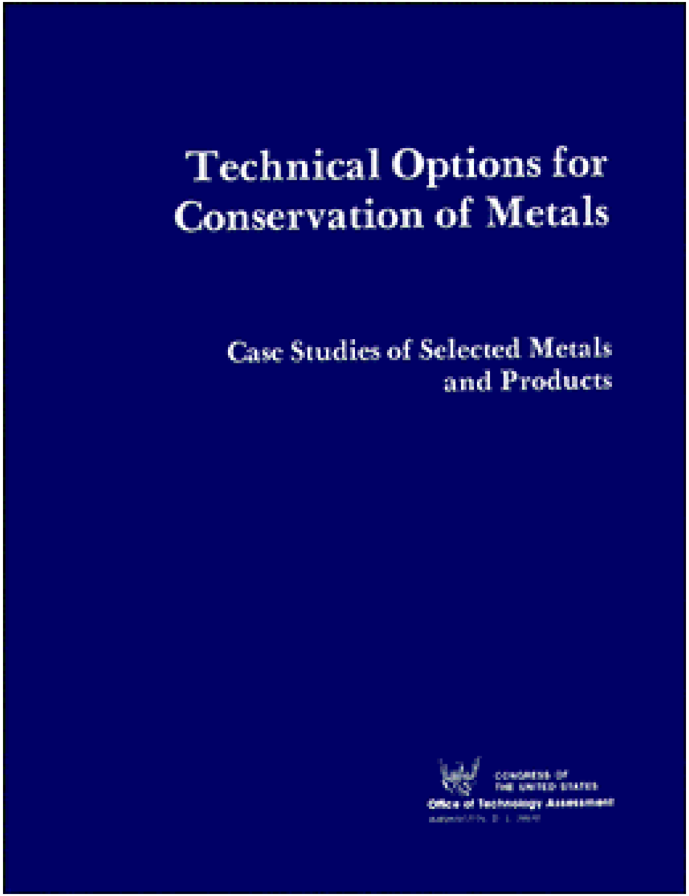

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Foreword

The shortages in many critical metals and other materials that the United States has experienced in recent years, along with its increasing dependence on foreign sources of supply for those materials, has intensified interest in the prospects for making less wasteful and more efficient use of materials.

This study explores the kinds and amounts of waste that occur in this Nation's use of eight critical metals and the technical options for reducing that waste. The eight metals studied are: iron, copper, aluminum, manganese, chromium, nickel, tungsten, and platinum. In their levels of import dependence and in other respects, these metals are a representative sample of commercially important metals.

This study was requested by the Committee on Commerce, Science, and Transportation of the U.S. Senate. It should provide useful technical information for all interested in more efficient use of materials.

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INTRODUCTION

The shortages in many critical metals and other materials that the United States has experienced in recent years, along with its increasing dependence on foreign sour-cm of supply for those materials, has intensified interest in the prospects for making less wasteful and more efficient use of materials. This report explores the kinds and amounts of waste that occur in this Nation's use of eight critical metals and the technical options for reducing that waste. The eight metals studied are: iron, copper, aluminum, manganese. chromium, nickel. tungsten, and platinum. In their 1evels of import dependence and in other respects, these metals are a representative sample of commercially important metals.

Metals are wasted, or lost, in two different ways: 1) amounts of metal are not productively used at various points along the materials cycle, from mining of ore to product disposal, and 2) excess amounts of metal are used in the materials cycle for product manufacture. The study identifies, for each of the eight metals, the levels at which each kind of waste occurs at major points of the materials cycle. In general, the study finds that the greatest waste occurs in product use and disposal rather than in metal extraction and processing or product manufacturing.

Of the many options available to reduce losses and reduce the use of excess metal, the study concluded that product remanufacturing, reuse, and repair (collectively known as product recycling) offer the greatest leverage for saving materials and energy. Product recycling already exists in several areas, such as auto parts, furniture, typewriters, and aircraft. But additional incentives are needed to encourage development of the aftermarket industry necessary for widespread recycling.

Perhaps of even more interest at this time, however, are options to improve materials availability during critical situations, such as import embargos or disruption of transportation facilities or supply shortages. Options considered include the establishment of a governmental contingency planning function, a public data system, a private sector contingency market for essential metals, and research and development on metal substitution.

* * * * *

This study was requested by the Committee on Commerce, Science, and Transportation of the U.S. Senate. The request was prompted by the following three factors:

First, the 1973 OPEC oil embargo demonstrated the risks of U.S. dependence on foreign energy resources and focused attention on the possibility of similar problems with mineral resources for which the United States is also heavily import-dependent. Second, in 1973-74, the increased demand for materials due to economic recovery from the 1969-70 recession led to supply shortages for a wide range of metals, thus generating concern among U.S. industrial consumers about the reliability of future supplies.[1] Third, U.S. per capita consumption of minerals has grown to more than four times the world average, prompting renewed attention on how to reduce consumption through conservation.

The study focused only on metals. Other materials might well have been considered, such as chemicals, wood, and plastics. But at the time this study was initiated, metals were shortest in supply. The eight specific metals selected for detailed analysis are listed in figure 1. The three major criteria used in selecting these metals were: level of import dependence, degree of importance to American industry, and the nature of use (e.g., volume, price, product applications). As a group, the eight constitute a reasonable cross section of commercially important metals. Most are substantially imported, as indicated in figure 1. However, while the group of eight is representative, other metals, such as tin and cobalt, constitute important omissions.

This report does not include detailed discussion of conservation options for recovery of metals from municipal solid waste, the subject of another OTA

[1] See app. C for a detailed discussion.

report—*Materials and Energy From Municipal Waste*, July 1979, OTA-M-93, Nor does this report give detailed consideration to the full range of impacts of conservation options.

Figure 1 .—Metals Selected for Study

Metal	Net import reliance[a]	Typical use
Iron	29%	Base metals used in major components of many manufactured products
Copper	19%	
Aluminum	93%	
Manganese	99%	Used primarily as alloying elements in other basic metals
Chromium	92%	
Nickel	77%	Used both as basic metals and alloying elements
Tungsten	50%	
Platinum[b]	91%	Precious metal used in small amounts in specialized products

[a] Net import reliance = imports minus exports plus adjustments for government and industry stock changes 1978 data from U S Department of the Interior, Bureau of Mines, *Mineral Commodity Summaries 1979* pp 4-5

[b] Refers to the platinum group metals, which Includes platinum palladium rhodium ruthenium, iridium and osmium

SOURCE OTA based on data from U S Bureau of Mines

TECHNICAL OPTIONS FOR REDUCING WASTE

Technical Options for Reducing Losses From the Materials Cycle

Losses from the materials cycle represent a major potential for waste. A typical materials cycle is shown in figure 2, which illustrates the total flow of a metal beginning with its extraction from the ground and processing of the ore to its manufacture, use. and disposal in the form of products. Losses can occur at each step in the cycle and particularly in the disposal stage where ultimately the product must be either stored, recycled, or discarded.

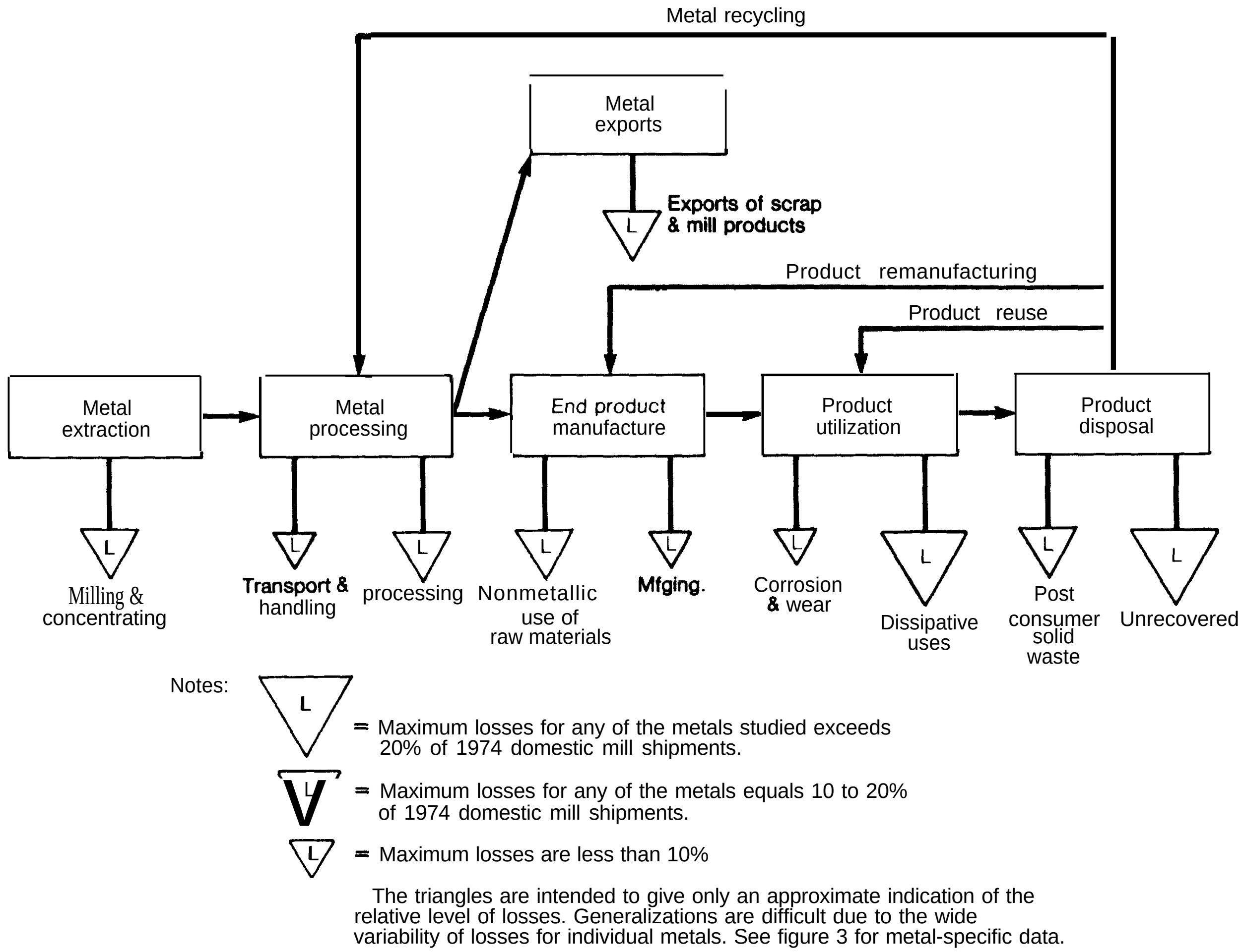
By tracing the flows of the eight metals through the materials cycle—from mining to disposal—the total losses for each metal were identified. Losses were calculated by subtracting the output at each stage of the materials cycle from the input. For example, the losses in processing aluminum were calculated by subtracting the output, mill products (7.2 million short tons) and mill scrap (5.8 million short tons), from the input. The input in this case is the sum of imported ingot and alloy elements, bauxite and alumina, and recycled scrap for a total of 13.4 million short tons. The difference is 0.4 million short tons, which represents the loss of aluminum during processing. All losses were verified through discussion with the appropriate industry. Almost 100 percent of every metal was accounted for.[2]

Figure 3 gives estimates of losses expressed as a percentage of domestic shipments of mill products of the metal (e. g., steel shipped by steel mills). In other words, these loss figures are expressed as a percentage of the amount of mtetal flowing at one place in the cycle, shipments of mill products, which is the traditional industry measure of productive output.

Excluding platinum and manganese, the total losses of the selected metals range from 55 to 78 percent. These losses occur over the life of the products containing the metal, which may range from 1 to 50 years. In reality, losses during mining, processing, and manufacturing occur during the

[2] For a complete discussion of how losses were quantified, see ch III.

Figure 2.—Typical Materials Cycle



SOURCE. OTA, based in parrt on data from Working Papers One and Two.

first year. Losses during use and disposal stretch over - the lifetime of the product, from 1 year for cans and 15 years for refrigerators to 50 or more years for buildings.

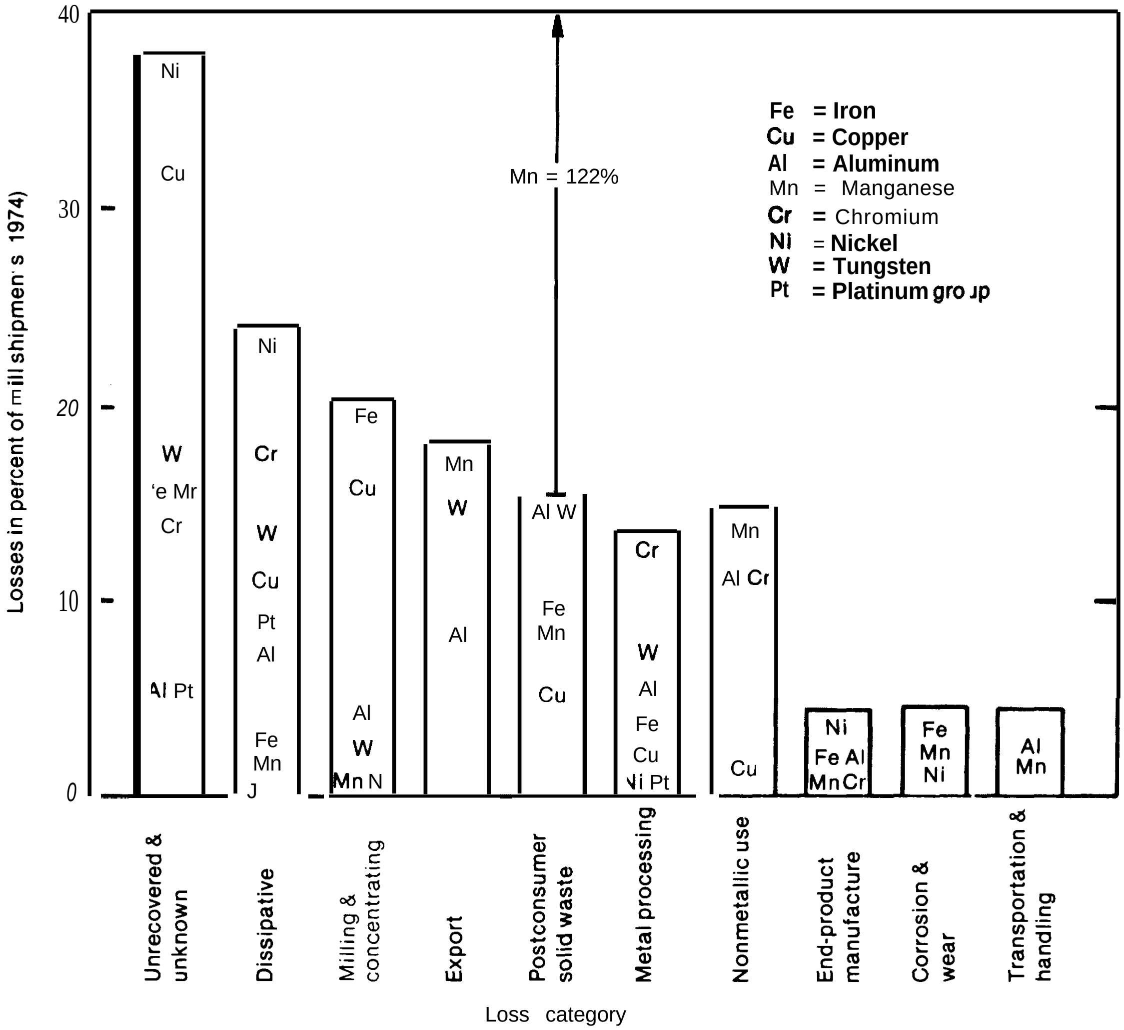
The loss of platinum is only 15 percent, due to the very high recycling rate for this precious metal. on the other hand, the loss of manganese exceeds 1()() percent, due to the primary use of this metal in steel production. More manganese is lost in the steel making process (e.g., as slags) than is contained in the steel products actually shipped.

For each metal the total loss is a sum of a large number of smaller losses that occur at every stage of the materials cycle. This dispersal of losses is a major harrier to effective overall waste reduction. However, some stages of the materials cycle experience greater loss than others, as illustrated in figure 3. The four largest loss categories are:

- Unrecovered metals in obsolete products . . . . 5-37% lost
- Dissipative uses of metals as alloys, powders, pigments (e.g., catalysts, paints, fertilizers) . . . . .4-23 % lost
- Milling and concentrating losses prior to metal smelting . . . . Nil-19X lost
- Metal losses through export of scrap and mill products . . . . 0-17 % lost

The technical conservation options with the greatest leverage in reducing each category of loss are shown in figure 4. The most highly leveraged

Figure 3.—Estimated Metal Losses for Each Loss Category, Expressed as a Percentage of Domestic Mill Shipments (1974)



NOTE See chapter III, tables 20 and 21 for data on which figure 3 is based
SOURCE OTA based on data from Working papers One and Two

options are metal recycling, product remanufacturing and reuse, R&D on substitute materials and processes, and R&D on metal recovery from low-grade ores.

Metal recycling and product remanufacturing have multiple leverage because, in addition to the direct reduction in losses of unrecovered metals in obsolete products, these options lead to an additional savings in future years. For example, if through product recycling an additional 10 percent of obsolete office equipment in a given year is remanufactured, 10 percent less metal will be required for next year's production run (assuming constant demand). This will eliminate the losses (e.g., milling and concentrating that would have been associated with producing that amount of metal.

Technical Options for Reducing Excess Metal in the Materials Cycle

Losses from the materials cycle, as discussed above, represent one of two major classes of waste. The second class of waste is the use of excess metal in the materials cycle. The different types of excess metal usage are shown in figure 5.

Figure 4. —Technical Options for Reducing Losses in the Materials Cycle

Loss category	Range of losses*	Technical conservation option
Unrecovered metals	5-37%	Metal recycling Product remanufacturing and reuse
Dissipative uses	4-23%	R&D on substitute materials and/or processes
Milling & concentrating	Nil-19%	R&D on metal recovery from low-grade ores, e.g. fine particle technology
Exports of scrap & mill products	o-17%	Export controls
Postconsumer solid waste	5-1470	Product recycling
Metal processing	0.5-1 2% (Mn=122%)	Capital replacement Alternative desulfurization process (for Manganese)
Nonmetallic uses of raw materials	Nom-11%	R&D on substitute metals & processes
End-product manufacture	Nil-3%	Improved management controls
Corrosion and wear	Nil-3%	R&D on improved corrosion and wear resistant treatments
Transportation & handling	Nil-3%	Improved management controls

• Range of losses for the eight metals in percent of 1974 domestic mill shipments. See figure 3 and tables 20 and 21 in chapter Ill for metal-specific data.
Nom = small but undetermined amount of losses.
Nil = amount of losses close to zero.

SOURCE OTA based in part on data from Working Papers One and Two

The seven major products listed in figure 6 were selected as case examples in order to evaluate 25 options for reducing excess metals These products were selected as typical of five major U.S. industries that collectively account for about 60 percent of total metal consumption in the United States.[4] As a group, these products use the selected metals in amounts typical of many metal products. Analysis of additional products was conducted where necessary. For example, office equipment, pipelines, and television sets were included in the analysis of product recycling.

Estimated metal savings for the case examples were then generalized to a whole range of products that contained the metals under evaluation. Thus, if 10 percent of the steel used in automobiles could be saved by a stress-optimized design, that percentage was applied to the amount of steel used in all transportation products.

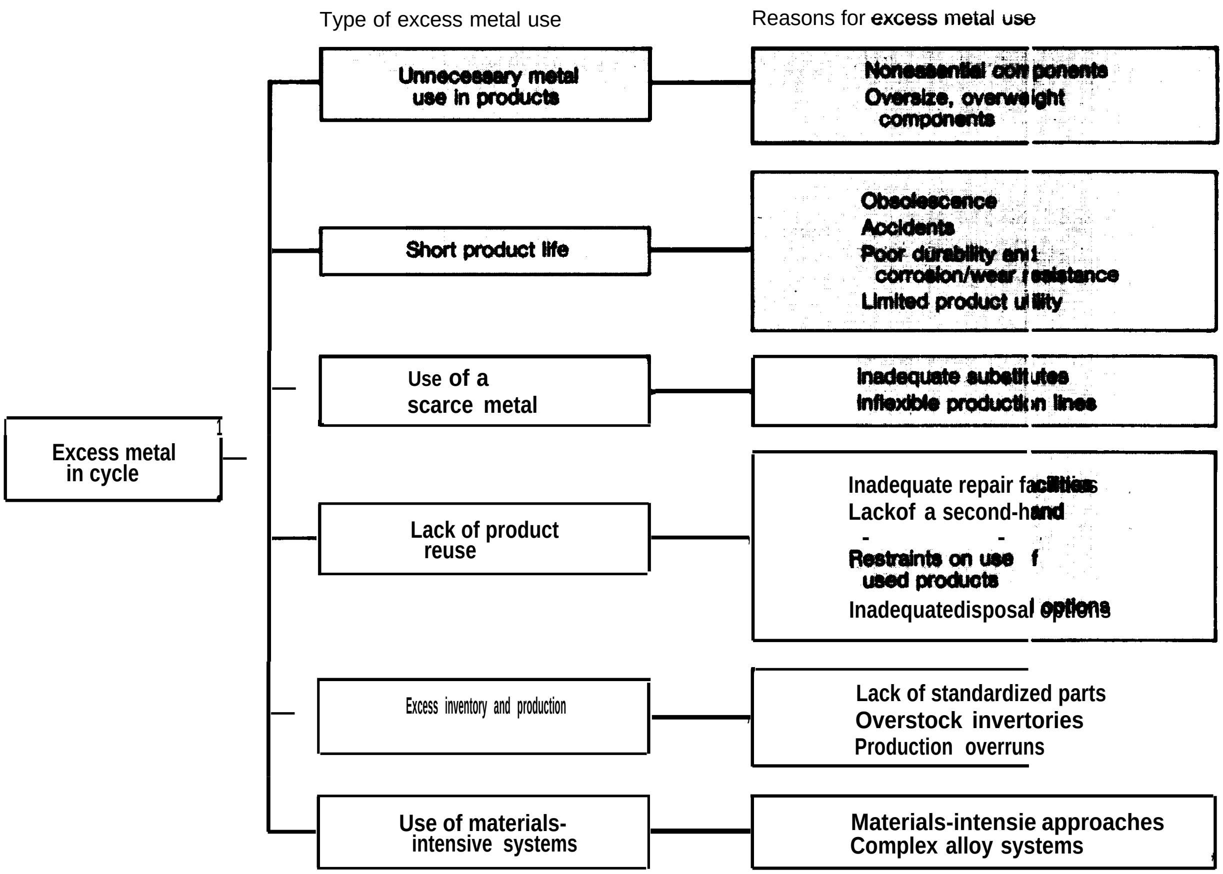
Figure 7 shows the percent of 1974 domestic mill shipments of each metal that could be saved by each conservation option listed.

These numbers are engineering judgments of the overall conservation potential for the listed options. The numbers are interdependent in that implementation of one option will reduce the savings possible with another option. Also, the percentages shown indicate the savings that are technically possible. Economic and other factors may severely limit the actual savings.

[3]For the complete list of options evaluated, see table 24, ch V

[4]See table 33, ch. VI

Figure 5.—Classes of Excess Metal in the Materials Cycle



SOURCE OTA

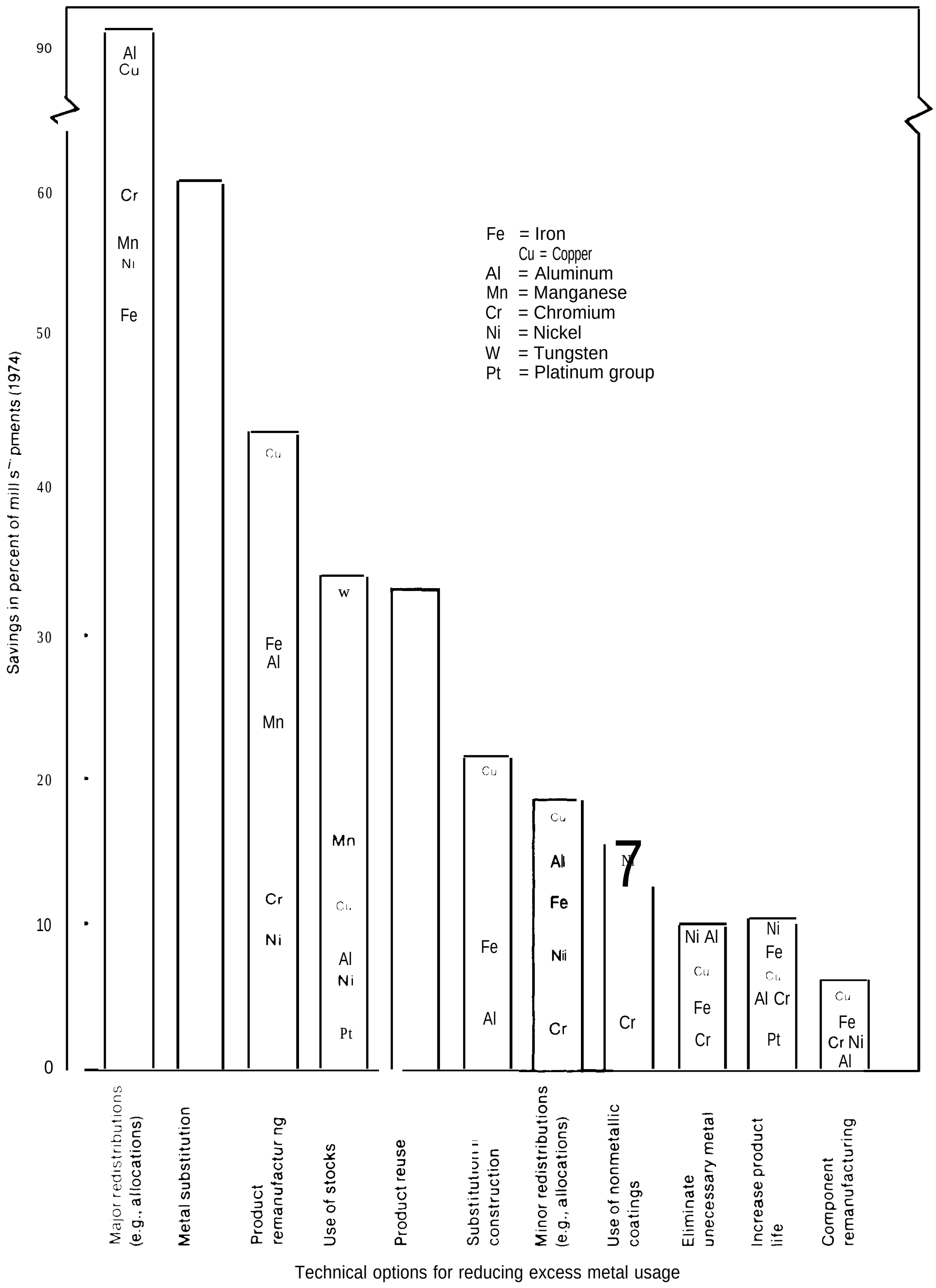
Figure 6.—Products Selected for Study

Product	Industry
Automobile	Transportation
Refrigerator	Appliances
Building	Construction
Bridge	
Lathe	Machinery
Tractor	
Can	Fabricated metal products

Three additional categories have been added to figure 7 for comparison purposes: major redistributions, minor redistributions, and use of stocks. The major redistributions option is based on experience with use of allocations during World War 11. The use of stocks option is based on the amount of metal that went into stocks during 1974. Although 1974 may not be a typical year, these numbers give some basis for comparison. (See pages 10 and 11 for an explanation of these categories).

Metal substitution, product remanufacturing and reuse, and savings through some sort of redistribution or allocation system, offer the largest potential for reduction of excess metal usage.

Figure 7.— Potential Savings From Technical Options by Reducing Excess Metal Usage, Expressed as a Percentage of Domestic **Mill Shipments (1974)**



NOTE See ch VI table 36 for data on which figure 7 is based
SOURCE: OTA based on data from Working Paper Three

SUMMARY OF TECHNICAL OPTIONS FOR REDUCING LOSSES AND REDUCING EXCESS METAL

A summary of the technical conservation options is presented in figure 8, which includes options for reducing losses (designated by 'L') as well as options for reducing excess metal ('E'). The percentages shown give the range of potential savings for the eight metals studied, rounded off to the nearest 5 percent. These percentages are nonaddictive, since many of the options are mutually exclusive, such as product recycling and metal recycling. The purpose of figure 8 is to show which options offer the most potential for conservation of metals.

The percentages shown in figure 8 represent the maximum technical potential for conservation. The actual amounts may be considerably less due to various barriers to implementation and undesirable impacts and costs. Only options with 10 percent or more potential metal savings for at least one metal have been included.

The conservation options are, of course, metal specific as indicated by the wide range of percentages. A metal like platinum, which costs over *$2,000* per pound, offers only limited additional opportunities for conservation. Metals used primarily for alloys (such as manganese and chromium) require different options than do the basic structural metals (iron, copper, aluminum). However, in this summary, the options are discussed only in general terms.[5]

Each of the technical conservation options presented in figure 8 is discussed below.

Major redistributions.—A review of the World War 11 experience (see appendix B) showed that from 50 to 90 percent of several of the metals studied were diverted from their then current use. During wartime, when flexibility became absolutely necessary, major metal savings in the *civilian* sector were accomplished with a very tight allocation system that drastically reduced the domestic products that could be manufactured and consumed. Production was diverted to war products, so severe economic consequences were averted. This would not necessarily be the case in peacetime. The World War 11 experience indicates the upper limit for conservation in the civilian sector under crisis conditions.

Metal substitution.–Con:iderable potential flexibility enters into materials use via the substitution option. However, several major impediments must be overcome. First, a successful substitution can often take years to implement. Second, many products are manufactured with a highly specialized production process that is costly to change. If the substitution option is to be acceptable, greater flexibility must be built into the production process so that alternative metals can be used. Third, every substitution involves a risk that will add to the product cost. Strong financial incentives will be required to overcome these barriers.

A special case is the construction industry, which uses 10 to 20 percent of metals. This industry is not tied down to a specific production process. For example, considerable dollar savings (on the order of $15 million out of a total cost of about $60 million) are found to be possible by substituting concrete, plastics, and fiberglass for iron and copper in the construction of a typical 40-story office building. Substitution is a common practice in the construction industry, particularly where local labor practices and customer preferences are favorable.

Use of nonmetallic coatings.--A substantial percentage of certain metals (cadmium 60 percent, chromium 5 percent, cobalt 18 percent, nickel 13 percent, tungsten 8 percent) is used to coat steel or alloys for corrosion and wear resistance. Use of nonmetallic coatings could save considerable metal. However, additional R&D is required to sufficiently develop such coatings.

Metal recycling.—Some industrial scrap is effectively recycled. Estimates of the potential for additional recycling of obsolete scrap (from products) range from 5 percent for platinum to 40 percent for copper.[6] Unfortunately, obsolete scrap metal has a limited market and competes with virgin ore of

[5] For the complete metal-specific discussion of options, see chs. IV, *v, and* VI.

[6] For the detailed estimates. see figure 21, ch IV,

Figure 8.— Summary of Technical Options for Reducing Losses and Reducing Excess Metal

	Option	Potential metal savings (%o of 1974 shipments)
E	Major redistributions (e.g., through allocations)	50-90
E	Metal substitution	15-60
E	Use of nonmetallic coating	5-50”
E	Product remanufacturing	10-45
L	Metal recycling	5-40
E	Product reuse	5-30
E	Use of stocks	5-30
L	Reduce dissipative uses	5-25
L	Reduce milling and concentrating losses	0-20
E	Metal substitution in construction	0-20
E	Minor redistributions (e.g., through allocations)	5-15
L	Reduce post consumer waste	5-15
L	Export controls on scrap and mill products	0-15
E	Eliminate unnecessary metal in products	5-1o
E	Increase product life	5-10

E =Promising options for reducing excess metal used in the materials cycle See figure 7 for metal specific data

L =Promising options for reducing metal losses from the materials cycle See figure 3 for metal specific data

“ For cadmium

SOURCE: OTA based on data from Working Papers One, Two and Three

known quality and more stable supply as well as with industrial scrap, which has a known consistency and presents fewer collection difficulties.

Options for increasing the recycling of obsolete scrap include investment tax credits, product charges, and freight rate changes. Several of these options have been studied in another OTA assessment.[7]

Moreover, most obsolete scrap exists in the form of a product. And as a product (with workable components), the scrap usually has more value than the metal alone. Thus, to a large extent, metal recycling can be accomplished through remanufacturing and reuse of products.

Product remanufacturing and reuse.—According to a recent OTA conference on the subject,[8] this option offers major potential for conserving metal, saving the energy already invested in products, and reducing the environmental pollutants associated with the manufacturing process. One major barrier to product remanufacturing and reuse is the lack of the necessary industrial infrastructure.

Another major barrier is economic. To be economically attractive, a product must be remanufactured at a cost that will allow a resale price at a reasonable discount under the price of a new product. For many current products, this discount averages 60 percent. However, for other products there is no difference between new and reworked product pricing.

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[7] Materials and Energy From Municipal Waste (Washington, D.C.: U.S. Congress Office of Technology Assessment, July 1979). OTA-M-93.

[8] Product Remanufacturing Forum, Nov. [illegible] 1978, co-sponsored by the U.S. Office of Technology Assessment, U.S. National Bureau of Standards, and U.S. Department of Energy.

Product remanufacturing is not a new concept and is extensively carried out for a wide range of products and components. Automotive parts are probably the best example of what can be accomplished when the economic conditions are favorable. Products that are most likely to be remanufactured are those with higher initial costs, where appearance or styling is not a problem, and where there is an abundant supply of used products to remanufacture.

For products where remanufacturing is feasible but economically marginal, two major barriers exist. First, the concept of a "used" product runs counter to established traditions and even regulations. The second major barrier is the lack of established industries to remanufacture and resell that product. The recycling business is labor-intensive and may not have as high a rate of return as others. Therefore, if product remanufacturing is to be encouraged, some additional investment incentives may be necessary, such as low-interest loans or tax benefits for plant and equipment, and perhaps tax credits or deductions for leased products made of recycled parts and materials.

Reduce dissipative uses.—Dissipative uses involve the dispersal of metals and alloys by chemical action or physical dispersion during use. For example, aluminum pig and aluminum scrap are often used during the deoxidation of steel. The aluminum is lost as an oxide in the slag. Relatively few options are available to reduce waste here. Most technical options have significant performance penalties, or increased costs, or both. In some cases, R&D programs to find substitute materials and/or processes might be successful.

Reduce milling and concentrating losses.–Althougth relatively large quantities of metal may be lost in the milling and concentrating stages, the value of the material lost is low and the cost of further recovery is high.

One option is to increase imports of high-grade ore concentrate. But this raises serious questions about the amount of risk associated with import dependence versus the increased costs of energy and environmental controls that would be required in domestic processing of lower grade ores. Another option is to invest in a major R&D program, perhaps building on current U.S. Bureau of Mines research, directed toward increased recovery of metal values from lower grade ores.

Minor redistribution (through, e.g., allocations, export controls, use of stocks).—During emergency situations, these options could reduce metal usage with relatively minor effort, for example, allocations that encourage the use of proven substitutes in industries where changes in production equipment would not be necessary. The exact percentage saved would depend on the timing and specific metal, but could be as high as 30 percent.

Reduce postconsumer waste.—Options for reducing postconsumer waste are discussed in another OTA report, *Materials and Energy From Municipal Waste,* July 1979, OTA-M-93. However, once metals enter the municipal solid waste (MSW) stream, their recovery is generally more difficult and at present is limited to aluminum cans and ferrous metals (along with paper and glass). Options such as product recycling may offer significant energy conservation and environmental quality benefits when compared to sources separation and centralized recovery from the MSW stream.

Eliminate unnecessary metal in products.—Strong economic incentives already exist for careful design to avoid unnecessary uses of metal, for example, material costs, shipping weights, and handling costs. A though some further elimination of excess metal is possible, the difficulties include increased manufacturing costs, increased cost of investment in engineering and equipment, decreased durability. and reduced safety.

For example, for the refrigerator, an estimated 11 lbs of steel could be saved of the 70 lbs now used in the outer shell. However, this would add $30 to the manufacturing cost for a plastic substitute and related adhesive and finishing, and would create moisture and flammability problems, among others.

Increase product life.—Technically, longer mechanical life can be designee into many products. But longer life can often be more costly and may not result in a significant increase in the actual average lifetime. Many products are retired due to obsolescence, appearance style changes, or other reasons not related to mechanical condi-

Figure 9.—Ability of Conservation Options to Meet Selected Materials Objectives

	Selected materials objectives: Improve materials availability during critical situations	Selected materials objectives: Reduce waste of materials and conserve energy
Most promising technical options (from figure 8)	**Major redistribution (e.g., through allocations)** **Metal substitution** **Use of stocks** **Metal substitution in the construction industry** **Minor redistributions** **Export controls**	**Increase metal recycling** **Increase product remanufactureing** **Increase product reuse** **Reduce dissipative uses** **Reduce milling & concentrating losses** **Reduce postconsumer waste** **Eliminate unnecessary metal in products** **Increase product life**
Illustrative implementation options	**Public data base** **Contingency planning function** **Market for contingency shares certificates** **Research and development on metal substitution**	**Public data base** **Improve product aftermarket (e.g., establish a scrap inventory, encourage product leasing, provide loans to establish aftermarket businesses)**

SOURCE: OTA.

Government options were evaluated, and four appear to warrant primary consideration:

- encourage product leasing through tax deductions,
- provide loans to establish after market businesses,
- provide funding to establish a scrap inventory, and
- increase public confidence in recycled products.

Product recycling would also save energy. As shown in figure 10, metal refining and fabricating are several times above the national average in energy intensity. Therefore, recycling of metal products and components—which involves the maintenance and manufacturing stages of the materials cycle—is more energy efficient than building products from scratch with newly mined, refined, and fabricated metal parts.

Contingency planning function. One option availab]e to Congress is to centralize a materials contingency planning function in the Government. This organization would be responsible for evaluating the severity of perceived threats to materials supply, and developing contingency plans on a commodity by commodity basis. Such a function could be an extension of the scope of work now performed by various existing offices and bureaus.

Public data systems. A public data base on materials would help to improve the quality and quantity of information available to Government and to industry for better analysis and forecasting on materials supply and demand problems. It would also help identify R&D needs for solving or alleviating technical problems in the materials cycle.

These two implementation options, contingency planning and a public data tree, have been studied in detail in an earlier OTA report on *Information* tions. Up to 50 percent of all products removed from service are still in working condition, according to one recent report on the subject.[9]

Longer product life would best apply to transportation and consumer durables (appliances) which together account for 12 to 28 percent of metal usage, depending on the metal. Even if the maximum savings per product (27 percent)[10] were applied to the maximum base of 28 percent, this would result in only a 7.5-percent metal saving.

[9] W. David Corm, *Factors Affecting Product Lifetimes*, NSF/RA Report 780219, August 1978.

[10] Based on the amount of metal saved per product per year with a 50-percent increase in mechanical lifetime. See ch. VI, table 32 and related discussion.

PRELIMINARY POLICY CONSIDERATIONS

As summarized above, the primary focus of this study was the assessment of technical options for conserving metal. However, preliminary consideration was given to materials objectives and problems and a range of possible implementation options that should be taken into account in policy discussions on materials conservation.

Materials Objectives and Problems

Conservation is a response to a real or imagined threat or condition. Conservation options are implemented in attempting to accomplish some objective. The primary objectives of concern in this assessment have been reducing the volume of waste and improving materials availability. There are a number of other objectives that might be relevant to public policy, such as conserving energy, stabilizing materials markets, protecting the environment, or promoting a resource-conserving society.

Materials availability, either short term during critical situations or long term with respect to resource depletion, is a vital concern to both industry and society. Without the proper materials, many industries would be forced to close unless alternative plans were made well in advance. As shown in appendix C, materials shortages have been commonplace for many years and will undoubtedly continue in the future. Conservation is a possible response to these problems.

Energy conservation can affect the availability of materials. Since metals refining consumes about 9 percent of the energy budget and all materials consume about 20 percent, materials conservation could be a response to the need for energy conservation. More realistically, in the foreseeable future, energy conservation will probably be more important than materials conservation.

Materials conservation may be an appropriate strategy to deal with a large number of other problems that threaten materials availability, such as: chronic lack of capacity in the metals industry, import dependency for essential metals, cyclical instabilities in supply and demand for metals, and environmental restrictions on the mining and processing of metals.

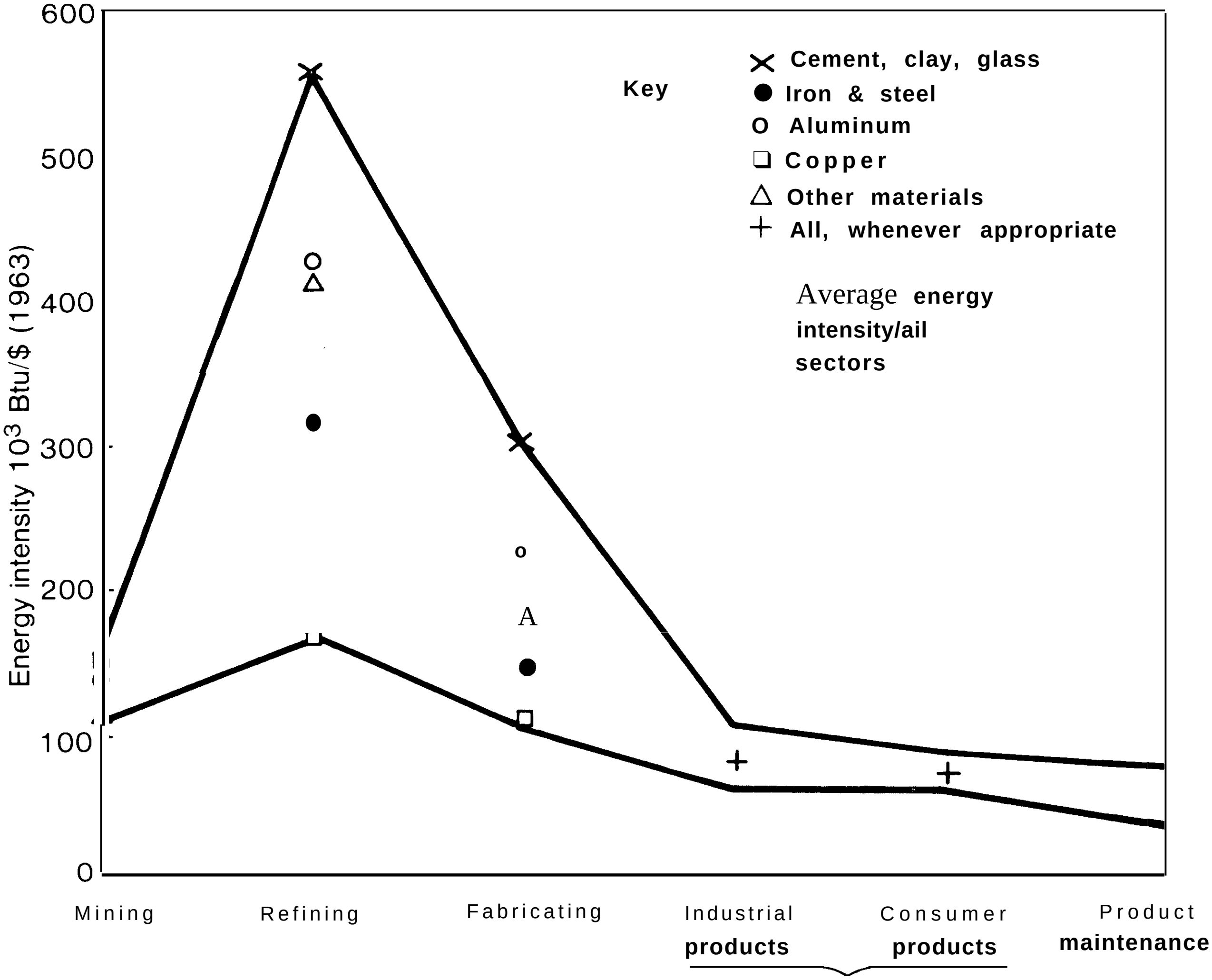
Illustrative Implementation Options

This study briefly considered several methods for implementing the more promising technical conservation options. Both technical and implementation options are listed in figure 9 as options to improve materials availability during critical situations and/or to redue waste and conserve energy. The impacts of these options were not assessed in detail.

Improve product aftermarket. Product remanufacturing, reuse, and repair (collectively known as product recycling) offer significant leverage for conserving materials and energy. Improved aftermarket (the market for recycled products) would help to reduce the mixing of scarce materials with the landfill waste stream as well as to improve the rate of recovery of the major metals—iron, steel, aluminum, and copper.

Improved product recycling to capture the residual value in products through a strengthened aftermarket would eventually have implications for the entire materials cycle. Twenty possible

Figure 10.— Energy Intensity at Each Stage of the Materials Cycle



SOURCE: OTA, based on data from Working Paper Six

Systems Capabilities Required to Support U.S. Materials Policy Decisions (December 1976). Option 3 in that report, known as the Bureau of Materials Statistics and Forecasting, encompasses these two options. Chapters VII and VIII of that report provide a detailed discussion of the impacts and issues associated with implementation of such a Bureau with contingency planning and public data base capabilities.

Market for contingency shares certificates, in this implementation option, a private sector market for contingency shares certificates would be established between materials suppliers and industrial customers of basic materials. This option would be a private allocation system.

R&D on metal substitution. Substitution promises substantial savings for specific metals. Discovering the available substitution options is in part a product of Government-sponsored R&D. Research programs to develop practical substitutes for scarce materials, with particular emphasis on products with high metal use, nonmetallic coatings for corrosion and wear resistance, and dissipative uses could be established.

Summary

The implementation options presented above avoid Government intervention in private decision processes to a large extent. Instead, they enable the private sector to more efficiently deal with their own needs while reducing the uncertainties and vulnerabilities for all parties. These means of implementation are to a great extent self-correcting. They do not require constant Government adjustment of standards or regulations in order to achieve a balance of interests. Nor do they involve excessive costs for administration, monitoring, enforcing, or recordkeeping.

This set of illustrative options is mutually reinforcing. The contingency planning and public data base support all other options. The contingency shares certificate market would moderate the extremes of materials supply and demand fluctuations. Substitution is very much the result of a private sector decision process. But through Government R&D, substitution can also be an important instrument of national materials and energy policy. Improvements in the product aftermarket will contribute to greater efficiency in materials use but could also provide an institutional mechanism to advance many other objectives such as energy conservation and environmenta protection.

11.

Congressional Interest and Scope of Assessment

Congressional Interest and Scope of Assessment

ORIGINAL CONGRESSIONAL REQUEST

This report is in response to a request from the Senate Commerce Committee in 1975 and since reaffirmed by the Subcommittee on Science, Technology, and Space Of the Senate Committee On Commerce, Science, and Transportation. This report also responds to interest expressed by the House Committee on Science and Technology and several other House and Senate committees concerned with conservation of natural resources in the U.S. domestic economy.

This report focuses on one major aspect of resource conservation, namely, the conservation of materials—and more specifically metals— through reduced waste in the materials cycle.

Following the congressional request, this report addresses:

- the kinds and amounts of materials wastage,
- techniques or technical options for reducing wastage,
- technical and institutional impediments to applying these techniques.

At the time this study was requested, the then recent (1973-74) shortages of many materials and the threat of future shortages were of particular concern to the Nation. Thus, emphasis in this study was placed on identifying conservation options that can improve materials availability—that is, the degree to which materials can be acquired on a timely basis.

DEFINITION OF MATERIALS WASTE AND CONSERVATION

Waste has two connotations: 1) residual material left over from processing, manufacture, and use; and 2) useless or unnecessary consumption, that is, materials use for which there is no adequate justification. The first definition of waste is precise in that it refers to specific losses that could be recovered if there is sufficient economic justification. The second definition is judgmental and depends on the conditions and incentives under which consumption takes place.

For example, under the conditions of an embargo on imported copper, it might be considered wasteful to use copper for plumbing since substitutes are available. On the other hand, during conditions of oversupply, it might be considered wasteful *not* to use copper.

In addition to changing conditions, there are changing incentives. Thus, for products containing excess metal, it may be the judgment of the manufacturer that the cost of waste is less than the cost of its elimination. But if there are sufficient economic, social, or political incentives, in many instances the excess metal can be removed. Here, the incentives, rather than the material scarcity, drive the elimination of unnecessary consumption.

Since the conditions and the consequences of consumption are difficult to define, the approach chosen in this study was to document losses from the materials cycle or losses that result from excess material in the cycle. The primary question then becomes: where are the losses that could be avoided should the need for conservation arise?

In traditional thinking, conservation has, like waste, two connotations: reducing usage as a response to an immediate or current shortage, or reducing usage to ensure that future needs will be adequately satisfied. In both cases, the concern is with the adequacy of supply, although the timing is different (short v. long term). Studies of conservation traditionally have almost always dealt with the long-term mineral supply and demand condition.

The definition of conservation used in this report is a more general one: reduced usage of resources as a response to either short-term supply interruption or long-term depletion. The important aspect of this definition is that the reduced usage be for some "cause" or to meet some societal objective. It is these "causes" or objectives that distinguish reduced usage for conservation from reduced usage due to normal supply/demand fluctuations.

SCOPE OF THE ASSESSMENT

The context of this assessment is illustrated in figure 11,

Materials availability is subject to short-term threats and conditions and long-term depletion for which some response, either public or private, is required. Possible short-term threats and conditions include:

- chronic lack of capacity,
- import dependency,
- energy shortages,
- cyclical materials shortages,
- environmental restrictions,
- international cartel actions,
- deteriorating U.S. balance of payments, and
- escalating U.S. inflation.

These threats and conditions are discussed in more detail in chapter VII.

As shown in figure 11, a variety of strategies are available to cope with materials availability problems, not all of which are materials strategies. One materials strategy is conservation. Others include, for example, stockpiling and expanded domestic production. A variety of options are available to conserve materials (substitution, recycling, use of less metal in product design etc.). For convenience, these options may be classified as those that reduce the losses from the materials cycle (e.g., reduce wastes) or those that reduce the amount of material in the cycle (e.g., reduce the excess material designed into products or unnecessary inventories).

While materials availability is the concern in this study, it is only one of several that can motivate conservation. Other concerns might include the equity of world distribution of resources or the environmental impact of materials consumption. These are not considered as objectives in this assessment.

In addition, while technical options for conserving materials receive major attention, public policies for implementing these options are given only preliminary consideration Finally, this report does not assess the impacts of either the technical or implementation options on the economy, energy conservation, environmental quality, employment, and the like.

SELECTION OF MATERIALS FOR DETAILED STUDY

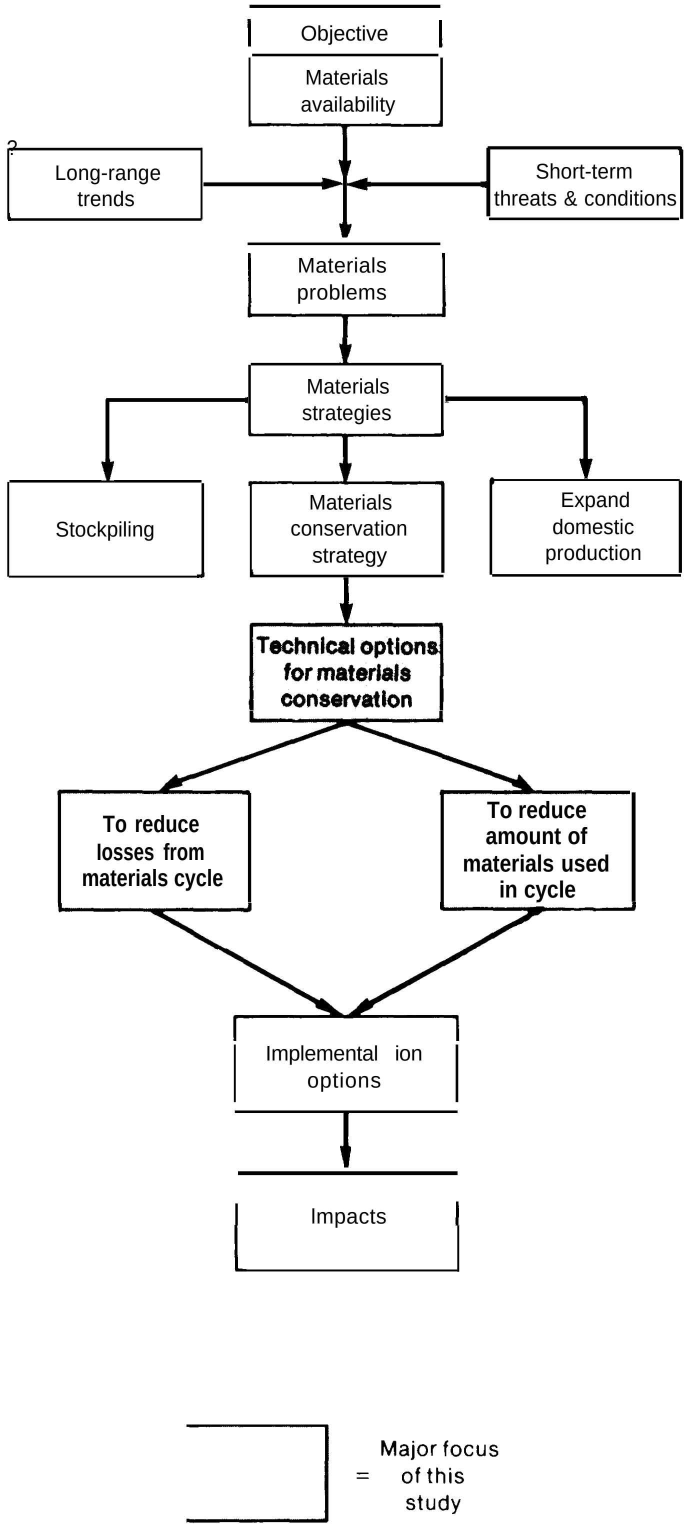
Literally hundreds of materials could be examined in an assessment of materials conservation. Two criteria were used for selecting the specific materials to be analyzed in this assessment: 1) economic and strategic criticality and 2) the nature of the materials and their usage. In the last several years, five major reports have been published dealing with supplies and uses of critical materials. Each of these reports developed a list of critical materials, as summarized in table 1.

In addition to criticality, a variety of characteristics relating to each material were examined: volume, price, import dependence, ease with which the metal is won from its ores, and the nature of its uses.

On the basis of these characteristics, eight metals were selected: chromium, manganese, nickel, platinum group, aluminum, copper, tungsten, and iron and steel. This selection represents a reasonable sample of metals that are commercially important.

For example, iron and steel, aluminum, and copper are basic metals to which minor amounts of alloying elements are sometimes added. Manganese and chromium, on the other hand, are used primarily for their properties as alloying elements

Figure 11.—Context of Assessment



SOURCE: OTA

in other basic metals. Nickel and tungsten are used both as basic metals in nonferrous alloys and as alloying elements in other basic metals. Platinum-group metals are representative of precious metals. With respect to the way metal products are used in articles of manufacture, at one end of the spectrum are iron, copper, and aluminum. These often are major elements in finished products, and thus are readily salvageable. Precious metals and tungsten, on the other hand, are often embodied in small components of end products, and salvage is more difficult.

Other materials might well have been considered, such as chemicals, food wood, industrial gases, paper, rubber, textiles, ceramics, and plastics. However, in the context of materials availability, metals represent the most critical materials.

Table 1 .—Critical Materials

Materials	Dyckman[a]	SRI[b]	Army War College[c]	Battened	Stockpile[e]	Metals selected
Petroleum	X					
Chromium	X	X	X	X	X	•
Manganese	X	X	X	X	X	•
Titanium.	x					
Nickel.	X	X	X	X	X	•
Platinum group	X	X	X		X	•
Aluminum	X	X	X	X	X	•
Columbium	X			X		
Antimony.	X	X				
Cobalt	X	X	X	X	X	
Thorium	x					
Vanadium	X				X	
Copper.	x					•
Mica	x					
Florine	X					
Graphite.	X					
Tungsten	X	X	X	X	X	•
Asbestos	X				X	
Tin	X	X	X	X	X	
Mercury	X	X		X		
Titanium.	X			X		
Tantalum	X				X	
Magnesium ... ,				X		
Iron.				X		•

[a]Edward J Dykman, "Review of Government and Industry Studies on Materials Supply and Shortages, " in Syrnposium of *Critical Materials, Proceedings,* U S Department of Defense, Dec 16, 1974

bMark D. Levine, *Department of Defense Materials Consumption and the Impacf of Material and Energy Resource Shortages,* November 1975, prepared by Stanford Research Institute and available from U S. Department of Commerce, NTIS #AD-A018-613.

cU.S. Army War College, A *Study of Critical Materials,* May 1976.

dA.M. Hall, *A Survey of Technical Actlvities and Research Opportunitie Affecting* the *Supply of Metallic Structural Materials,* September 1974, prepared by Battelle, Inc and available from NTIS # PB 246106.

eNational Materials Advisory Board, A Screening for *Potentially Critical Materials for the National Stockpile, 1977* NMAB 329.

SOURCE: OTA, based on reports cited above.

III.

Quantification of Losses From the Materials Cycle

Quantification of Losses From the Materials Cycle

As a first step in the assessment, a classification of material losses was necessary so that they could be identified and quantified on an orderly basis. A precise accounting of losses would require tracing each material through its production and processing and into its use in the manufacture and consumption of thousands of products. However, since materials availability is the primary concern of this assessment, then it is the major losses (e.g., more than 10 percent of the yearly demand for a material) that are important, since only they would be large enough to affect the availability of materials.

A typical materials cycle is shown in figure 12, which illustrates the various material and product stages. Losses can occur at each step in the cycle and particularly in the utilization stage where ultimately the product must be disposed of either by putting it in storage, recycling it in a variety of ways (metal, components, products), or discarding it. The various types of losses that occur at each stage of the materials cycle are also illustrated in figure 12.

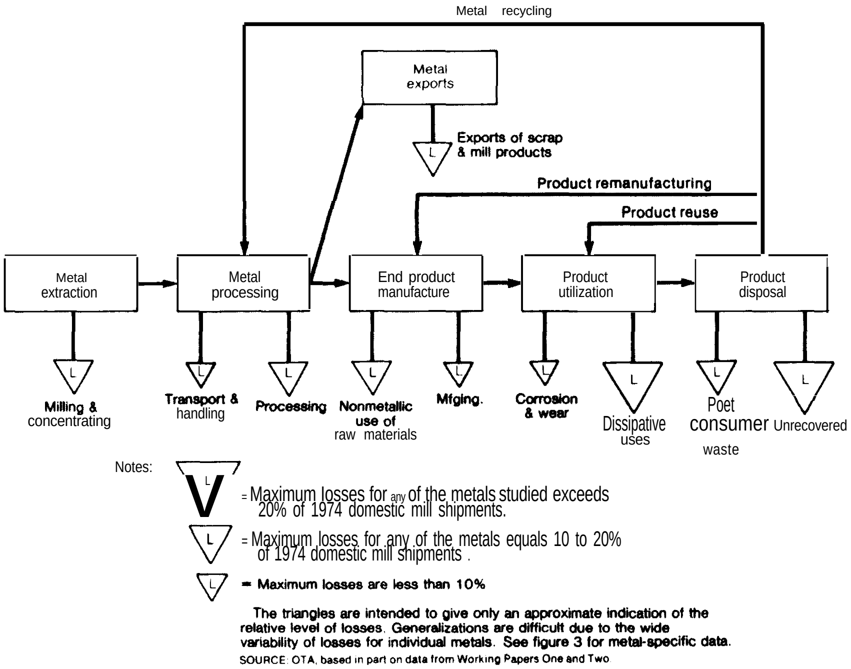
The approach used for quantification of losses was to trace the physical flows for each of the eight selected metals at each stage in the materials cycle. The losses could then be quantified both directly (e.g., from a knowledge of the yields in metal extraction) and indirectly (from a knowledge of the amount of material entering and leaving a given stage) From these data, the major loss categories were identical.

Losses from the 1974 materials cycle were estimated for eight metals: iron and steel, aluminum, copper, platinum-group metals, manganese chromium, nickel, and tungsten. Data on materials flows and losses for 1974 were used. The year 1974 was chosen for several reasons. First, that year represented a high level of economic activity and resource usage. The following year, 1975, was a recession year when resource usage and flows were depressed and possibly distorted. Further, when this assessment was initiated, only fragmentary data were available for 1976.

The estimates presented here are given in summary fashion. Substantially more detail is available in Volume II—Working Papers. In particular. *Working Paper One** (vol. II-A) providesbasic data in support of the estimates of losses from the materials cycle and materials consumption by end use. These data provide the basis for estimating the quantities of wastage.

*A list of the Working Papers is in app. E. The Working Papers are available from the National Technical Information Service (NTIS), Department of Commerce, Springfield, Va. 22161.

Figure 12.—Typical Materials Cycle



SOURCE: OTA based in part on data from Working Papers One and Two

IRON AND STEEL

Domestic iron and steel plants in 1974 shipped about 124 million tons* of iron and steel products to manufacturers and fabricators. In addition, 16 million tons of iron and steel mill products were imported and nearly 6 tons were exported. Of the more than 134 million tons of iron and steel mill products used by end-product manufacturers and fabricators, nearly 111 million tons of iron and steel were embodied in end products in 1974. The remainder was returned to iron and steel plants and foundries in the form of prompt scrap.

Iron and steel mill products represent by far the largest tonnage of basic metal used in the United States. The tonnage of iron and steel used is roughly 20 times that of the next largest metal—aluminum. It is important to consider the conservation options for iron and steel because of the sheer size of the iron and steel industry, the magnitude of its use of energy, and its importance in the manufacture of almost every product.

Estimates of flows in the iron and steel cycle and summary losses from the cycle are given in figure 13. The total losses shown in figure 13 amount to about 79 million tons. This is nearly three-quarters of the total amount of iron and steel embodied in products in 1974.

Estimated amounts of ferrous materials entering useful life in 1974 are given in table 2. Table 2 provides a broad market breakdown of the amount of iron and steel embodied in end products in 1974. By using estimates of the useful life of iron and steel products and data on past production and use of iron and steel, amounts of iron and steel that became obsolete in 1974 were estimated. Table 3 gives a breakdown, by market category, of the estimated 72.5 million tons of iron and steel that became obsolete in 1974. Estimates of the amount of obsolete iron and steel scrap that was recovered and recycled in 1974 are given in table 4, classified by broad category of product from which the scrap was derived. The loss category designated "unrecovered and unknown" (in figure 13) represents the difference between the calculated value of obsolete products (72.5×10^6 tons) and that which is accounted for by recycling, postconsumer solid waste, corrosion and wear, and dissipative uses.

From the preceding data, estimates of the total losses from the domestic iron and steel cycle in 1974 were as follows:

Nature of loss	*Millions of tons*
Milling, concentrating, and handling	23.3
Unrecovered and unknown	19.4
Postconsumer solid waste.	11.0
Scrap exports	7.8
Processing in iron and steel plants	6.8
Disssipative uses	5.4
Corrosion and wear	4.0
Manufacturlng losses	1.1
Total	78.8

*All data are given in short tons (2,000 lbs).

Table 2.–1974 Distribution of Products Manufactured From Iron and Steel
(millions of short tons of iron and steel alloys)

Market category	Quantity
Automotive	17.2
Machinery, including equipment	18.5
Rail transportation	56
All iron and steel castings	12.3
Construction, including maintenance	152
Contractors products	12.0
Electrical machinery	5.0
Shipbuilding and marine.	
Agricultural	3.0
Appliances	3.9
Other domestic equipment	3.8
Containers	9.3
Ordnance and military	1.0
Mining, quarrying, etc.	1.0
Oil and gas drilling	075
Aircraft and aerospace	o.15
Total .	1108

SOURCE Working Papers One and Two

Table 3.–Obsolescence of Iron- and Steel-Containing Products in 1974
(millions of short tons in ferrous materials)

Market category	Assumed average useful life (years)	Quantity
Automotive	13	12.3
Machinery, including equipment		9.0
Rail transportation	3.0	6.5
AH iron and steel castings		10.0
Construction, including maint.	30	7.5
Contractors products	27	4.2
Electrical machinery		
Shipbuilding and marine	30	0.8
Agricultural	20	
Appliances	11	2.8
Other domestic equipment	12	
Containers	<1	9.6
Ordnance and military	15	10
Mining, quarrying, etc.		04
Oil and gas drilling	30	
Aircraft and aerospace	20	0.1
Total		725

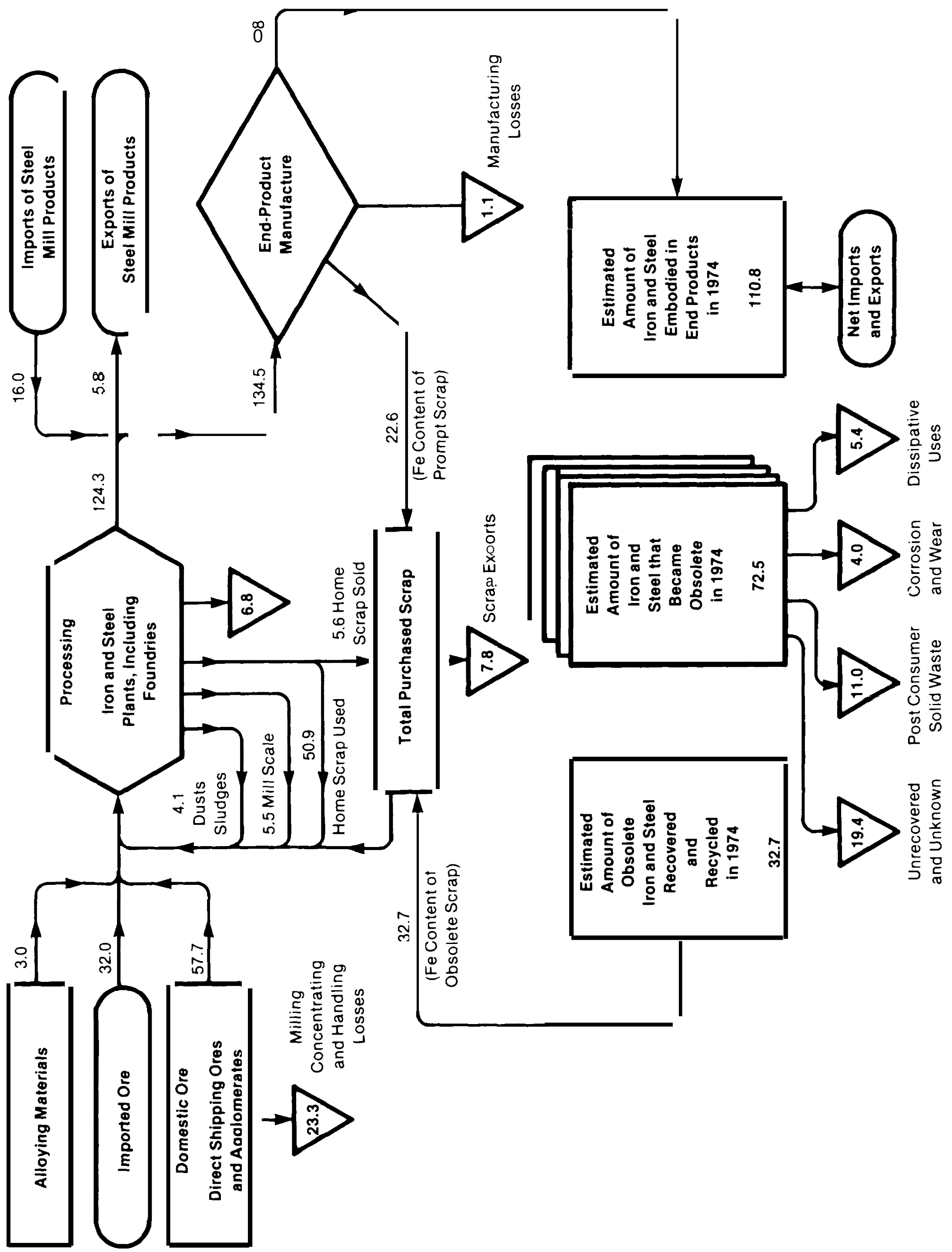
SOURCE Working Papers One and Two

Table 4.–Recycling and Recovery of Iron and Steel in 1974

Market category	Millions of short tons of metal	Percentage recycled
Automotive	10.9	89
Machinery, including equipment	69	
Rail transportation	5.6	86
All iron and steel castings	24	24
Construction, including maint.	22	29
Contractors products	16	38
Electrical machinery	11	42
Shipbuilding and marine	0.6	75
Agricultural	04	25
Appliances	02	7
Other domestic equipment	02	7
Containers.	0.2	
Ordnance and military	02	20
Mining, quarrying, etc	01	25
Oil and gas drilling	01	
Aircraft and aerospace	0 0	_
Total	.32.7	45

SOURCE Working Papers One and Two

Figure 13.—Iron and Steel Cycle: Flows and Losses, 1974 (Millions of short tons of contained ferrous materials)



NOTE: Flows are in millions of short tons of iron and alloying elements.
SOURCE: Working Papers One and Two.

ALUMINUM

In 1974, the aluminum industry produced about 7.2 million tons of aluminum. It exported about 0.5 million tons, placed in stock about 0.4 million tons, and shipped about 6.3 million tons to end-product manufacturers, of which 5 million tons were embodied in end products. Except for minor manufacturing losses, the remainder was returned to primary aluminum plants, secondary smelters, or aluminum foundries in the form of prompt scrap.

Figure 14 presents a summary of the flows of aluminum in the U.S. economy and the losses from the aluminum cycle in 1974. Figure 14 indicates that 5 million tons of aluminum were embodied in end products in 1974. A market breakdown of this figure is given in table 5. Table 6 presents estimates of the amount of aluminum and aluminum alloys contained in products that became obsolete in 1974. The breakdown by market category is based on assumptions of useful life in each of the product categories. Table 7 indicates the amount of obsolete scrap recovered from obsolete products in 1974 classified by market category. A total of about 343,000 tons of aluminum was recovered and recycled.

Losses from the domestic aluminum cycle in 1974, based on data in the foregoing paragraphs are shown to the right.

The total losses from the domestic aluminum cycle in 1974 amounted to over 4 million tons of aluminum content. This loss is sizable, particularly in relation to the 5 million tons of aluminum that were embodied in useful products in 1974.

Nature of losses	*Millions of tons*
Postconsumer solid wastes	1.0
Other uses of alumina	0.5
Exports of ingot and mill products	0.5
Unrecovered and unknown	0.4
Losses in bauxite mining and alumina production	0.4
Aluminum processing	0.4
Dissipative uses of scrap	0.4
Other uses of bauxite	0.3
Dissipative uses.	0.2
Losses in end-product manufacture	0.1
Total	4.2

Table 5.–Products Manufactured From Aluminum in 1974
(millions of short tons of aluminum alloys)

Market category	Quantity
Buildings and construction	1.43
Electrical products	0.85
Transportation products	0.80
Containers and packaging	0.78
Consumer durables	0.44
Machinery and equipment	0.40
Other	0.30
Total	5.00

SOURCE: Working Papers One and Two

Table 6.–Obsolescence of Aluminum Products in 1974
(millions of short tons of contained aluminum)

Market category	Assumed useful life (years)	Quantity
Building and construction	30	0.1
Electrical products	30	0.013
Transportation products	10	0.5
containers and packaging	<1	0.78
Consumer durables	10	0.3
Machinery and equipment	20	0.1
Other	10	0.1
Total	8	1.893

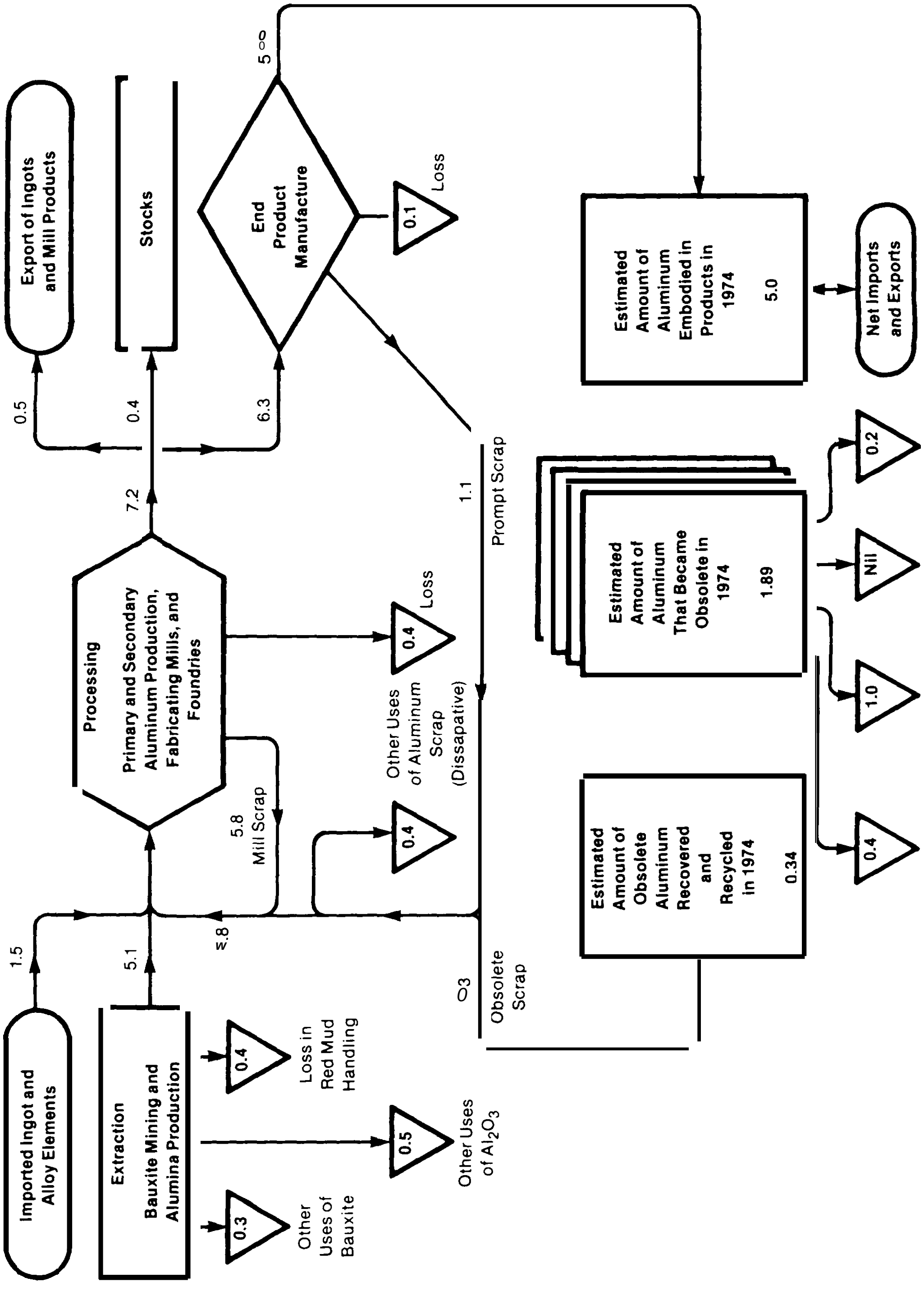
SOURCE: Working Papers One and Two

Table 7.–Recycling and Recovery of Aluminum in 1974
(millions of short tons of aluminum alloys)

Market category	Percent recycle	Quantity recovered
Building and construction	15	0.015
Electrical products	92	0.012
Transportation products	34	0.169
Containers and packaging	7	0.052
Consumer durables	14	0.042
Machinery and equipment	25	0.025
Other	29	0.028
Total	18	0.343

SOURCE: Working Papers One and Two

Figure 14.—Aluminum Cycle: Flows and Losses, 1974
(Millions of short tons of aluminum and alloys)



SOURCE: Working Papers One and Two.

COPPER

The production of copper in 1974 from domestic, primary, and secondary operations amounted to about 2.7 million tons. About 2.2 million tons of copper and copper alloys were embodied in end products in 1974.

The tonnage of copper used in the United States is third largest, after steel and aluminum, of the basic metals consumed. Of the basic primary metals, copper also ranks third in consumption of energy.

Estimates of the flows of copper in the domestic materials cycle are given in figure 15.

An estimate of the copper embodied in end products in 1974 by major end-use category is given in table 8. This end-product distribution has not changed significantly for the past several years. The estimated amounts of copper and copper-base alloys that became obsolete in 1974 are given in table 9. The quantities shown are based on the shipment data available for prior years and on an average estimated useful life for each of the product market categories. Estimates of obsolete copper and copper alloys, which were recovered as scrap in 1974, are given by end-use market category in table 10. The total amount of obsolete scrap recycled in 1974 amounted to about 0.56 million tons.

From the foregoing data and estimates, losses from the domestic materials cycle in 1974 were estimated as follows:

Nature of losses	Millions of tons
Unrecovered and unknown	0.9
Milling .	0.4
Dissipative uses	0.3
Postconsumer solid wastes	0.2
Smelting and refining	0.065
Brass mills, wire mills, etc	0.009
End-product manufacturing	0.006
Total	1.88

Table 8.–Distribution of Copper End Products to Major Use Categories in 1974
(millions of short tons of copper and copper alloys)

Market category	Quantity
Buildings and construction ...	05
Transportation. ., ..., .,	0.2
Consumer and general .,	0.5
Industrial machinery. ... .,	0.4
Electrical and electronics.	0.6
Total. ... ., ., ...	2.2

SOURCE: Working Papers One and Two

Table 9.–Obsolescence of Copper-Containing Products in 1974
(millions of short tons in ferrous materials)

Market category	Assumed average useful life (years)	Quantity
Buildings and construction.	30	0.2
Transportation . .	12	03
Consumer and general. . . .	10	0.5
Industrial machinery ., ...	20	0.3
Electrical and electronics .	10	0.7
Total		2.0

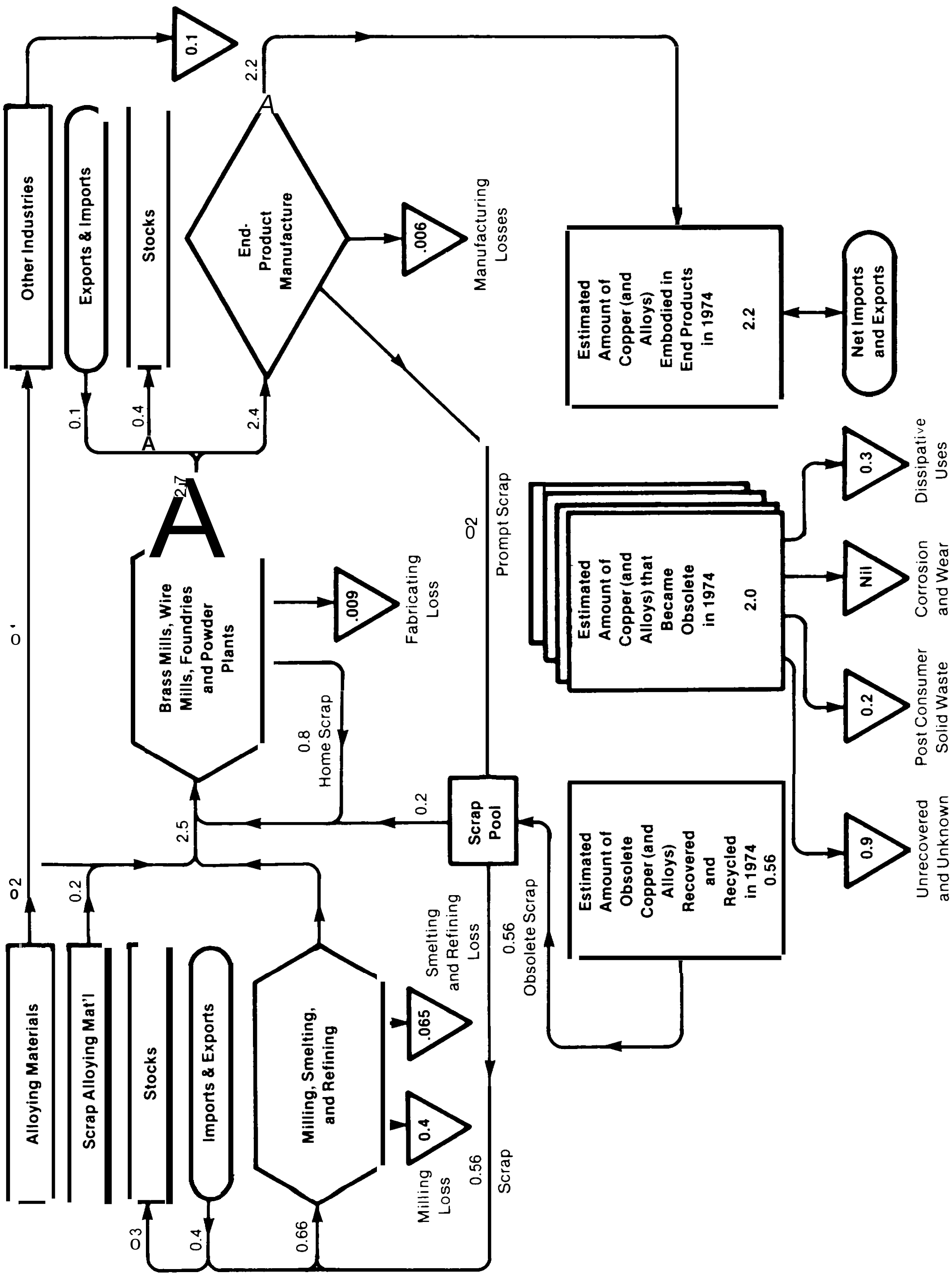
SOURCE Working Papers One and Two

Table 10.–Recycling and Recovery of Copper and Copper Alloys in 1974
(millions of short tons of copper and copper alloys)

Market category	Percent recycle	Quantity
Buildings and construction. . .	25	0.05
Transportation ., ...,	57	0.17
Consumer and general. ...	20	0.10
Industrial machinery .,	13	0.04
Electrical and electronics ... ,	28	0.20
Total ... .,		0.56

SOURCE Working Papers One and Two

Figure 15.—Copper Cycle: Flows and Losses, 1974
(Millions of short tons of copper and copper alloys)



SOURCE: Working Papers One and Two

The six metals included in the platinum group, in order of annual consumption are platinum, palladium, ruthenium, rhodium, iridium, an-d osmium. Prices for all six metals of the group are very high—between $50 and $450 per troy ounce. The platinum group metals are used primarily as catalysts and in electrical and electronic applications. The flows and losses of platinum-group metals are considered to be representative of one class of precious metals.

A simplified flow diagram is given in figure 16 showing the flows of platinum-group metals in the domestic materials cycle and losses for the year 1974. As shown in figure 16, about 3 million troy ounces of platinum-group metals are used by end- product users and fabricators with only a minor manufacturing loss; essentially the same amount was embodied in end products in 1974. Table 11 shows a breakdown by market category of the products manufactured from platinum-group metals in 1974. Most of the usage of platinum-group metals in chemicals and petroleum was in the form of platinum catalysts. The practice of toll refining for these major users of catalysts is very large. Nearly 1 million troy ounces per year are toll-refined. Table 12 gives estimates of the amount of platinum in products that became obsolete in 1974. As with the previous metals, these estimates were based on the assumed average life for each of the categories. About 1.64 million troy ounces of platinum-group metals were recovered from obsolete products in 1974 and recycled. A breakdown by market category of this amount is given in table 13.

From the above, the losses of platinum-group metals from the domestic cycle in 1974 were as follows:

Loss	Millions of troy ounces
Dissipative	(),25
Processing . .	0.015
Unrecovered and unknown	0.014
End-product fabricators and users	0,009
Total ... ., . .	0.288

Table 11 .–Products Manufactured From Platinum-Group Metals in 1974
(millions of troy ounces of platinum-group metals)

Market category	Quantity
Chemicals.	0.58
Petroleum ., ..., ...	0.73
Glass	0.19
Electrical.	0.80
Automotive ... ., ...	0.50
Dental, medical, jewelry, and misc.	0,25
Total. . . . ., .,	3.05

SOURCE Working Papers One and Two

Table 12.–Obsolescence of Platinum-Group Products in 1974
(millions of troy ounces of contained platinum-group metals)

Market category	Assumed average useful life (years)	Quantity
Chemicals	c 1	0.72
Petroleum	<1	0.69
Glass	<1	0.19
Electrical.	20	0.31
Automotive ., ...	6	–
Dental, medical, jewelry, and misc.	20	0.13
Total ., ...		2.04

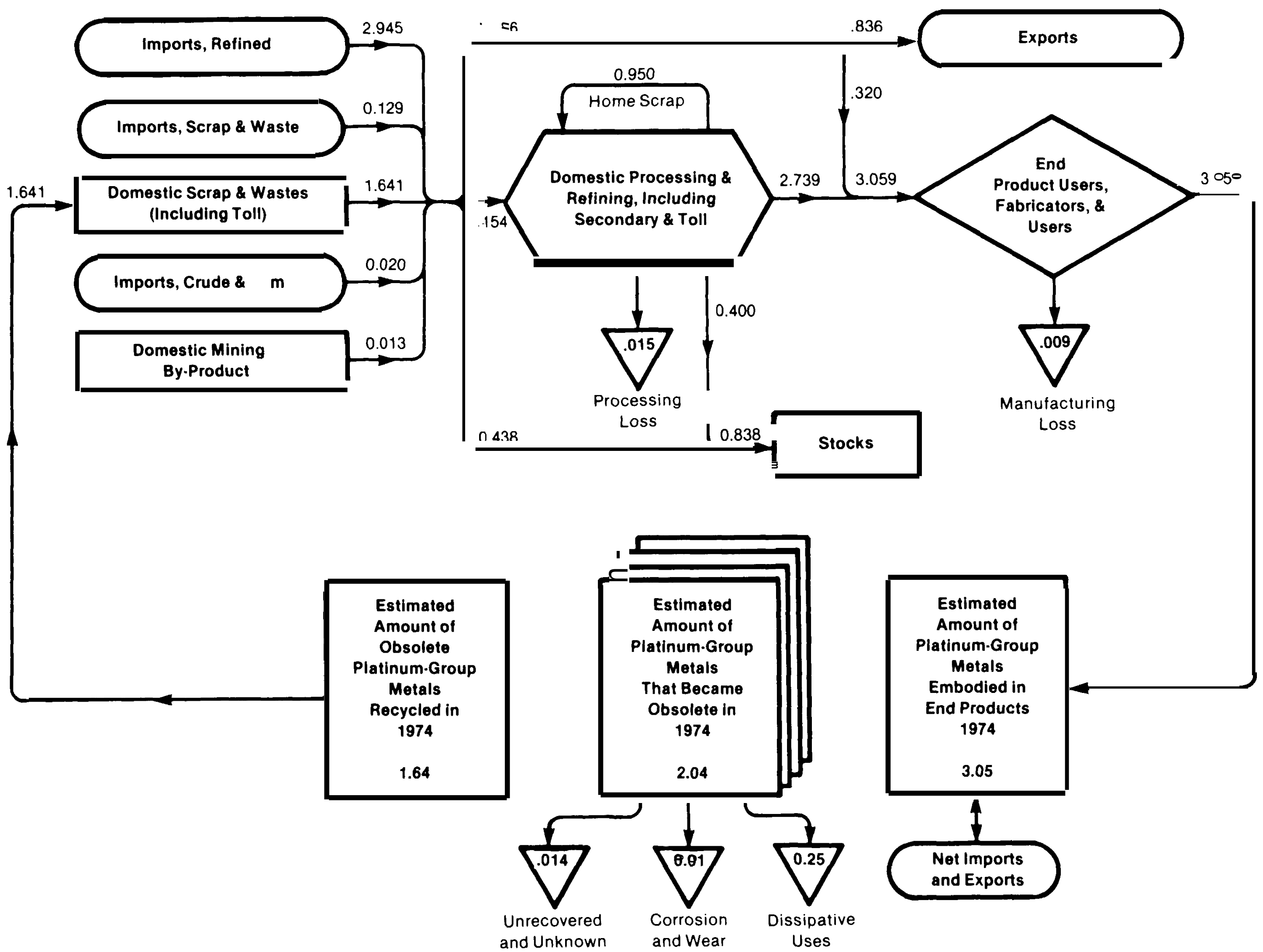
SOURCE Working Papers One and Two

Table 13.–Recycling and Recovery of Platinum-Group Metals in 1974
(millions of troy ounces of platinum-group metals)

Market category	Estimated percentage of obsolete platinum-group metals recycled	Quantity
Chemicals	85	0.61
Petroleum ... ., ...	97	0.67
Glass . .	98	0.19
Electrical. . ., ...	45	0.14
Automotive	0	–
Dental, medical, jewelry, and misc. . . . . ,	20	0.03
Total ., ., ...	80	1.64

SOURCE: Working Papers One and Two

Figure 16.—Cycle for Platinum-Group Metals: Flows and Losses (Millions of troy ounces)



SOURCE: Working Papers One and Two.

MANGANESE

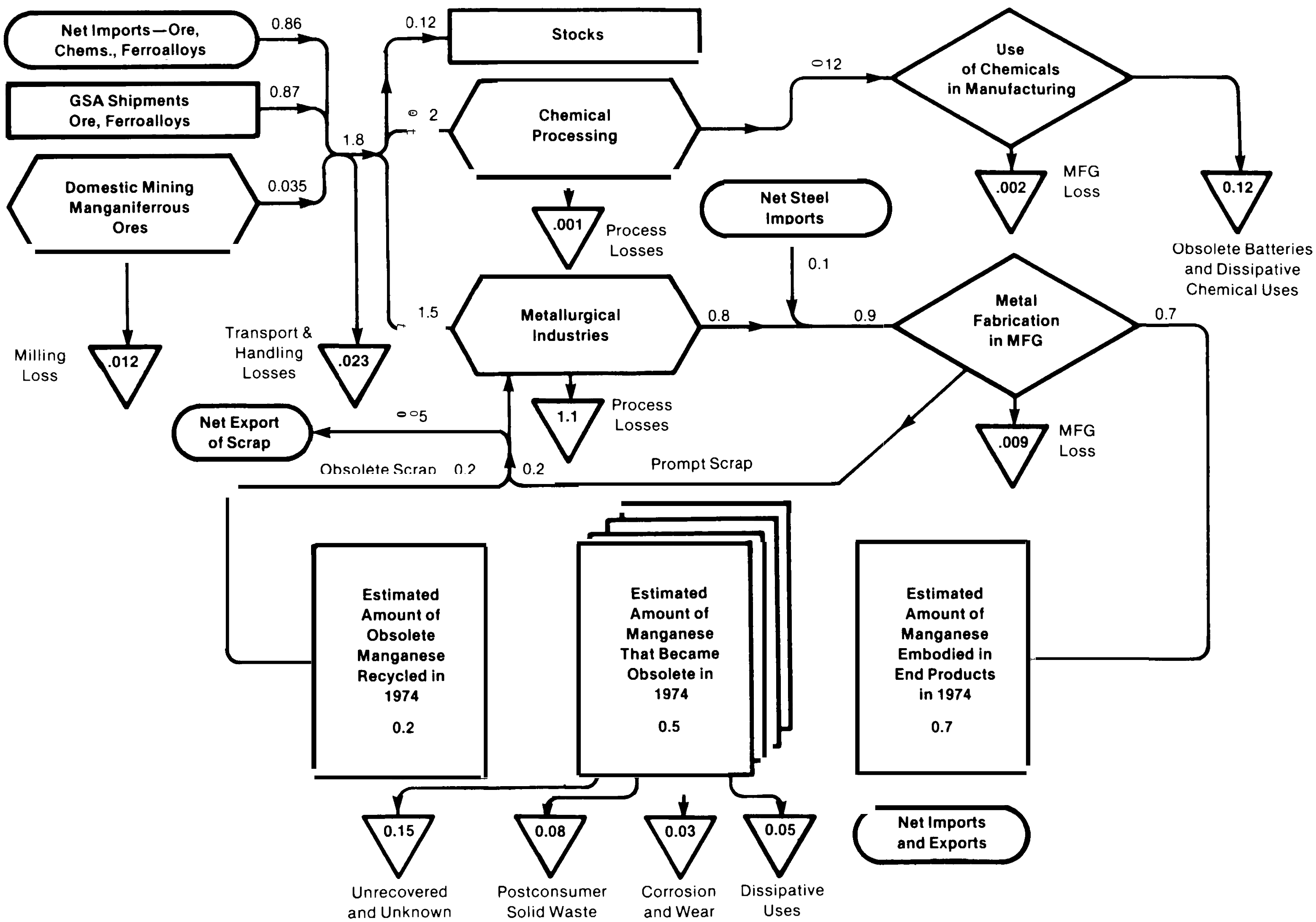
About 90 percent of the domestic usage of manganese is in the production of iron and steel. Although manganese, in amounts usually on the order of one-half to 1 percent, is important to steel properties, the predominant use of manganese is as an inexpensive chemical reagent in the desulfurization (and sulfur control) and deoxidation of steel. The other major domestic use of manganese is primarily as a chemical reagent.

The flow of manganese and losses from the domestic manganese cycle are given in figure 17. About 1.5 million tons of contained manganese were used by the metallurgical industries, while about 0.12 million tons were used in chemical processing. Of the 1.9 million tons of contained manganese entering the metallurgical industries, only 0.8 million tons remain in the metal that is shipped to metal fabricators. The loss of 1.1 million tons occurs in processing (steel). Referring again to figure 17, the net manganese content in end products entering useful life in 1974 was about 0.7 million tons. To a first approximation, the analysis of obsolescence and losses from the consumer cycle for manganese would be similar to that for steel. Estimates of the amounts of manganese that became obsolete in 1974 were based on the end-use pattern of steel, estimates of the amount of iron and steel that became obsolete in 1974, and on the amounts of iron and steel that were recovered and recycled in 1974. On those bases, it was estimated that 0.5 million tons of contained manganese became obsolete in 1974, and of that, 0.2 million tons of obsolete manganese were recycled in 1974.

The pattern of losses from the domestic manganese cycle is different from the patterns of losses from other materials cycles, mainly because of the high processing losses. As has been mentioned, the loss is associated with the use of manganese as an inexpensive chemical reagent in the desulfurization (and sulfur control) and deoxidation of steel. These high processing losses can be reduced technologically by an order of magnitude or more through the use of higher cost reagents and processes. The losses from the domestic manganese cycle in 1974 were estimated to be as follows:

Nature Of losses	Milliosn of *tons*
Process losses	1.1
Unrecovered and unknown	0.15
Postconsumer solid waste	0.08
Dissipative uses	0.05
Corrosion and wear	0.03
Transport and handling	0.023
Milling losses of domestic ores	0.012
Manufacturing and fabricating	0.009
Total	1454

Figure 17.— Manganese Cycle: Flows and Losses, 1974
(Millions of short tons)



SOURCE: Working Papers One and Two.

CHROMIUM

Chromium is used primarily as an alloying element in stainless and heat-resistant steels; in chemicals, including those required for plating; and in refractories. Although chromium is expensive as a metal ($2.60 per lb), it is as low-priced as ferrochrome (30 cents to 45 cents per lb of contained chromium) or as the ore (28 cents per lb of contained chromium). Figure 18 presents the flows and losses in the 1974 domestic chromium cycle. About 840,000 tons of contained chromium in the form of chromite, ferroalloys, and scrap are consumed in materials processing and manufacturing. Figure 18 indicates that of the 724,000 tons of contained chromium used by end-product manufacturers, 639,000 tons were embodied in end products in 1974. Table 14 lists end products manufactured in 1974. Table 15 gives estimates of the amount of chromium contained in the end products that became obsolete in 1974. These estimates of obsolescence were based on assumed values of useful life for each of the product's market categories. Table 16 presents estimates of the amount of obsolete chromium that was recovered and recycled in 1974. Most of the 51,000 tons of contained chromium recycled in 1974 was recovered from transportation equipment and industrial machinery.

Based on the foregoing, losses from the chromium cycle in 1974 were as follows:

Losses	*Thousands of tons*
Dissipated uses	113
Unrecovered and unknown	110
Process losses	83
Manufacturing losses	
Corrosion and wear	Nil
Total	311

Table 14.–Products Manufactured From Chromium-Containing Materials in 1974 (thousands of short tons of contained chromium)

Market category	Quantity
Construction	128
Transportation	102
Machinery	85
Refractories	71
Chemicals and plating	77
Fabricated metal products	77
Other	99
Total	639

SOURCE Working Papers One and Two

Table 15.–Obsolescence of Chromium-Containing Products in 1974 (thousands of short tons of contained chromium)

Market category	Assumed average useful life (years)	Quantity
Construction	30	29
Transportation	13	39
Machinery	16	20
Refractories	1½	55
Chemicals and plating	10	58
Fabricated metal products	10	39
Other	15	34
Total		274

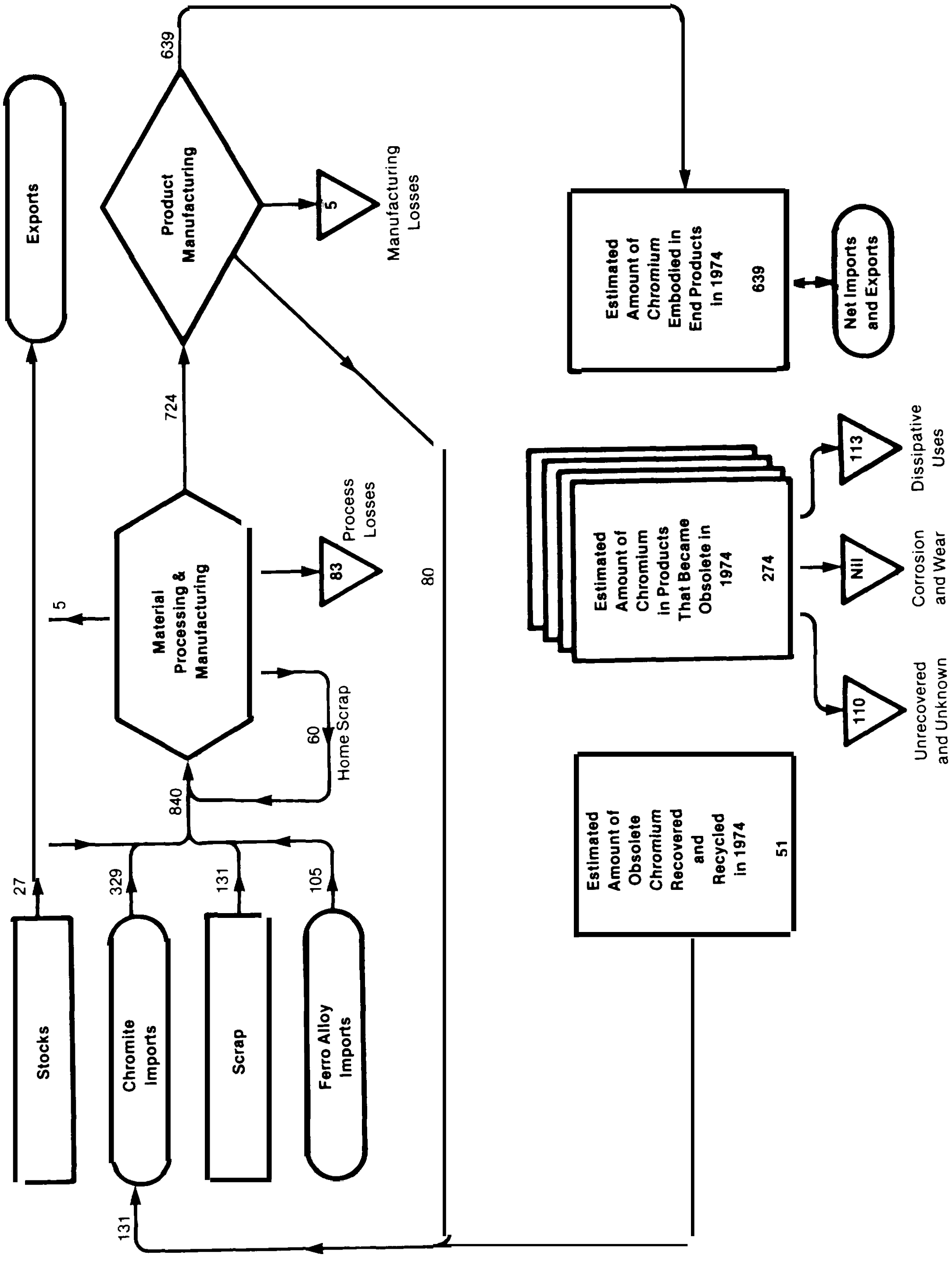
SOURCE Working Papers One and Two

Table 16.–Recycling and Recovery of Chromium in 1974 (thousands of short tons)

Market category	Estimated percentage of obsolete chromium recycled	Quantity
Construction	10	3
Transportation	60	23
Machinery	55	11
Refractories	–	–
Chemicals and plating	–	–
Fabricated metal products	10	4
Other	30	10
Total		51

SOURCE Working Papers One and Two

Figure 18.—Chromium Cycle: Flows and Losses, 1974
(Thousands of short tons of contained chromium)



SOURCE: Working Papers One and Two.

NICKEL

Nickel is a relatively high-priced ($1.74 per lb in 1974), moderate-volume (250,000 tons industrial demand in 1974) specialty metal. About half the annual consumption is by the steel industry in the manufacture of stainless and heat-resisting steels and in alloy steels. One-fourth is consumed in the manufacture of heat- and corrosion-resistant nickel-base alloys and superalloy. About one-eighth is used in electroplating, and the remainder is used as an alloying element in other nonferrous alloys and in various chemical and miscellaneous uses.

Estimates of the flows and losses from the total domestic nickel cycle are given in figure 19. Referring to figure 19, about 252,000 tons of contained nickel were used by end-product manufacturers, of which about 211,000 tons of contained nickel were embodied in end products in 1974.

The estimated amount of nickel embodied in end products in 1974 by product category is given in table 17. From a weighted average of product life for the various broad market categories, the overall "life" of nickel-containing products is probably about 18 years. In the year 1956, an estimated 170,000 tons of nickel in end products entered service. Hence it was estimated that this amount would become obsolete in 1974.

On the basis of fragmentary information, it was estimated that about 25,000 tons of nickel in obsolete products were recycled in 1974. From the foregoing, losses of nickel from the materials cycle in 1974 were estimated as follows:

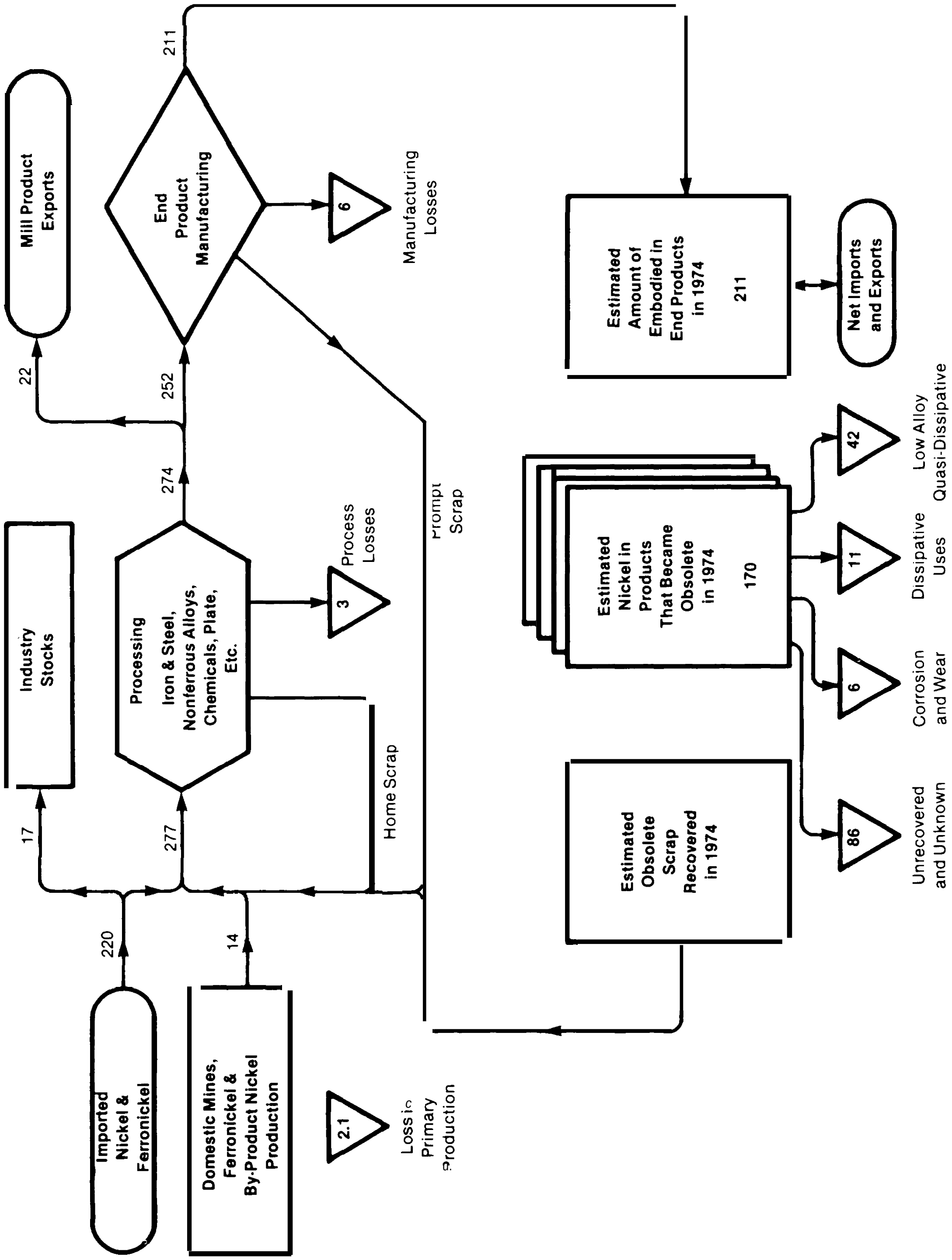
Losses	*Thousands of tons*
Unrecovered and unknown	86
Dissipative	53
Wear and corrosion	6
End-product manufacture.	6
Alloying and mill product manufacturing	3
Domestic ferroalloy manufacturing	2
Total	156

Table 17.–Estimated Nickel Embodied in End Products in 1974
(thousand short tons)

Market category	Quantity
Appliances. . .	13
Other domestic equipment ., ...	9
Ordnance and military	5
Construction ., ...,	7
Contractors products.	16
Automotive	40
Rail transportation	5
Shipbuilding and marine	12
Aircraft ...	18
Oil and gas. .,	10
Mining, quarrying ., ...	5
Agricultural equipment ...	3
Machinery and industrial equipment	49
Electrical machinery ., ...	19
Total	211

SOURCE Working Papers One and Two

Figure 19.—Nickel Cycle: Flows and Losses, 1974
(Thousands of short tons)



SOURCE: Working Papers One and Two.

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TUNGSTEN

Tungsten in any form is a valuable commodity. In 1974 its value was nearly $5 per pound, and in the past 3 years the price has nearly tripled. The various sectors for domestic manufacture of tungsten-containing products in 1974 handled 16,000 tons of new and recycled tungsten. In comparison with most other materials, tungsten is regarded as a low-volume, high-priced specialty metal.

Flows and losses from the domestic tungsten cycle are given in figure 20. In 1974, 14,800 tons of contained tungsten were processed from foreign and domestic sources. After accounting for changes in industry stocks and tungsten product exports, 9,100 tons of contained tungsten were used by fabricators and manufacturers. About 8,100 tons of contained tungsten were embodied in end products in 1974. Table 18 provides a breakdown by end-product category of the tungsten embodied in manufactured products in 1974. Table 19 provides estimates of the amounts of tungsten that became obsolete in 1974 and the amounts that were recovered. Table 19 shows that the recovery and recycling of tungsten came primarily from the tools, guides, and dies used in metalworking machinery and cutting tools used in mining and construction.

Based on the foregoing, losses from the domestic tu ıgsten cycle in 1974 were as follows:

Losses	*Thousands of tons*
Unidentified losses	2.5
Exports of tungsten products	2.3
Discard of tungsten carbide inserts	2.1
Dissipative uses	1.9
Tungsten processing and manufacturing	1.0
Domestic milling and concentrating of tungsten areas and byproducts	0.35
Total	∩ 5

Table 18.—Products Manufactured From Tungsten-Containing Materials in 1974
(thousand short tons of contained tungsten)

End-product category	Estimated amount of tungsten quantity
Metalworking machinery	4.2
Cutting tools	(2.2)
Guides, dies, etc.	(2.0)
Mining and construction	1.5
Cutting tools	(0.9)
Wear resistant surfaces	(0.6)
Transportation	1.0
Lamps and lighting	0.6
Electrical	0.3
Chemical	0.2
Other	0.3
Total	8.

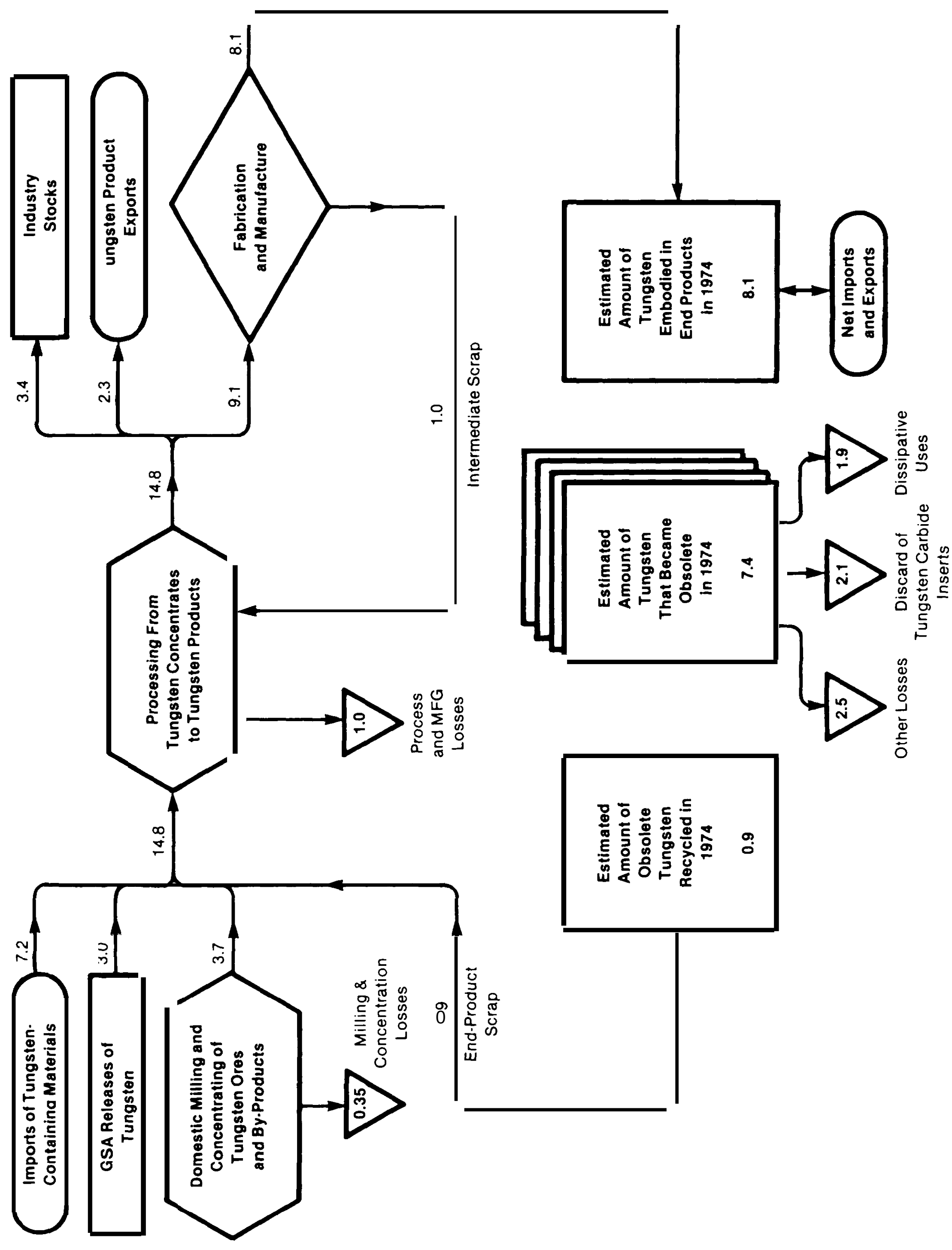
SOURCE: Working Papers One and Two.

able 19.—Estimated Amount of Tungsten That Became Obsolete in 1974 and the Amount Recovered and Recycled
(thousand short tons)

Market category	Estimated age of products (years)	Amount that became obsolete	Obsolete scrap recovery	Percent recycled
Metalworking machinery				
Cutting tools	<1	2.3	○5	22
Guides, dies, etc.	5	1.7	○2	12
Mining and construction				
Cutting tools	<1	0.9	0.2	22
Wear-resistant parts	10	0.4		
Transportation	3	0.9		
Lamps and lighting	3	0.6		
Electrical	' 5	0.2		
Chemical	1	0.2		
Other	, 0	0.2		
Total		7.4	0.9	˙2

SOURCE: Working Papers One and Two

Figure 20.—Tungsten Cycle: Flows and Losses, 1974 (Thousands of short tons)



SOURCE: Working Papers One and Two

SUMMARY OF LOSSES FOR SELECTED METALS

A summary of the losses in physical terms is shown in table 20. The losses are listed in the sequence of materials flow—from mining through processing and manufacture and then through usage and recycle. As indicated in table 20, the largest quantities of losses in physical terms are those associated with the high-volume basic materials—iron and steel, aluminum, and copper. Quantities classified as unrecovered and unknown are significant because of their size and because they represent losses that one way or another enter the environment in the form of gaseous, liquid, or solid waste.

In order to develop a better perspective on the various kinds of losses, table 21 gives estimates of losses in percentage terms. In each case, the losses are expressed as a percentage of domestic shipments of mill products of the metal. In other words, these percentages are expressed as a percentage of the amount of metal flowing at one place, arbitrarily selected, in the cycle–shipments of mill products.

As shown in table 21, the most significant losses take place at the end of the materials cycle (unrecovered material, postconsumer waste, dissipative uses). If there are to be substantial reductions in metal losses, techniques must be developed and implemented with emphasis placed on the end of the materials cycle. The end of the material cycle is important for another reason: for each pound of material saved at the end of the cycle, the accumulated losses associated with the production and use of that pound of metal are also saved. For example, referring to the steel flow diagram in figure 13, 110.8 million tons of steel were embodied in production in 1974. Direct losses associated with the production of that amount of steel are 39 million tons of processing losses. Thus for each pound of material in a product, 0.35 lb has been lost in reaching the product stage. This means that 1 lb of metal saved at the end of the cycle translates into a total of 1.35 lbs saved.

Table 20.—Quantities Lost From the Materials Cycle of Selected Metals, 1974

	Quantities lost from cycle							
Nature of loss from cycle	Iron and steel (million short tons)	Aluminum (million short tons)	Copper (million short tons)	Platinum (million troy ounces)	Manganese (million short tons)	Chromium (thousand short tons)	Nickel (thousand short tons)	Tungsten (thousand short tons)
Milling and concentrating	23.3	0.2	0.4	Nil[b]	0.012	0	2.1	0.35
Transportation and handling[a]	(c)	0.2	·	Nil	0.023	Nil	Nit	Nil
Nonmetallic uses of raw materials	Nom[d]	0.8	0.1	Nom	0.12	71	Nom	Nom
Metal processing	6.8	0.4	0.074	0.015	1.1	83	3	1.0
End-product manufacture	1.1	0.1	0.006	0.009	0.009	5	6	Nil
Exports (net)								
Mill products	(10.2)[e]	0.6	(0.1)	(2.1)	(0.1)	0	0	2.3
End products		na	na	na		na	na	na
Scrap	7.8	0	0	0	0.05	0	0	b
Dissipative and quasidissipative uses	5.4	0.6	[illegible]	[illegible]	[illegible]	[illegible]	53	1.9
Corrosion and wear	4.0	Nil	Nil	0.01	0.03	Nil		(9)
Postconsumer waste	11.0	1.0	0.2	(h)	0.08	(h)	(h)	2.1
Uncovered (and unknown)	19.4	0.4	0.9	0.14	0.15	110	86	2.5

[a] These losses from the materials cycle are in nonmetallic form and low in value. Such losses cannot be compared directly with other losses of metallics later in the cycle.
bNil = amount of losses close to zero.
cIncluded in "metal processing losses."
dNom = small but undetermined amount of losses.
e() = net imports.
fna = data not obtained.
gIncluded in "dissipative losses "
hIncluded in 'unrecovered and unknown losses."

SOURCE Working Papers One and Two

Table 21.— Percentage Losses From the Materials Cycles of Selected Metals, 1974

Nature of losses from cycle	Losses as a percentage of 1974 domestic shipments of contained metal[a]							
	Iron and steel	Aluminum	Copper	Platinum	Manganese	Chromium	Nickel	Tungsten
Milling and concentrating	19	3	15	Nil[c]	1	Nil	1 –	2
Transportation and handling[b]	d	3	—	Nil	3	Nil	Nil	d
Nonmetallic uses of raw materials.	Nom[e]	11	4	Nom	13	11	Nom	Nom
Metal processing	4	5	3	0.5	122f	12	1	7
End-product manufacture	1	1	1	0.3	1	1	3	Nil
Exports (net)								
Mill products	(8)[i]	8	(4)	0	11	0	0	15
End products	na[j]	na	na	na	na	na	na	na
Scrap	6	0	0	0	6	0	0	g
Dissipative and quasidissipative uses	4	6	11	9	4	16	23	13
Corrosion and wear	3	0	Nil	0.4	3	Nil	3	h
Postconsumer solid waste	9	14	7	g	9	g	g	14
Unrecovered (and unknown)	16	5	33	5	16	15	37	17

[a]All losses are expressed as a percentage of 1974 domestic mill shipments of mill products containing the metal. For reference purposes, the total 1974 domestic mill shipments for each metal were as follows, in millions of short tons Fe (124 3), Al (7.2), Cu (2 7), Pt (3 9 million troy ounces), Mn (O 9), Cr (O 724), Ni (O 274), W (O 0148).

bThese losses from the materials cycle are in nonmetallic form and low in value Such losses cannot be compared directly with other losses of metallics later in the cycle

[c]Nil = amount of losses close to zero

d Included in "metal processing losses"

eNom = small but undetermined amount of losses

fLosses of manganese exceed 100 percent because more manganese is lost as a slag in the Sseelmaklng process than is contained in the steel products actually shipped

gIncluded in "unrecovered and unknown losses"

h Included in "dissipative losses"

1( ) = net Imports

Ina = data not obtained

SOURCE: Workinq Papers One and Two

IV.

Identification of Technical Options for Reducing Losses From the Materials Cycle

IV.

Identification of Technical Options for Reducing Losses From the Materials Cycle

This chapter reviews each of the loss categories discussed in chapter III in order to identify techniques for reducing these losses.

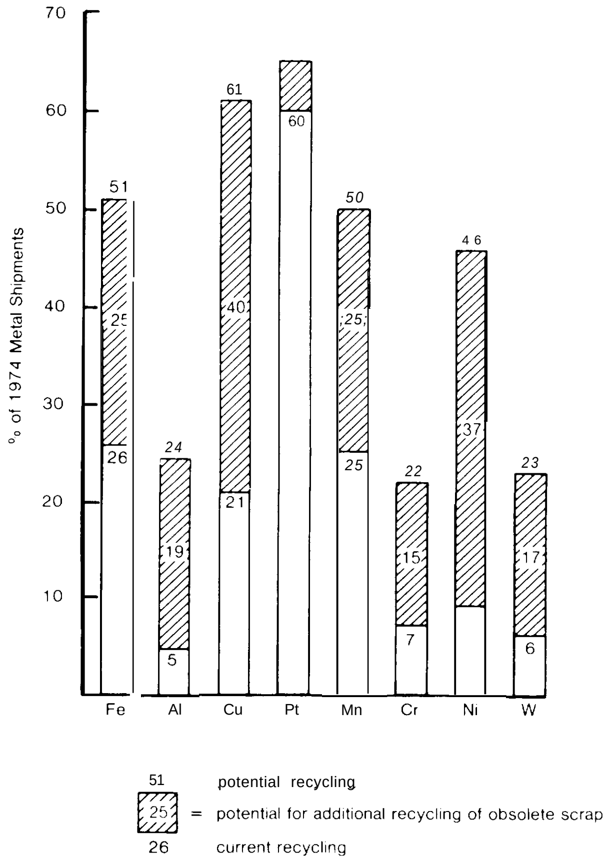
UNRECOVERED AND UNKNOWN LOSSES

As shown in the flow charts (figures 13 to 20), most industrial scrap is effectively recycled. On the other hand, estimates of unrecovered and unknown losses range from 5 to 37 percent of shipments (table 21). Regardless of estimating errors included in these figures, such losses are substantial. Figure 21 shows current levels of obsolete scrap recycling as a percentage of 1974 mill shipments. The data is from figures 13 to 20. With the exception of platinum, current recycling of obsolete scrap ranges from 5 to 26 percent. The potential for additional recycling is calculated as the sum of the unrecovered materials and postconsumer waste (from table 21), and ranges from 5 to 40 percent. However the extent to which this obsolete scrap can actually be recovered is a matter of considerable controversy.

The Institute of Scrap Iron and Steel contends that there is a large inventory of obsolete iron and steel scrap that has accumulated over the years. This view has been substantiated by two studies, the most recent of which places the inventory at over 600 million tons.[1] On the other hand, some economic studies indicate that this scrap may not be available even with much higher scrap prices.[2]

In order to gather further information on this question, the flow of obsolete products (and the metals and other materials contained in them) to their "final resting place" was evaluated for six kinds of products (buildings, lathes, office equipment, pipelines, refrigerators, and television sets) in five geographically dispersed cities of the United States. The results, which are described in detail in chapter VI, show that many of these products

Figure 21.— Recycling of Obsolete Scrap



SOURCE: OTA, based in part on data from Working Papers One and Two.

[1] Robert Nathan Associates, *Iron and Steel Scrap: Its Accumulation and Availability as of 31 December 1975*, prepared for The Metal Scrap Research and Education Foundation, August 1977.

[2] William T. Hogan and Frank T. Koelble, *Purchased Ferrous Scrap: U.S. Demand and Supply Outlook*, Industrial Economics Research Institute, Fordham University, June 1977.

rapidly find their way to landfills even though they bypass the municipal solid waste system. While not completely conclusive because of the limited range of products examined, the results do indicate that the amount of obsolete scrap available for recycling is smaller than previously calculated. However, this only reinforces the need for additional recycling to prevent materials from being lost forever.

The barriers to obsolete scrap recycling have received detailed study.[3] Obsolete scrap has a limited market and competes with higher quality virgin ore and industrial scrap that has a known consistency and presents fewer collection difficulties. Options for increasing obsolete scrap recycling include: industry goal-setting, investment tax credits, tax deductions for usage, product charges, reduction of freight rate chages, and additional research. Several of these options are included in current energy legislation and have been studied in detail in another OTA assessment.[4]

One final option is product rework and reuse. Most obsolete scrap is available in the form of a product. And as a product (with workable components), the scrap has more value than the metal alone. The main reason that products are not reused is the lack of a well-established institutional framework for collecting obsolete products and introducing them back into service in one form or another. Product rework and reuse as a recycling option are discussed in detail in chapter VI.

[3] *Economic and Technological Impediments To Recycling Obsolete Ferrous Solid Waste,* NTIS report PB-223034, October 1973.

[4] *Materials and Energy From Municipal Waste* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, July 1 979), OTA-M-93.

LOSSES IN THE POSTCONSUMER SOLID WASTE STREAM

Postconsumer solid waste includes beverage and food containers, worn-out residential and commercial hardware, obsolete and worn-out small appliances, toys, sporting goods, automotive parts, etc. Such obsolete parts become a minor but significant part of the total refuse stream of kitchen waste, paper, glass, and plastics. As shown in table 21, large quantities of basic metals are in the postconsumer solid waste stream, representing 7 to 14 percent of domestic shipments of the metals studied. The total ferrous content of solid wastes is about 11 million tons of iron and steel (which ineludes manganese and other alloying elements). In all probability, there are substantial quantities of other metals in postconsumer solid waste, roughly in proportion to this general usage.

Options for solid waste handling and resource recovery from the postconsumer solid waste stream are the subject of another OTA assessment, and are therefore not discussed in this reports

[5] U.S. Congress, Office of Technology Assessment, *Materials and Energy From Municipal Waste: Volume II Working Papers,* July 1978.

LOSSES IN DISSIPATIVE USES

Dissipative uses involve the dispersal of metals and alloys by chemical action or physical dispersion during use. For example, aluminum pig and aluminum scrap are used in the deoxidation of steel. The aluminum is lost as an oxide in the slag. Another dissipative use of aluminum is as a powder in the manufacture of aluminum paint or in munitions. Similarly, uses of steel such as in reinforcing bars or as nails are considered dissipative.

As another example, large quantities of alloying elements are used at low levels in the production of high-strength low-alloy steels. These steels with low levels of alloy content are difficult to identify and segregate from the ferrous scrap stream. As a result, alloying elements such as chromium, nickel, and tungsten are diluted and lost in the normal recycling of iron and steel scrap.

Referring to table 21, from 4 to 23 percent of the domestic shipments of the selected metals is lost in dissipative uses. A number of technical and economic barriers make it difficult to reduce this form of waste. In cases where metals and alloys are dispersed by chemical action, performance and cost considerations dictate their use over other materials and processes. For example, aluminum is used in the deoxidation of steel because aluminum is a reactive metal at the temperature of molten steel and is more effective and lower in cost than other alternatives.

In cases where metals and alloys are physically dispersed as nails, hairpins, etc., the costs of their collection would be very high in relation to the value of the metal they contain.

If there is to be conservation here, it will be through the development of substitutes on a case by case basis. Research and development on substitute materials and processes is underway and would be accelerated by any threat to supply. However much of this work is uncoordinated and sporadic.

LOSSES IN EXPORTS

Of the metals studied, none has a large net export. On the contrary, imports of metals are a major problem for domestic producers. A large amount of material does leave the United States through exports of fabricated products. However, specific quantities are not known since data on imports and exports of fabricated products are available only in terms of dollars and number of items. A detailed analysis would have to be made to calculate the total metals contained in such products. As shown in table 21, a significant amount of aluminum and manganese is lost from the domestic materials cycle through exports of iron and steel scrap.

Losses through exports differ from other kinds of losses because of foreign policy concerns. For several years the United States has needed to increase exports in order to reduce an unfavorable balance of payments. Further increases in exports and imports are an integral part of U.S. foreign policy and relations with all countries in the free world. Any change in the pattern of exports, and particularly through overt imposition of export controls, would likely have severe political repercussions and invite counter restrictions. In addition, controls on fabricated product exports would be a high price to pay for metal, since products on the average have a value of from 2.5 to 5 times their contained metal, During an emergency, however, this approach could be and has been used as a materials conservation measure.

LOSSES IN MILLING AND CONCENTRATING OF ORES

After mining, ore is usually beneficiated before smelting. Beneficiation involves milling of the raw ore and processing to separate the desired mineral from the rock associated with it. Although large quantities may be lost in the milling and concentrating steps, the value of the material lost is low and the cost of further recovery is high.

This report has focused on losses from the domestic materials cycle. Any losses from milling and concentrating in a foreign country are outside of the domestic materials cycle and the scope of this report. The low level of milling and concentrating losses for aluminum, platinum, manganese, chromium, nickel, and tungsten reflects U.S. dependence on imported concentrates and semirefined products of these metals. In this case, much of the waste occurs overseas.

With respect to beneficiation of iron and copper ores, the level of losses is fixed by the technology and economics of processing taconite (iron ore containing about 25 percent iron) and low-grade copper ores (containing 0.4 to 0.8 percent copper). Presently available technology cannot significantly reduce the losses shown in table 21. In addition, processing of lower grade ores incurs increasing energy and environmental costs.

One obvious option is to increase imports of high-grade ore concentrate. Higher grade deposits of iron ore and many other metals are available outside the boundaries of the United States. But increasing U.S. dependence on imports raises serious questions about the amount of risk associated with dependence on foreign supplies. This must be balanced against the increased costs of energy and environmental controls that would be required in domestic processing of lower grade ores.

Another option for reducing losses during milling and concentrating is to invest in a major R&D program directed toward increased recovery of metal values from low-grade ores. Most experts in the field point to the need for research in fine-particle separation, since a considerable portion of the losses during milling and concentrating are in the form of fine particles and slimes. A major advance in fine-particle technology might bring about significantly increased recovery rates and reduced losses. In this way, a higher proportion of the mineral values in the ground might be economically converted to usable concentrates.

LOSSES IN METAL PROCESSING

The metal-processing stage of the materials cycle includes smelting, refining, and producing mill products. These operations are generally capital-intensive. As shown in table 21, losses in metal processing range from less than 1 to 12 percent of domestic shipments of the selected metals—except for manganese. The use of manganese in steelmaking is unique. A substantial portion of the manganese functions as a reagent in removing oxygen and in controlling sulfur in steel.

The major barriers to waste reduction in the processing of metals are technological and economic. Current technology is the average technology of all plants in operation. Average technology shows improvement only as new plants with new technology are brought online and old plants with old technology are either upgraded or dismantled. Substantial time and financing are required to turn over the capital stock in any of these basic material industries.

Besides capital replacement using new technology, few options are available for making a significant reduction in the losses associated with metal processing. One exception is the use of alternatives to manganese for controlling sulfur in steelmaking. Materials such as magnesium and calcium carbide can be used in external desulfurization processes. The economics of alternative desulfurization processes depend on many technical factors and the availability and cost of manganese. Thus far, manganese has a clear-cut cost advantage over available alternatives. Nonetheless, significant changes in availability of manganese and or costs of the alternatives could change this picture.

LOSSES IN END-PRODUCT MANUFACTURE

The losses in end-product manufacture for the selected metals range from less than 1 to 3 percent of domestic shipments of mill products. These relatively low levels of loss occur as metals are fabricated into end products, such as automobiles, appliances, electrical equipment, and buildings. The losses are associated with literally hundreds of different types of fabrication processes. Since the losses are so small, opportunities for conservation are limited to marginal improvements in management controls over the manufacturing process.

LOSSES IN CORROSION AND WEAR

As indicated in table 21, losses of material directly associated with corrosion and wear are generally small and range from essentially O to 3 percent of domestic mill shipments. These are direct losses from corrosion and wear and do not include indirect losses from the effects of corrosion and wear on product life, which are discussed in chapter V. Thus, promoting improved corrosion and wear resistance is not an efficient way to reduce material losses, but there can be substantial economic benefits through improvements in reliability, durability, and performance.[6] In addition, as is shown later, the development of improved corrosion and wear resistant treatments can be used to build a great deal of flexibility into materials usage.

[6]L. H. Bennett, *Economic Effects of Metallic Corrosion in the United States,* A Report to the Congress, National Bureau of Standards, March 1978.

LOSSES IN NONMETALLIC USES OF RAW MATERIALS

The nonmetallic use of raw materials varies substantially. Significant quantities of aluminum, chromium, and manganese raw materials are used in ceramics, abrasives, refractories, and chemicals. These are generally accepted uses of metals and would not receive separate consideration except for the fact that many of such uses are dissipative. Because of this, the same options for reducing losses would apply to nonmetallic uses as would apply to dissipative uses.

SUMMARY OF TECHNICAL OPTIONS

The technical options that have the greatest leverage in reducing each category of loss are shown in figure 22. The most highly leveraged options are scrap and metal recycling, R&D on substitute materials and/or processes, and R&D on metal recovery from low-grade ores.

Metal recycling and product remanufacturing have multiple leverage because, in addition to the direct reduction in losses of unrecovered metals in obsolete products, these options lead to an additional savings in future years. For example, if through product recycling an additional 10 percent of obsolete office equipment in a given year is remanufactured, 10 percent less metal will be required for next year's production run (assuming constant demand). This will also eliminate the losses (e.g., milling and concentrating) that would have been associated with producing that amount of metal.

Figure 22.—Technical Options for Reducing Losses in the Materials Cycle

Loss category	Range of losses"	Technical conservation option
Unrecovered metals	**5-37%**	**Metal recycling** **Product remanufacturing and reuse**
Dissipative uses	**4-23%**	**R&D on substitute materials and/or processes**
Milling 8 **concentrating**	**Nil-19%**	**R&D on metal recovery** from low-grade ores, e.g. fine *particle* technology
Exports of scrap& milt products	**0-17%**	**Export controls**
Postconsumer solid waste	*5.14%*	**Productr recycling**
Metal **processing**	0.5"12% (Mn=122%)	**Capital** *replacement* **Alternative desulfurization** *process (for Manganese)*
Nonmetallic uses of raw materials	**Wrn-11 %**	R&D on **substitute metals & processes**
End-product manufacture	**Nit-3%**	**Improved management controls**
Corrosion and wear	**Nil-3%**	R&D on **improved corrosion and wear resistant treatments**
Transportation & handling	**Nil-3%**	*Improved management controls*

• Range of losses for the eight metals in percent of 1974 domestic mill shipments
See figure 3 and tables 20 and 21 in chapter III for metal specific data
Nom = small but undetermined amount of losses.
Nil = amount of losses close t o zero.

SOURCE: OTA based in part on data from Working Papers One and Two

V.

Design Review of Technical Options for Reducing Excess Material in the Cycle

V.

Design Review of Technical Options for Reducing Excess Material in the Cycle

METHODOLOGY

The second major class of waste is the use of excess materials in the materials cycle. This chapter identifies technical options for reducing materials usage in the design, manufacture, and use of products.

Table 22 presents a list of options grouped in six basic classes or categories:

- use of less metal in products,
- substitution for critical metals,
- product rework and reuse,
- extended design life and durability,
- reduced inventories and overproduction, and
- use of less intensive materials systems and products.

These are technical options that, if implemented, would reduce metal usage. The list does not include implementation options such as education, increased R&D, and regulations, which could be used as a means of implementing a given technical option. Implementation options are considered in chapter VII.

The overall approach of this chapter's analysis is shown in figure 23. For selected products, the potential material saving for each option was estimated by conducting a design review. The design review was carried out on a product-by-product and component-by-component basis for each of the eight metals studied in chapter IV.

Table 22.—Options for Materials Conservation in Product Design, Manufacturing, and Use

Use of less ***metal***
- Reduce size
- Stress optimization
- Better manufacturing techniques
- Eliminate unessential components
- Functional changes in product
- Standardization of components
- Design for recycle
- Decreased scrap generation
- Powder metallurgy manufacture

Substitution for critical materials
- Use of less critical materials
- Use of renewable resources
- Recyclable materials for nonrecyclable

Extended life through rework and reuse
- Product rework
- Reuse of components
- Remanufacture of components

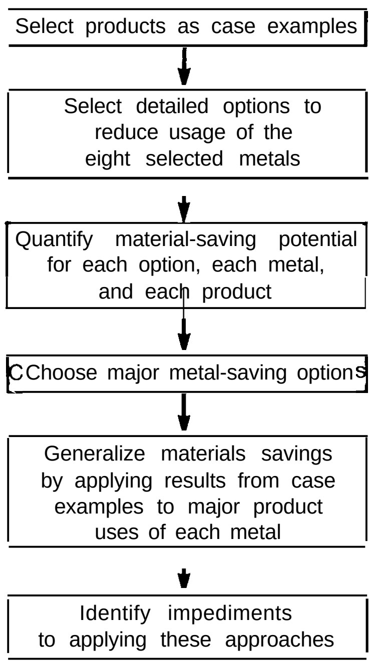
Extended design life and durability
- Reduced obsolescence
- Failure avoidance
- I reproved maintenance procedures
- I reproved corrosion and wear resistance

Reduced inventories and production
- Combined inventories
- Production control

Use **of less-intensive materials systems and products**
- Use of coatings for alloys
- Reduction of alloy content
- Combined usage of products

SOURCE: OTA, based on Working Paper Three

Figure 23.— Methodology for Evaluating Options for Reducing Excess Material in the Cycle



SOURCE: OTA

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Estimated material savings were then generalized to a whole range of products that contained the metals under evaluation. For example, if 10 percent of steel used in automobiles could be saved by a stress-optimized design, that percentage was applied to all transportation products containing a given amount of steel.

Because of the great variety of products and the large variations in material usage in each product, only a few products could be selected for review of their design, manufacture, usage, and disposal. The products are listed in table 23. These products were selected because they are typical of the specific industries indicated and because each product uses a relatively large amount of metal.

Table 23.—Products Selected as Case Examples

Industry	Product
Transportation	Automobile
Appliances	Refrigerator
Construction	Buildings Bridges
Machinery	Lathes Tractors
Fabricated metal products	Cans

SOURCE: OTA.

DESIGN REVIEW OF SELECTED PRODUCTS

In order to quantify the amount of material that could be saved using the technical options listed in table 22, a design review of each of the products listed in table 23 was carried out. The details of the methodology are described in the *Working Papers* (vol. II-C); an example of the methodology for refrigeration is given in chapter VI. Basically, each product and component were reviewed for alternative designs that would use less metal. The metal savings would be the difference in metal usage between the present and the proposed design.

The potential metal savings of every option is shown by product in table 24, The numbers in the table represent the percentage of the total weight of the product that could be saved or substituted for. For substitution options, the numbers represent the percentage saved of the second metal by substituting the first. A hyphen (dashed line) in the table indicates the savings are small but that no quantitative estimate has been made. NA indicates an option is not applicable to the product.

These numbers are engineering judgments of the overall conservation potential for the listed options. The numbers are interdependent in that implementation of one option will reduce the saving possible with another option. Also, the percentages shown indicate the savings that are technically possible. Economic and other factors may severely limit the actual savings. Finally, the purpose of these numbers is only to identify the most promising options, not the practicalities of implementation.

As shown in table 24, the potential metal savings are generally small for options that would use less metal. Removing excess metal through improved manufacturing techniques shows significant potential for metal cans, but not for other products. Stress optimization or "design to stress" is generally applicable and could save up to 30 percent of the metal depending c n the product. Other options save insignificant amounts of metal either because they represent the current practice or because they cannot be implemented. Design for recycling is not an effective strategy at present because it is not the design that limits the recycling, but rather ineffective methods of disposal and metal separation. This situation may improve in the future, but the net effect on material savings cannot be ascertained at this time (as indicated by an "X" in table 24).

Initially, standardization of components appeared to be a desirable option for saving metal through a reduction of inventory. However, this investigation showed that standardization could lead to increased, rather than decreased, use of metals because all components would have to be designed for the maximum usage condition. To be effective, standardization would have to be combined with component recycling so that the built-in excess durability could be fully utilized.

Substitution as a general option has the widest applicability and offers the largest potential savings. A substitution of one metal for another does not reduce the overall use of metal nor would substitution be an effective option if all materials, in-

Table 24.—Potential Metal Savings of Conservation Options for Selected Products

	Product					
	Cars	Refrigerators	Tractors	Lathes	Cans and containers	Fabricated metal structures
Use of less metal						
Reduce size	3-45	**10**	1	NA	NA	NA
Better manufacturing techniques	**1-6**	< 1	2	8	{23-33}	NA
Stress optimization	5-16	*30*	*2*	8		NA
Eliminate unessential components	< 1	—	—		NA	
Functional change	< 1	—	—		—	—
Standardization of components	< 1	—	—		NA	**10**
Design for recycle	< 1	x	—	—	x	**x**
Decrease scrap in manufacturing	2	1-2	< 1	1-2	—	—
Powder metallurgy	3-5	1-2	< 1	1-2	**100**	
Product recycling						
Product rework	15	80	NA	NA	NA	NA
Reuse of products or components	NA	NA	NA	NA	0-80	10-80
Remanufacture of components	15	1	50	5	NA	NA
Substitution’						
Al/steel	68	74	< 1	2	**100**	*40*
Plastic/steel	17-20	31-85	< 1	2	*40*	NA
Al/Cu	100	100	100	100	NA	100
HSLA/St	6	NA	2	1	NA	30
Steel/Al	100	75	NA	NA	100	100
Wood/steel	NA	NA	NA	NA	NA	< 30
Concrete/steel	NA	NA	NA	*50*	NA	*< 30*
Composites	*0-90*	*0-84*	< 1	4	NA	NA
Glass/St	NA	NA	NA	NA	40	NA
Glass/Al	NA	NA	NA	NA	91	NA
Lead/steel	NA	NA	30	NA	NA	NA
Plastic/Al	NA	NA	NA	NA	91	NA
Increase product life						
Increase component life	50-60	60	3	3	NA	—

Numbers indicate percentage of metal, by weight, that could be saved for each option and product studied A dash means negligible metal could be saved. NA means that option is nonapplicable X means savings cannot be determined at thls time
.The substitutions should be interpreted as follows, for example
Al/steel = substitution of aluminum for steel.
Al/Cu = substitution of aluminum for copper
HSLA/St = substitution of high-strength low-alloy steel for steel.

SOURCE: Working Paper Three.

eluding plastics, were in short supply. However, where a supply crisis develops with a particular metal (or material), substitution would be the most effective option if there were sufficient time to implement it.

Product recycling appears to be an effective option. A product reaching the end of its life (as defined by its owner) maybe returned to useful life in a variety of ways. It may be used again in its current state (reuse). Either the whole product or its individual components can be repaired, reworked, or remanufactured. Repaired means that the product is made operable. Reworked means that the product is returned to its orginal state or close to it by adding new parts, repairing parts, painting, etc. (overhaul). Remanufacture means essentially the same thing as rework except that in remanufacturing the original parts are not reassembled (see glossary, appendix D).

Product rework appears to be technically possible for most products except cans (which only have one life) and structures. The potential of this option is limited for automobiles since most of the automobile is now effectively recycled, but would amount to about 80 percent (the same as refrigerators) if this were not the case. The rework option does not apply to tractors and equipment that are already used almost to the limit of their useful lives.

Reuse of products or components offers some potential savings for containers and fabricated metal structures. The amount of metal saved would depend on the amount of metal used. Finally, remanufacturing of components is already extensively used for automobiles and could be applied to a wide variety of other products.

Increasing product life by increasing the lifetime of life-limiting components would save considerable metal, but only for certain products. A more detailed analysis is necessary to determine if enough products are involved to realize a substantial savings.

In sum, based on these selected products, the technical options that offer the greatest potential for saving metal are the following:

- substitution,
- stress-optimized designs,
- rework and reuse of products and components, and
- extended product life.

The following section presents estimates of the total savings possible if each of these options was applied to all products, not just the ones listed in table 24.

In table 25, the results from the specific case examples presented in table 24 are generalized to the industry as a whole. The numbers in table 25 are the percent of 1974 domestic shipments that could be saved by each option listed. The detailed methodology used to develop these percentages is described in volume II-C of the *Working Papers.* In brief, the percentages derived for the individual products were applied to all o the products within a given industry.

More specifically, the flows of materials were disaggregate into all major end-use products for each of the eight selected metals. Then each of the end-use products was placed in one of the following categories:

- transportation,
- electrical equipment,
- building and construction,
- industrial machinery and equipment,
- off-the-road equipment,
- commercial equipment,
- domestic equipment, and
- cans and containers.

Based on the data from table 24 and engineering judgments as to their applicability, the following metal-saving percentages were applied to the end-use products in each category.

1. For substitution, metal savings ranged from 2 to 100 percent with the following rough breakdown: (variations were also made on a metal-by-metal basis)
   - 2 percent for metalworking and manufacturing equipment;
   - 10 percent for tractors and related machinery;
   - 40 to 100 percent for building and construction materials;
   - 40 percent for electrical machinery;
   - 70 percent for appliances;
   - 70 to 100 percent for automotive; and
   - 100 percent for containers.
2. For using less metals, both manufacturing techniques and stress optimization were con-

Table 25.—Potential Metal Savings of Conservation Options[a]

Metal	Substitution	Substitution in construction industry[b]	Use of less metal[c]	Increase product life	Remanufacture of components	Reuse of products or components	Product rework
Aluminum	60	6	8	5	1	15	30
Copper	59	23	6	6	4	32	
Iron and steel	29	6	9	8	3	11	30
Chromium	16	—	4	5	2	6	12
Nickel	20	—	8	9	2	15	12

aNumbers indicate percent of total 1974 end use of each metal, generalized from product to industry.
bIncluded in substitution.
cBy better manufacturing techniques and stress optimization.
SOURCE: OTA, based on Working Paper Three.

sidered together. Where appropriate, the following numerical values were applied:
- 8 percent for machinery and manufacturing equipment;
- 10 percent for electrical machinery; and
- 10 to 20 percent for appliances, construction, containers, and automotive.

3. For increased product life, computations were carried out as follows: A factor of 50 percent was applied to automobiles, some appliances, household products, domestic and office furniture, and air-conditioners. Three percent was applied to some industrial equipment.

4. For remanufacture of components:
   - 15 percent for automotive, appliances, watches, clocks, motors, generators, transformers, and air-conditioners;
   - 50 percent for locomotives, tractors, and agricultural machinery; and
   - 5 percent for industrial materials-handling equipment.

5. For reuse of products and components:
   - 50 to 80 percent for architectural products such as windows, doors, screens, awnings, canopies, plumbing, and other builders' hardware; reusable containers such as barrels, pails, domestic and office furniture; wire and cable;
   - 10 percent for limited other categories such as cabinet sheet stock; and
   - The percentages shown for product rework were based on an independent study of the products for which rework was made possible and a determination of the amount of metal contained in these products.

For each technical option and metal, the total potential metal savings as a percentage of end usage is given in table 25.

VI.

Analysis of the Most Significant Technical Options for Reducing Excess Metals Use

Analysis of the Most Significant Technical Options for Reducing Excess Metals Use

Based on the design review in chapter V, the most significant technical options in terms of potential metal savings as a percent of domestic shipments are listed below:

- substitution (16 to 60 percent),
- product rework (12 to 43 percent),
- product reuse (6 to 32 percent),
- substitution in construction (O to 23 percent),
- eliminate unnecessary metal (4 to 9 percent),
- increase product life (5 to 9 percent), and
- component remanufacture (1 to 4 percent).

All of these options are discussed in more detail in this chapter, along with one general option not included in the design study (reduced use of materials-intensive systems). Particular attention is given to identifying the impediments or barriers to implementation of the technical options.

SUBSTITUTION

In theory, substitutes of one material for another are easily made, in a variety of ways, to cope with supply shortages. In practice, however, it is much more difficult; substitutes are not always available. [n product design, materials are selected based on a wide variety of criteria and specifications such as: strength, corrosion resistance, fatigue resistance, thermal expansion to match mating parts, damping capacity, strength to weight ratio, wear resistance, dimensional stability, modulus of elasticity, weldability, appearance, and, of course, cost. Thus, the selection of materials is always a compromise among a number of factors, and the necessity to substitute may make the product design inadequate or the product itself uncompetitive. Secondly, substitutes may not be available when needed; substitutions can take many years to implement, often longer than the duration of the shortage.

For these reasons, new product substitutions are relatively straightforward compared with the complexities of substitution for products already designed and in production.

The ease of making substitutions depends primarily on the type of production. Some products are made to order by assembling purchased materials and components (e.g., home construction). Under these circumstances, materials substitutions can be made with relative ease. To make a component from plastic instead of metal means selecting a different subcontractor who has the appropriate production equipment. Other products (e.g., lamps) are made with general production equipment (lathes, drill presses, etc.), which is either adaptable to various metals or is relatively inexpensive and can be changed as the need arises.

However, with many mass-produced products (e.g., autos, refrigerators) all the input elements, including materials, are optimized, and very specialized equipment is utilized.

Here, the material used is integral with the production method, including the form in which the metal is purchased (sheet, wire, powders, etc.) and the method of scrap salvage. In most cases, the particular talents of the labor force (welders, grinders, etc.) are also integrated with the materials and methods of production, and material changes are therefore expensive and slow to implement.

For example, a new engine or a new transmission in an automobile might require capital investments of $200 million to $500 million, a new body shell from $100 million to $500 million, and a new car between $500 million and $900 million. Just changing a single component can run into millions of dollars. One automobile manufacturer reports that the introduction of a plastic tailgate would alone cost $300,000. Even if accepted and introduced into limited production in 1979, the plastic tailgate would not be in full production until 1990.

Thus, if substitution is to be considered a workable alternative, greater flexibility must be built into the production process. Secondly, a new substitution involves a risk that will add to the product cost, even if no problems develop. Strong financial incentives will be required to speed up the substitution process.

PRODUCT RECYCLING (PRODUCT REWORK AND REUSE, COMPONENT REMANUFACTURE)

Product and part recycling may be viewed on a continuum ranging from full-scale remanufacturing to minor repair at the consumer level. In all instances, the life of the product is extended by bringing it back up to some useful functioning level of performance. An additional category "reuse" might be added to this continuum to imply reuse without any repair, refurbishing, or remanufacturing effort applied to the product or part. The returnable container is an example of product reuse.

Product remanufacturing is a process in which reasonably large quantities of similar products are brought into a central facility and disassembled. Parts from a specific product are collected by part type, cleaned, and inspected for possible repair and reuse. Products are then reassembled, usually on an assembly-line basis, using recovered parts and new parts where necessary. Product remanufacturing is a rather high-volume factory arrangement similar to new product manufacturing, except that the parts flowing to assembly lines are mostly reconditioned parts.

Product rework is a process where products are usually also brought back to some central facility for processing. However, on disassembly a product's component parts are kept together and after cleaning, inspecting, and replacing with new parts where necessary, the original product is reassembled with most of its original parts. Rework (also known as "refurbishing" or "reconditioning") is not as amenable to mass-production methods as is remanufacturing.

Lack of recycling of obsolete products does represent a major metal loss. Quality, cost, and other barriers have limited metal recycling. As a result, the use of obsolete scrap has increased only marginally during the past 20 years. Component and product recycling is a possible alternative that offers several distinct advantages over metal recycling.

Product recycling and reuse does have considerable potential to save metal, and it can be applied to a wide range of products. Indeed, product recycling is already taking place in a variety of forms. For example, automobile parts are extensively reworked and reused; aircraft are reworked on a periodic basis; some construction firms separate and reuse building components; and certain consumer durables like refrigerators are reworked and sold overseas.

In this assessment, a review was made of a variety of products that are currently recycled in order to determine if any common elements of successful recycling existed. The results are outlined in the following paragraphs:

1 Trucks: Several companies rebuild and sell trucks, and there is a strong demand for such vehicles. For automobiles, recycling is done only by the military and certain fleet owners. Product recycling is not practical for most autos because of the detail work that must be done (trim, upholstery, etc.) to restore the appearance to a level acceptable to the customer. In any case, an effective recycling system already exists. A major portion of the income of auto wreckers is from parts salvaged from

vehicles of all ages. Auto wreckers know the market for salvaged parts, and delay the final scrapping of auto hulks until the valuable parts have been removed. One of the markets for components, including engines and transmissions, is remanufacture of such components. The institutional problems and relationships in automobile manufacture, repair, and components salvaging make it difficult for any one institution to develop assured supplies and management control over all operations.

2. **Copying Equipment:** One of the major manufacturers of copying equipment has established a components and products salvage and remanufacturing operation for its main lines of copiers. In this case, the supplies of components and products and management control are all within one institution. This is because copying equipment is not sold but instead is leased and therefore remains under the control of the manufacturer. In this case, sophisticated diagnostic tools and high-technology repair facilities can be developed. All service and parts are the responsibility of, and in the control of, the manufacturer. As a result, the manufacturer has a better knowledge of service problems and is able to modify the design so that products are returned in better condition. The manufacturer can also modify the design to make the product easier to recycle.

3. Off-the-Road Equipment: One of the major producers of off-the-road equipment has a similar program of component salvage and remanufacture. Unlike copying equipment, most off-the-road equipment is sold to the user, and maintenance is the responsibility of the user. The off-the-road manufacturer has discovered that he can provide a valuable customer service in the form of a component salvage and rework operation. This service is provided at lower cost than could be achieved with new parts and components.

4. **Typewriters:** Extensive recycling of the IBM electric model C typewriter is carried out, both by private industry and by the Government. The General Services Administration (GSA) maintains a repair facility that repairs and reworks the IBM model C. Typewriters are collected during the repair process. The cost of rework is one man-day of labor plus miscellaneous parts cost. These typewriters are then resold to Government agencies at about one-half the cost of a new typewriter. The ingredients of success include: an existing collection pipeline, favorable economics of repair, and most important, a popular product. GSA rebuilds only this model because of the large volume and high demand. Rework is not done for other typewriters, which instead are sold as is or for scrap.

5. Aircraft: Aircraft are extensively refurbished. A study of the costs of rework for one military aircraft showed that a $6 million plane could be reworked for $120,000. However, this was done on a production-line basis with a well-developed system of parts inspection, inventory, and control. Each part is reworked in a prescribed manner and on a prescribed schedule.

Some examples of other recycled products include:

- machine tools,
- mattresses,
- diesel engines,
- auto bumpers,
- furniture,
- motors, and
- air-conditioning compressors.

From these examples, it can be seen that the major ingredient of success is the existence of a "pipeline" for pickup and resale where a close relationship has been established between repair or leasing facilities. Where appearance or style is important, the trend seems to be to salvage the parts and scrap the body of the product. To achieve economies of scale, it appears to be essential to use production-line methodology. Products reworked on a one-by-one basis are almost always more costly than the new models. Very complicated products with many features are also difficult to recycle. The major barrier to more widespread product recycling is economic. To be economically attractive, used products must be reworked or remanufactured at a cost that will allow a resale price at a reasonable discount over the price of the new product. Products for which recycling is most likely to be economic are those with large volume, where appearance or styling is not a problem, and which can be recycled on a production-line basis. For those products where recycling is economically sound, the major barrier is the lack of established industries to recycle that product.

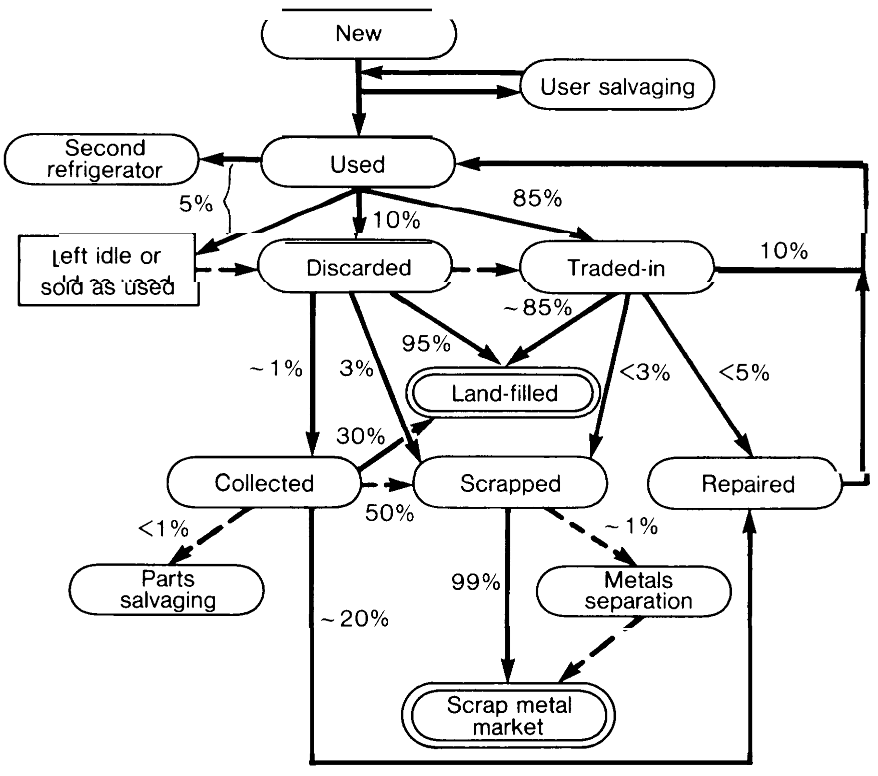
Another impediment is the consumer's desire for new products. This barrier was identified in a survey of consumers carried out by Corm where "25 percent of the respondents disposed of their products because they preferred new ones."[1] This consumer behavior pattern is in part encouraged by Government regulations that require the labeling of recycled products.

In order to better understand the product disposal pipeline, patterns of disposal were identified for selected representative products in widely separated geographic areas (see *Working Paper Four, vol.* II-D, for details). The products covered in this part of the study include buildings, lathes, office equipment, pipelines, refrigerators, and television sets. The cities selected were: Ashland, Ohio; Dodge City, Kans.; Knoxville, Term.; Pittsburgh, Pa.; and Phoenix, Ariz.

A typical disposal pattern for refrigerators is shown in figure 24. A summary of the results of this investigation for each of four products and four locations is shown in table 26. The patterns of disposal are very similar with a few exceptions. The major finding is that most of these products when discarded do not go directly to landfills but are first collected or traded in. An effective collection pipeline already exists. Unfortunately, remanufacturing facilities do not exist. This prevents the effective rework and reuse of used products and components.

[1] W David Corm, *Factors Affecting Product Lifetime,* NSF/RA Report 780219, August 1978.

Figure 24.—Typical Disposal Pattern for Refrigerators



SOURCE Working Paper Four

Table 26.—Disposal Patterns of Selected Products in Percent of Total Disposals

City	TV sets							Refrigerators						
	Second	Idle	Sold	Collected	Scrapped	Landfill	Traded-in	Second	Idle	Sold	Collected	Scrapped	Landfill	Trade-in
Ashland		← 20-25 →		20	1-16	14	30-40		← 20 →		14	20	10	60
Dodge City		← 1-15 →		10	1-15	24	50		← 5 →		-		10	85
Knoxville		← 15 →		-	-	25	60		← 10 →		14	8	24	10
Phoenix		← 40 →		15	-	5	40		← 45-65 →		5	12	8	10-30
Pittsburgh		← 10 →		5	-	80	-		← 20-25 →		5	8	40	25

City	Office equipment							Lathes						
	Second	Idle	Sold	Collected	Scrapped	Landfilled	Trade-in	Second	Idle	Sold	Collected	Scrapped	Landfilled	Trade in
Ashland	-	-	40	5	21	3	25	61	← 30 →		2	8	-	-
Dodge City	-	-	60	6	4	1	30	20	← 70 →		-	10	-	-
Knoxville	-	-	50	2	1	17	30	15	← 65 →		16	4	-	-
Phoenix	-	-	35	6	25	13	30	45	← 25 →		7	23	-	-
Pittsburgh	-	-	40	12	6	2	40	30	← 40 →		3	27	-	-

Numbers in the table represent the percentage of total products that are disposed of in the indicated manner. For example, in Knoxville, 60 percent of TV sets are traded in.

SOURCE Working Paper Four

SUBSTITUTION IN THE CONSTRUCTION INDUSTRY

Of the industrial sectors that account for much of the metal usage (construction, transportation, machinery, appliances, and electrical), the construction industry is the most flexible. At almost any time during the construction process, metal and nonmetal substitutions can be made for any given component. Tables 27, 28, and 29 show the substitutions possible for aluminum, copper, and steel, respectively. The potential material savings are 6 to 23 percent, as shown earlier in table 25. These numbers are quite large, given that only one option and one industry are involved.

In order to get an estimate of the cost of this saving, the construction cost of a 40-story office building was estimated with and without reduced metal usage. For this building, all uses of metal were reviewed and cost estimates for reasonable substitutes were prepared. This data is shown in table 30. The building with reduced metal costs about $14.5 million less than the total cost of $60 million without substitution, and would save 4,020 tons of steel. The only questionable item in this saving is the sprinkler system that would have to be demonstrated to be fireproof. Thus, the economics of construction are in favor of using less metal. However, other factors work against substitution in the construction industry, such as the lack of necessary labor skills and customer preferences for traditional building materials.

ELIMINATE UNNECESSARY METAL IN PRODUCTS

As shown in table 25, the elimination of excess metal in products might save between 5 and 10 percent of metal consumption. In order to determine whether this could be realized in practice at a reasonable cost, a detailed analysis was made of the metal uses in a variety of products and the potential for conservation. A summary of the results for refrigerators is presented below to illustrate the problems involved.

The typical metal usage in a refrigerator is shown in table 31. [t consists of 161 lbs of steel, 12 lbs of aluminum, 6 lbs of copper, and 0.5 lb of chromium for a total of 179.5 lbs of metal. A majority of the metal is in the box, which consists of 70 lbs in the shell, 16 lbs in the door and 49 lbs in the inner liner for a total of 135 lbs.

If the refrigerator sides and top are made of steel with holes cut in the sheet and covered with a flame-retardant plastic, a considerable weight savings will be realized. An estimated 11 lbs of steel could be saved of the 70 lbs now used. However, this metal savings results in manufacturing and cost penalties. First of all, a manufacturer estimates that this would add $30 to the cost of making the refrigerator, including the cost of the plastic, the adhesives, and some method of finishing the edges. Also, the use of plastic on the exterior poses a moisture and flammability problem. In ad-

Table 27.—Opportunities for Saving Aluminum in the Construction Industry

SUBSTITUTION	Primary doors & windows	Secondary doors & windows	Screen frames & screening	Residential siding	Rural roofing & siding	Mobile homes	Bridges, streets & highways	Awnings & canopies	Heating & ventilation (ex-ducts)	Store fronts & entrances	Curtain wall	Gutters & downspouts	Industrial, commercial & rurai prefabs	Duct work	Fences & gates	Venetion blinds	Weather stripping	Builder's hardware	Other
Fiberglass				•		•							•						
HSLA						•	•												
Reinforced concrete				•			•						•						
Steel	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•
Wood	•	•		•	•					•	•		•			•			
Wood/coating				•						•	•		•						
Surface coatings	•	•	•	•	•	•	•	•		•			•		•	•	•	•	

SOURCE" Working Paper Three

Table 28.—Opportunities for Saving Copper in the Construction Industry

SUBSTITUTION	Builder's hardware	Architecture products	Plumbing & heating (plumbing)	Plumbing & heating (heating)	Other building products	Plumbing tube	Wiring
Steel	•	•		•			
Wood	•	•					
Wood/coating	•	•					
Fiberglass	•	•					
Aluminum	•	•		•			•
Plastics	•	•	•			•	

SOURCE: Working Paper Three.

Table 29.—Opportunities for Saving Steel in the Construction Industry

SUBSTITUTION	General construction	Mobile homes, modular housing	Pre-engineered buildings	Pipelines	Steel industry - construction, maintenance, repair, etc.	Air conditioning, heating, cooling & ventilation systems	Building hardware	Culverts & concrete pipes	Storage tanks	Plumbing equipment	Building products	Rain goods, roofing and siding	Reinforcing products
Aluminum	●	●	●			●	●			●	●	●	
Copper											●		
Fiberglass		●	●			●	●				●	●	
HSLA	●	●	●		●								●
Plastics				●			●	●		●			
Reinforced concrete	●		●	●	●				●		●		
Wood	●	●	●										
Wood/coating		●	●										

SOURCE Working Paper Three

Table 30.—Construction Cost Estimates for a Metal-Free Building*

Building component	Metal saved	Substitute	Savings
Structure	(Fe) 2,117 tons	Reinforced concrete (706 tons steel used)	($1,903,293)
Skin	(Fe) 200 tons	Sand-blasted concrete (20 tons steel used)	14,041,963
Ductwork.	(Fe) 1,300 tons	Plastics (130 tons steel)	1,587,500
Plumbing. , ... , ... , ...	(Cu) 3 tons (Fe) 16 tons	Plastics	391,420
Sprinkler	(Fe) 125 tons	Plastics	406,250
Electrical	(Fe) 18 tons	Fiberglass	—
Curtain walls.	(Fe) 1,100 tons	Block wall	—
Total.	(Fe) 4,876 tons	856 tons steel	
Net savings	(Fe)4,020).tons		$14,523,840

. Forty stories, 1.3 million ft^2 of floor space, total cost of $60 million without substitution.
SOURCE: OTA, based on Working Paper Three

dition, plastics do not age as well as steel. The manufacturing process would be somewhat more complicated since the steel would have to be handied in the conventional way. Then, instead of enameling or coating in a single process, the plastic would have to be attached by hand. Thus, the primary barriers to the use of less steel are the increased manufacturing cost and the uncertainty of the results. The increased cost results from the fact that metal is not just removed (as it could be in other applications), but, that something else must be added to take its place. This would probably be true for any application where the metal is used for "containment ."

If the refrigerator sides are made of thinner steel (0.010 inch) and ribs are added to bring the stiffness up to the original level, approximately 58 lbs of steel can be saved. The cost of the material saved would be $10.88. This would be counterbal-

Table 31.—Summary of Refrigerator Materials Content

Material	Part	Wt. (lbs.)
Steel	Total	161
	Outer shell without door	70
	Door only	16
	Inner foodliner	49
	Compressor shell	7
	Other compressor parts	2
	Condenser	11
	Shelving	6
Copper	Total	6
	Condenser (coating)	1
	Tubing for interconnections	1
	Motor and wiring	4
Aluminum	Total	12
	Compressor and motor	
	Compressor	6
	Motor	3
	Evaporator	2
	Handles and trim	1
Chromium	Total	½
	Plating	½
Total	Refrigerator	179½

SOURCE Working Paper Three

anced by increased handling, reject, and manufacturing costs. If current tooling is used (welding) for attaching the ribs, then the side would have to be refinished before the acrylic finish could be applied. Excessive finishing to remove a ''bad spot" could drastically weaken that spot so much that damage could result from handling and usage. Thin metal is, of course, more damage prone. More dents in the metal sides would result in increased reject rates and scrapage. Although these costs were not estimated, they would surely be larger than the costs of the metal saved.

In addition, for many products a certain amount of "extra" weight is required for stability or some other important reason. This is particularly true for refrigerators. The danger of a child tipping over the refrigerator by hanging on the door must be reconciled with the saving of metal. This same general concern applies to almost every other piece of equipment studied. In machine tools, extra metal is added for damping out vibrations that would shorten the life of the equipment and affect the quality of the work. In tractors, the weight of extra metal is considered necessary for adequate traction. This excess weight need not be metal, and substitutes such as concrete and water have been used with some success. These substitutes were not reflected in the 5- to 10-percent calculation.

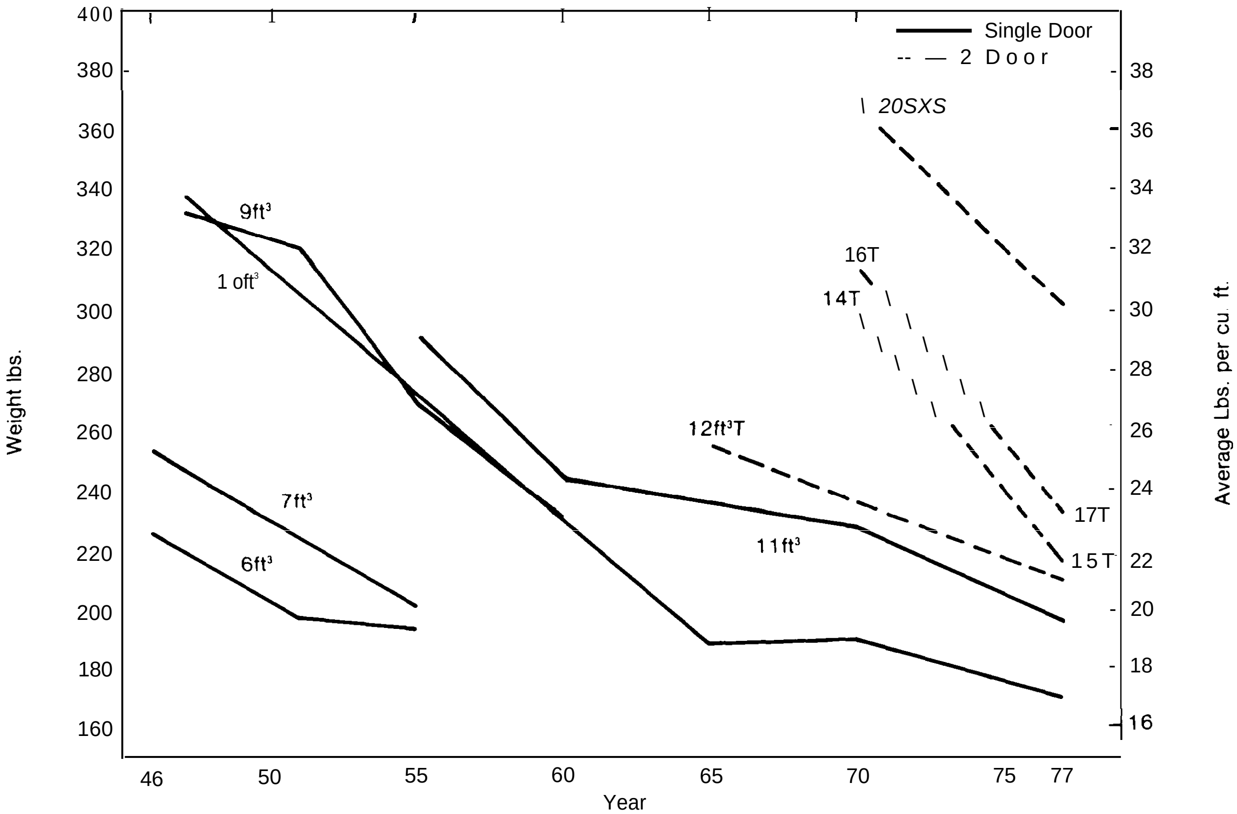
The results presented for refrigerators apply generally to the other products of this report. That is, although elimination of some excess metal is possible, the difficulties include increased manufacturing costs, increased cost of investment in engineering and equipment, decreased durability, and reduced safety. This is a large price to pay for the small savings of metal possible. And, if there were adequate recycling, this small amount would be of no concern since the metal would be reused. Furthermore, strong economic incentives already act to encourage the minimum possible use of metal in the manufacturing process. The fact that these factors do operate in the interests of conservation is demonstrated by the data of figure 25. As shown, the weight of specific models of refrigerators has dropped substantially in the past, and will undoubtedly continue to do so in the future. Such data have not been assembled for other products, but the same considerations would apply.

EXTEND PRODUCT LIFE

Extension of product life was first thought to be a method of saving a considerable amount of materials. However, the design study did not indicate that extended life would save very much (5 to 10 percent). In order to further check this option, a more detailed study was conducted.

The approach used was to (a) determine the amount of aluminum and copper that could be saved by a 50-percent increase in the mechanical life of refrigerators, automobiles, and shipping containers; (b) apply these results to a range of high-metal-use products for which life extension was

Figure 25. —Refrigerator Weight Reduction for Different Models as a Function of Time



SOURCE: Data supplied to OTA by a refrigerator manufacturer

considered possible; and (c) identify the practicality, benefits, and costs of product life extension.

The detailed methodology is discussed in the next section. Basically, a quantitative model was developed that described the chain of cause and effect underlying each product's sales, discards, consumption of copper and aluminum, and mechanical lifetime. With this model, a change in one variable (lifetime) allows an estimate to be made of changes in other variables (copper and aluminum consumption).

These models were used to estimate the amount of material that could be saved per year with a 50-percent increase in mechanical life, as shown in table 32. For refrigerators, increasing the lifetime from 15 to 23 years would result in a 15-percent saving of both aluminum and copper. These results are similar to that found in the design study for automobiles and refrigerators.

Table 32.—Percent of Metal Saved Per Product Per Year*

Product	Metal saved per product per year
Refrigerator	1 50/0
Automobile.	90/o
Aluminum vans	25°/0
Air freight containers	27 %

*With a 50-percent Increase in mechanical life
SOURCE: OTA, based on Working Paper Five

Although a 50-percent increase in mechanical lifetime is quite large and more dramatic results might have been expected, the impact has been limited by a number of factors. First, nonreplacement refrigerator sales, which arise from the growing number of households, are not affected. Secondly, it takes many years before the new, longer lived refrigerators gradually replace the large number of older, shorter-lived refrigerators currently in

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use. As a result, the discard rate does not change for a number of years. Third, the continuing demand for refrigerators with more up-to-date features implies that some refrigerators are being replaced before they physically wear out. Thus, the actual average lifetime of refrigerators does not keep pace with the increasing mechanical lifetime, but only rises from the present 15 years to about 20 years by 1990. Finally, the saving of 4,000 to 5,000 tons of aluminum and copper must be balanced against the 15-percent reduction in sales and employment that the analysis indicated would result from the longer life.

In sum, increasing the mechanical lifetime by 50 percent reduces 1990 sales and materials consumption of refrigerators by only 15 percent and automobiles by only 9 percent, largely because these products are subject to voluntary scrapping before they reach their full mechanical lifetimes. The impact of increased durability is greater for industrial products, however, because these goods tend to be pushed to the limits of their useful lifetimes. For example, a 50-percent increase in the life of airfreight containers reduces airfreight container sales and materials consumption by 27 percent by 1990. Based on this analysis, industrial products with short service lifetimes have greater potential for metal savings than do consumer products with long lifetimes.

To explore the conservation potential of increased product life, a workshop was held in Washington, D. C., on February 23, 1976. (A summary of the findings is given in appendix A.) Wear control was chosen as an example of a technology to increase product durability. Experts from the field along with representatives from industry discussed the status of wear-control technology and its application in the design and maintenance of a range of products (railroad equipment, automobiles, aircraft propulsion, naval aircraft structures, metal-cutting machinery, tools, and heavy construction equipment). The workshop concluded that technology is not a limiting factor for increasing product durability. Almost any desired life could be obtained. Improved product durability is available if the consumer wants it, demands it, and is willing to pay for it.

Secondly, the workshop found that product life is often not limited by the mechanical condition of the equipment. For almost all of the products considered, obsolescence was the most important reason for removal from service, not mechanical life. For household products and appliances, customer preferences are vital in determining the life expectancy of products. A recent study of small appliances showed that 50 percent of the products removed from service were still operable.[2] Thus, many consumer products are discarded regardless of their mechanical conditions. This occurs for a variety of reasons, such as rising service costs, affluence, appearance, style changes, population mobility, availability of disposable income, or inability to locate adequate repair facilities or parts.

In sum, the workshop concluded that technically longer mechanical life can be designed into a product. But a longer mechanical life will probably cost more, may not result in a significant increase in the actual average lifetime (due to the fact that many products are retired because of reasons having nothing to do with lifetime, as listed above), and at best would take many years to accomplish (since only the replacement market would be affected).

Furthermore, product life extension is a practical materials-saving strategy for only a limited number of products, particularly those which have a short life and are not disposed of, or consumed in use. Table 33 shows the 1974 distribution of the eight metals by industry. Product life extension would apply to transportation and consumer durables (appliances), which account for 12 to 28 percent of metal usage, depending on the metal. Even if the maximum savings from the previous product analysis (27 percent in table 32) were applied to the maximum base of 28 percent, this would result in only a 7.5-percent metal saving.

However, table 33 shows 43 percent of the iron in the remainder column and therefore unaccounted for, along with large amounts of manganese, chromium, and nickel that are used primarily as alloys in steel. Accordingly, a second approach was used to doublecheck the results. From data on metal distribution into end-use products, a list was compiled of all products for which life extension was even remotely possible. By adding the

[2] W. David Corm, op. cit

Table 33.—Distribution of Metal Flows by Industry Sector (percent of 1974 metal shipments)

	Al	Fe	Cu	Pt	Mn	Cr	Ni	W
Construction	23a	12	20	Nil	11	21	9	–
Transportation	18	19	11	28	21	17	21	12
Machinery	8	16	19	Nil	16	14	7	71
Appliances	9	2	3	Nil	2	–	7	–
Packaging	17	8	-	Nil	7	–		–
Electrical	13		28	28	5	–	13	11
Remainder	12	43	19	44	38	43	43	6
Alloying & plating	3	-	—	—	97	82	64	84
Amount of metal to which product life extension applies	27[b]	21	14	Nil	23	17	28	12
Amount of metal to which product life extension applies (product-by-product analysis)	19	26	24	Nil	19	5	11	

aPercentage of aluminum used in construction Industry
bDetermlned from sum of transportation (18 percent) and appliances (9 Percent)
SOURCE: OTA, based on Worktng Paper Two

amount of metal in each of these products, a second estimate was calculated (as a percent of 1974 domestic shipments). These estimates are included in the bottom row of table 33 and are quite similar.

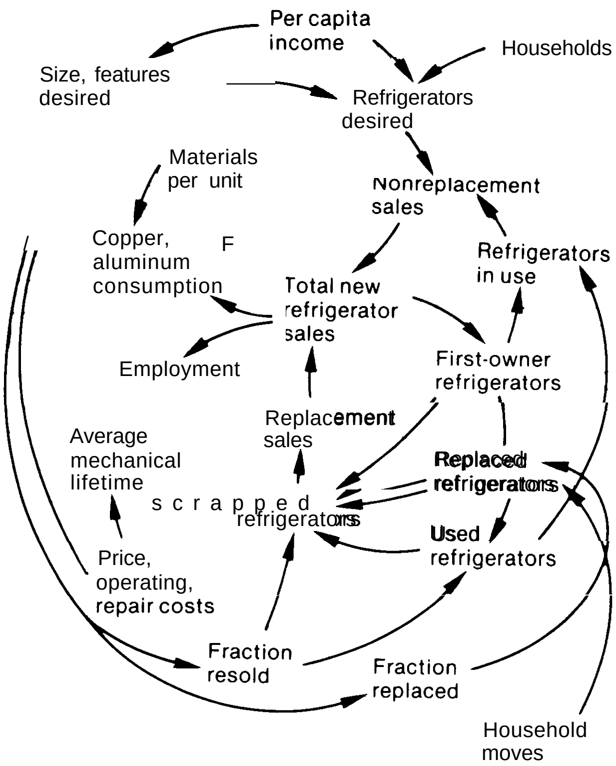
EXTEND PRODUCT LIFE OF REFRIGERATORS: AN EXAMPLE OF SYSTEMS DYNAMICS METHODOLOGY

As summarized in the previous sections, a separate study was conducted to determine the materials saved by a 50-percent increase in mechanical lifetime. Systems dynamics, an analytical methodology, provided a conceptual framework and mathematical technique for investigating the materials savings and impacts of product life extension. In this section, the refrigerator case is described in detail to illustrate the approach. The details of this study are given in *Volume II— Working Papers,* and *Working Paper Five (vol.* II-E) in particular.

To assess the impact of extended mechanical lifetime on materials consumption, a quantitative model was developed that described the chain of cause and effect which underlies refrigerator sales, discards, consumption of copper and aluminum, and mechanical lifetime. The model developed is shown in figure 26. The materials consumption of the refrigerator industry is determined by refrigerator sales and the metal content of aluminum and copper per unit. Sales of new refrigerators can be divided into two components: nonreplacement sales that arise from population growth and an increasing number of units desired per family; and replacement sales which replace the refrigerators that are discarded. The difference between the total number of refrigerators desired and the actual stock of refrigerators in use is what drives nonreplacement refrigerator sales. The scrapping of refrigerators that are worn out or that are simply discarded is what motivates replacement sales.

Based on this description of the refrigerator sales and materials consumption system, a mathematical representation of the system was developed using the DYNAMO computer simulation language. Equations were written to represent the quantitative relationships that determine refrigerator sales and copper and aluminum usage. Numerical parameters used to quantify the model were obtained from a variety of sources (such as Bureau of the Census reports, journal articles, and industry data).

Figure 26.—Overview of Refrigerator Model Structure



SOURCE: Working Paper Five.

The quantified refrigerator model was then simulated by computer over the period from 1960 to 1990. Starting the simulation in 1960 allows a comparison of model behavior with the actual course of events, thus providing one check on the validity and accuracy of the model. Sensitivity testing, that is, varying the base case assumptions, provided insights into the critical factors governing the behavior of the system. Finally, the model was used to examine the impacts on refrigerator sales, materials consumption, and employment of potential conservation policies such as increasing product lifetime.

The results of this analysis showed that materials consumed in the production of refrigerators has grown through the 1960's and early 1970's. This growth of sales and associated materials use is due to two factors. First, the number of households was growing rapidly because of the relatively high rate of population growth and especially because of the coming of age of the postwar "baby boom" generation. Secondly, the price of refrigerators was declining relative to disposable personal incomes, tending to increase the average number of refrigerators desired per family. In the future, the forecasting model developed indicates that refrigerator sales, and thus materials consumption, will increase only slowly. This is due to several factors. First, census projections indicate that the number of new households will increase much more slowly since the postwar generation has already largely established their own households and population growth has slackened. Second, there will likely be little increase in the number of refrigerators desired per family, even if it is assumed that the relative price of refrigerators continues to decline. The model indicates that the combination of these factors will cause the reduced growth rate.

In the forecast, the average lifetime of refrigerators in service remains close to 15 years. This value is in close agreement with results of several consumer surveys of appliance lifetimes conducted since the late-l 950's. This average service life is, however, 2 years less than the average mechanical lifetime of refrigerators. This occurs because some refrigerators are discarded when their owners replace them to get larger ones or units with more up-to-date convenience features. This process contributed to the historical growth of sales, for as incomes rose, people desired larger refrigerators and replaced their old ones. In the future, the average desired refrigerator size is not foreseen to increase as rapidly as in the past. As a result, the model indicates that refrigerator sales will lose some of this additional source of replacement sales.

Aluminum, due to its cost advantages, has been making inroads into refrigerator heat exchanger and some electrical uses that have been held by copper. Thus, aluminum consumption in refrigerator production increased from about 20 million to 45 million lbs between 1960 and 1974, while copper consumption only increased from 20 million to 35 million lbs. Direct employment in the production of refrigerators grows only slowly in the future, again due to the slow growth in sales.

Increasing the mechanical lifetime of refrigerators would reduce materials consumption in the future by reducing the refrigerator discard rate to some degree and thus the attendant replacement sales. The model was used to test the impacts of such a policy by assuming that the average mechanical lifetime of refrigerators produced after 1977 is increased by 50 percent, to about 23 years (see figure 27). By 1990, refrigerator sales, copper and aluminum consumption, and employment are 15 percent lower than they would be without the longer refrigerator lifetime (see figures 28 and 29).

REDUCED USE OF MATERIALS-INTENSIVE SYSTEMS, SUCH AS ALLOYS

In part, because of the relatively low cost of materials, the United States has become "materials intensive" and has chosen the use of systems that use a large amount of material. Examples might be the use of private vehicles instead of public transportation, larger homes rather than small apartments, private equipment ownership rather than rental, and large sizes rather than small. As metal resources are depleted, it may be necessary for society to become more resource-conserving as it is now attempting to do with energy. One aspect of this approach was investigated in detail in this assessment, the use of alloys.

Over the years, the development and use of alloys has proliferated to meet the needs of increasingly stringent product and manufacturing requirements and specialized production machinery. A large number of metals are used almost exclusively as alloy additives or coatings. The technical option explored in this section is the reduced use of alloys or the reduced-use of metals used in alloys. In considering this option, it must be recognized that a small change in the alloy ingredients can drastically change the resulting properties of the alloy.

The use of metals in alloys is shown in table 34. This table shows the percent of each metal listed in the vertical column that is used in each alloy listed in the horizontal column. This table accounts for a large percent of metal usage as indicated by the column totals. The only items not included are chemical uses of metals and the use of certain metals, for example, zinc, in their own alloys. In regard to conservation of alloying metals, the major conclusions using this table are as follows:

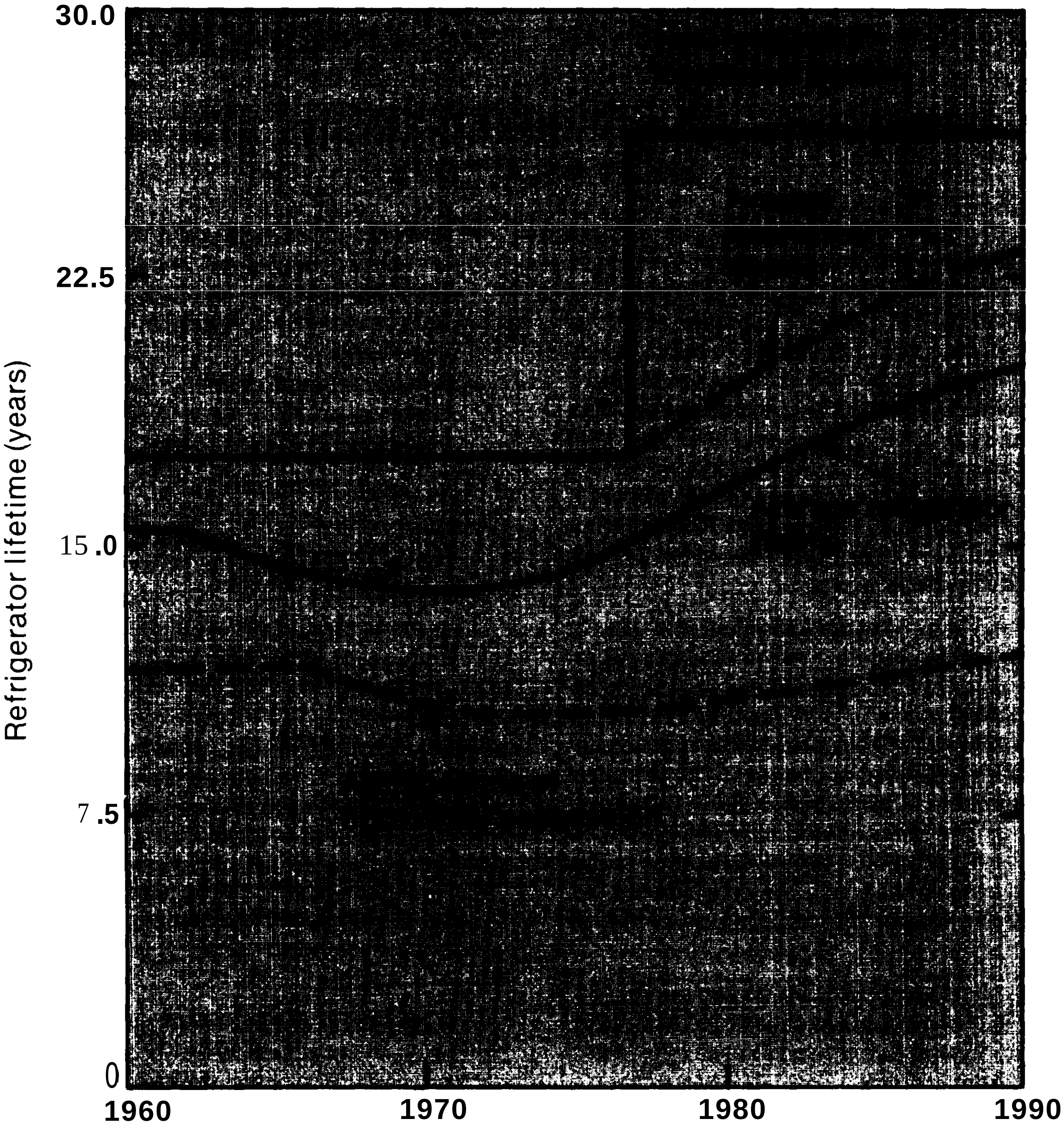
- The amount of metal used in any given alloy is small. Only under very critical circumstances would it be justifiable to conserve the alloy in order to conserve a few percent of its ingredients.
- A large amount of metal is used with steel, either as an alloy or as a coating; the total percentage is shown in table 35.

If these metals are to be conserved, reductions or changes in their use with steel will be more effective than reductions or changes in the use of the steel products themselves.

Two major options are available—use of substitute coatings or substitute materials in alloys. A large percentage of many metals are used as coatings to protect steel from corrosion and wear. In addition, a significant percentage of stainless steel alloys, tool steels, copper alloys, and carbides are used for corrosion and wear prevention. If nonmetallic coatings (e.g., ceramic or plastic) could be substituted, appreciable metal would be saved. This approach would reduce demand for metals that the United States must import, and would increase the demand for steel, which is in adequate domestic supply.

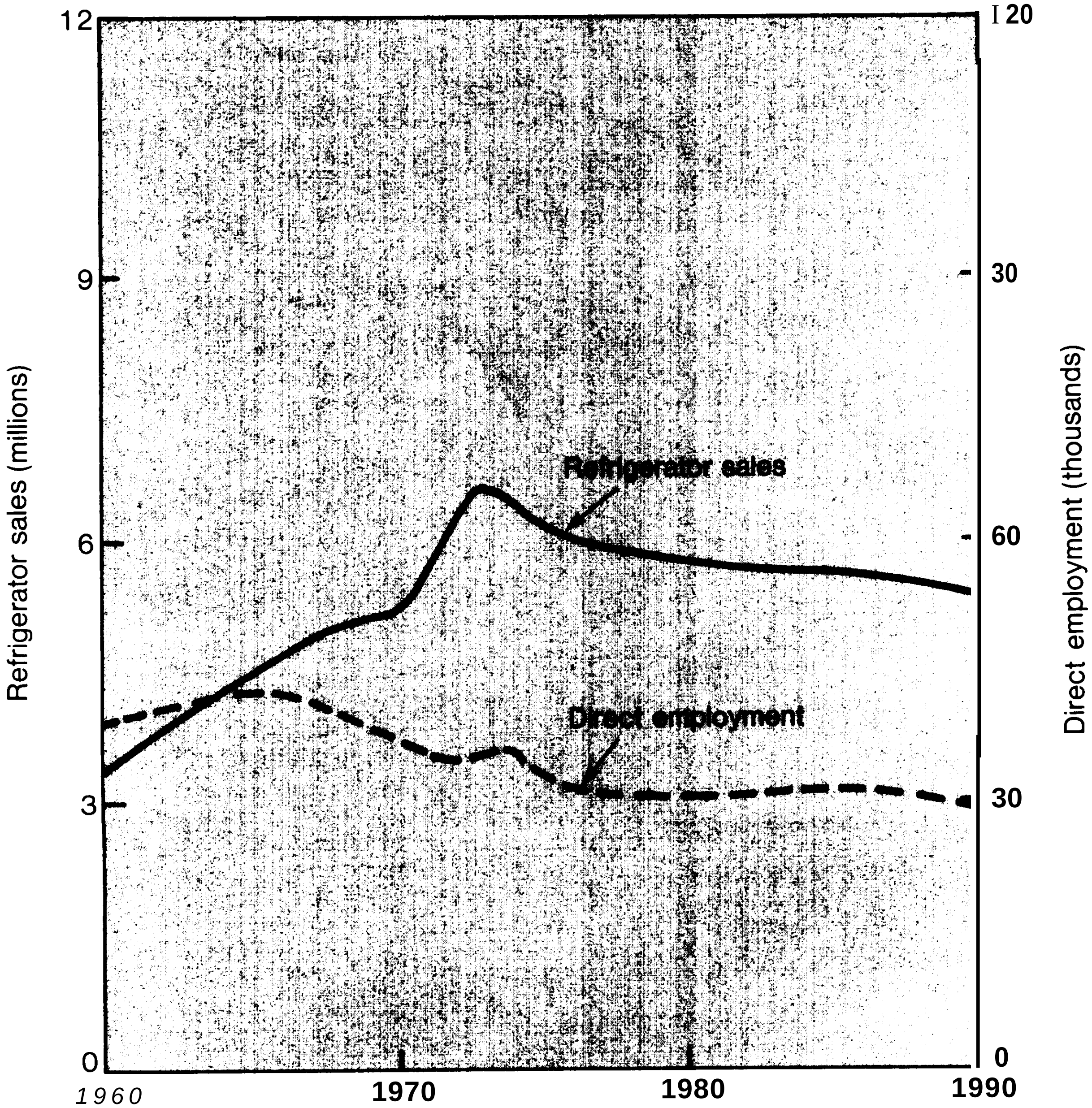
A wide variety of nonmetallic coatings are used for corrosion and wear resistance, although they do have certain technical limitations such as brittleness, lack of electrochemical effects, etc. A major benefit of the use of substitute coatings is flexibility. It is much easier to change a coating than to change the whole material. A more detailed investigation of metallic and nonmetallic coatings is needed.

Figure 27.— Refrigerator Model: Longer Mechanical Lifetime Case, Refrigerator Lifetime Over Time



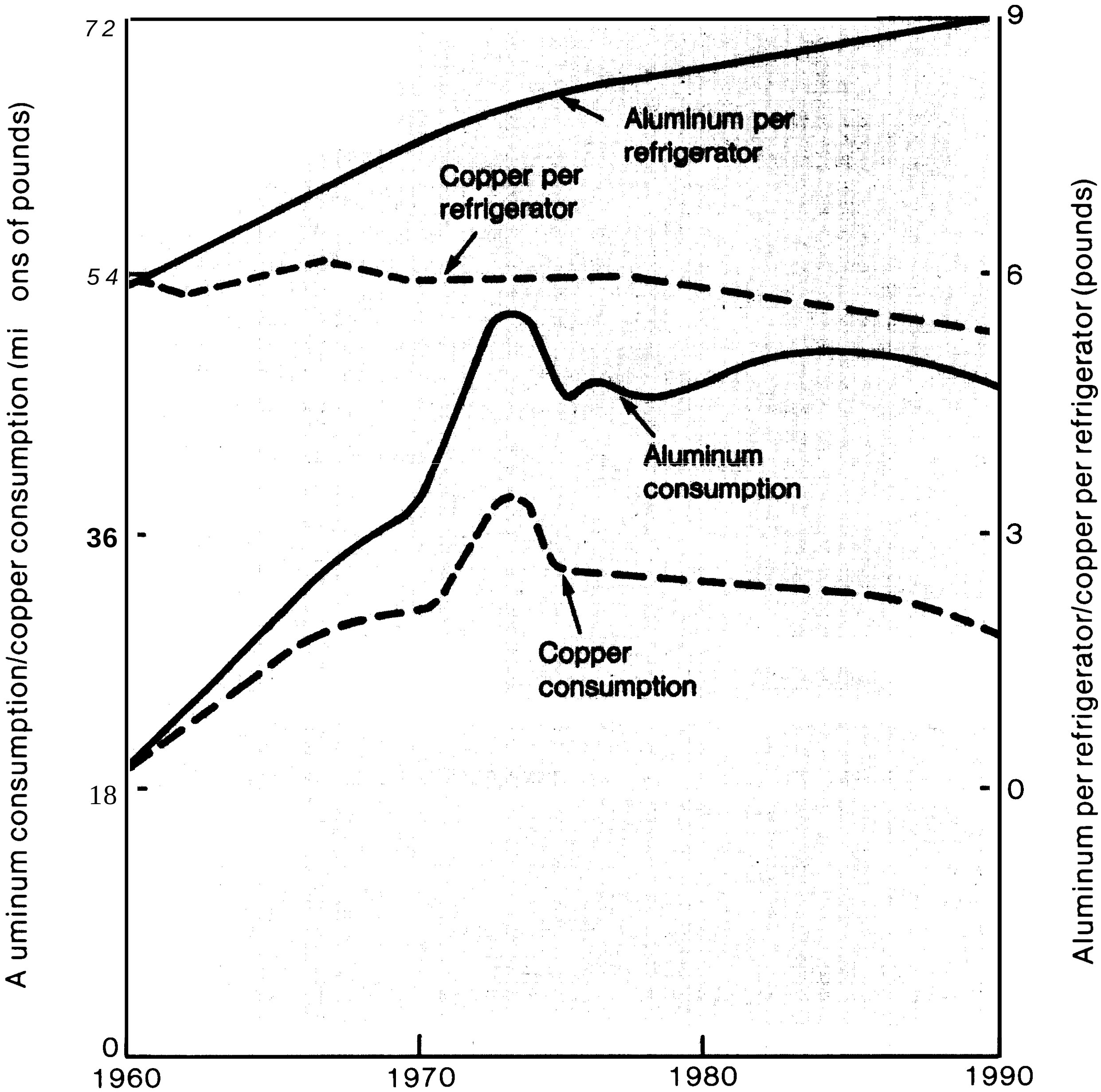
SOURCE Working Paper Five.

Figure 28.— Refrigerator Model: Longer Mechanical Lifetime Case, Employment and Sales Over Time



SOURCE: Working Paper Five

Figure 29.— Refrigerator Model: Longer Mechanical Lifetime Case, Aluminum and Copper Consumption Over Time



SOURCE Working Paper Five

Table 34.—Materials Usage in Alloys (percent)

Metal	Stainless steel	Full alloy	Cast iron	Tool steel	HSLA steel	Carbon steel	Coated steel	Al alloys	Cu alloys	Ni alloys	Co alloys	Pb alloys	Ti alloys	Carbides	O	
Al								91								9
Cd							60									6
Cr	**50**	**8**	**1.2**	2.2			5			10	5					8
co	**3**	**1.3**	**9**				18			22	13					66
Cu									90							9
Cb	4 - .	. — —	**95** -	—	— —	— →										9
Fe	**3**	**16**	**24**	1		49										9
Mg			8					48					6			8
Mn	3	11	3	1	8.5	70										96
Mo	2	**51**	**2**	9	6	3				3						6
Ni	**35**	**1**	2		7		13			21	6					8
Pb									40			60				
Sb												86				86
Fn							34		14			24				
Ti													← 82	→		8
W	1	**3**		10			8			3				59		8
V	.5	**24**	**1**	14	13	13										
Zn							41		14					3		8

SOURCE: OTA based on Working Paper Three

Table 35.—Metals Used With Steel as Alloys or Coatings

Product	Percent usage in or on steel
Iron	93
Manganese	96
Columbium	95
Molybdenum	73
Chromium	66
Vanadium	66
Cadmium	60
Nickel	58
Zinc,	41
Tin	34
Cobalt	31
Tungsten	22
Magnesium	8

SOURCE: OTA based on table 34.

SUMMARY OF OPTIONS AND POTENTIAL SAVINGS

Table 36 summarizes the technical options and the potential metal savings for each. Three additional categories have been added to this table for comparison purposes. The first category "savings-minor" indicates the reductions in metal usage that could be accomplished with relatively minor effort, primarily through the use of proven substitutes in cottagetype industries where changes in production equipment would not be necessary. The "saving-major" category is based on World War II experience and indicates the amount of metal diverted from the civilian sector to war production (for details see appendix B). These percentages show the range of flexibility in metal usage.

During wartime when flexibility became absolutely necessary, major metal savings in the civilian sector were accomplished with a very tight allocation system that drastically reduced the consumer products that could be manufactured. Production was diverted to war products, so severe economic consequences were averted. This would not be the case in peacetime. Table 36 also indicates the amount of metal that went into stocks during 1974. Although 1974 may not be a typical year, these numbers given some basis for comparison with the other options.

Clearly, the largest potential savings apply to three options: substitution, product reuse and remanufacturing, and during wartime or crisis conditions, some sort of an allocation system. The elimination of excess metal would decrease the use of steel by 9 percent but would save relatively little of the other metals. The use of nonmetallic coatings yields potential savings of 13 percent for nickel but would increase the use of steel by approximately 4 percent. By comparison, the other options (component remanufacturing, reduced product size, and increased product life) offer very small potential savings.

Table 36.—Potential Savings From Technical Options by Reducing Excess Metal Usage

	Savings as percentage of 1974 shipments							
Technical options	Iron/steel	Aluminum	Copper	Platinum	Manganese	Chromium	Nickel	Tungsten
Metal substitution;	29	60	59	24	—	16	20	32
Metal substitution in construction.	7	6	20	—	—	—	—	—
Product reuse.	11	15	32	—	—	6	15	—
Product remanufacturing	30	30	43	—	24	12	9	—
Component remanufacturing	3	1	4	—	—	2	2	—
Eliminate unnecessary metal	9	8	6	—	—	4	8	—
Reduce size	3	3	2	—	—	1	4	—
Increased product life	8					5	9	—
Nonmetallic coatings	(4)	—	—	—	—	5	13	—
Other options (for comparison purposes)								
Savings—minor.	11	14	18	—	—	4	8	—
Savings—major	52	90	90		57	60	57	—
Use of stocks	—	6	13	3	17	—	6	32

SOURCE: OTA. based on Working Paper Three

VII.

Preliminary Policy Considerations

VII.

Preliminary Policy Considerations

INTRODUCTION: MATERIALS CONSERVATION OBJECTIVES

In the previous six chapters, the technical options were evaluated for their potential to conserve metal. Several promising options were identified. However, these options must also contribute in some meaningful way to the solution of current or anticipated materials problems, or to the accomplishment of some recognized materials objectives. In this chapter, the technical options are evaluated in terms of materials objectives and problems. Through the use of systems analysis, the technical options are matched with materials problems. And finally, illustrative methods of implementing the more promising options are presented and briefly discussed.

Conservation is a response to some real or imagined threat or condition, and conservation options are implemented in attempting to accomplish some objective. The primary objective of concern in this assessment has been materials availability, either short term or long term. However, there are a number of other objectives that might be relevant to materials conservation, such as conserving energy, reducing the volume of waste, stabilizing materials markets, protecting the environment, or promoting a resource-conserving society. These objectives are not independent of each other but are merely different "end points" which may be achieved through materials conservation.

Materials availability, either short term (during critical situations) or long term (with respect to resource depletions), is a vital concern to both industry and society. Without the proper materials, many industries would be forced to close unless alternative plans were made well in advance. As shown in appendix C, materials shortages have been commonplace for many years and will undoubtedly continue in the future. If these problems become severe enough, conservation is a possible response.

Likewise, energy conservation can affect the availability of materials. Since metals refining consumes about 9 percent of the energy budget and all materials 20 percent, materials conservation could be a response to the need for energy conservation. Indeed, for the foreseeable future, energy conservation will probably be more important than materials conservation because energy availability is a prerequisite for materials production and use.

MATERIALS AVAILABILITY PROBLEMS

Conservation is one appropriate strategy to deal with a large number of materials problems that threaten materials availability, such as the following conditions:

- chronic lack of capacity,
- import dependency,
- energy conservation,
- cyclical instabilities,
- environmental restrictions,
- long-term depletion, and
- technological changes.

This report does not attempt to judge which, if any, of these problems are serious enough to justify conservation measures and whether conservation is the best among available strategies.

Energy and environmental considerations are introduced here not as objectives for materials conservation but rather as factors that could and probably will affect materials availability. For example, weight reduction in vehicles to conserve energy will affect both steel and aluminum availability. Use of catalytic converters has greatly increased the demand for platinum. And installation of solar energy units in homes will most likely increase the demand for certain specialty metals.

Chronic Lack of Capacity

Chronic lack of capacity occurs when new domestic plant capacity is not built due to lack of sufficient investment incentives. As demand increases, the margin between capacity and average demand shrinks. Shortages increasingly become the "rule" rather than the exception. This shortage condition encourages customers to buy the materials from foreign sources at inflated prices, which then encourages new capacity overseas. Once installed overseas, strong incentives work to keep this capacity operational, even if it means operating at a loss. A trend towards shrinking U.S. capacity and growing foreign capacity is thereby established.

Import Dependency

import dependency is a potentially critical problem. Currently, the United States imports approximately 30 percent of its metal needs. Some nations are completely import-dependent and have learned to live with this situation. However, the United States is in a unique position as a world leader and may not find import dependency to be in the national interest. Even if import dependency can be tolerated now, it may not be acceptable in the future under changed world conditions. Some argue that the United States is import-dependent, and there is very little that can be done to change that fact. This is true to a degree. However, changes in materials usage through conservation can reduce this dependency to a minimum or eliminate the use of import-dependent materials from critical applications. If the supplier countries become less economically dependent on minerals, they may become "conservationists" and no longer encourage the exploitation of their natural resources. Furthermore, import dependency aggravates the U.S. balance of payments, and leaves us vulnerable to possible supply disruptions from political or military activity.

Energy Conservation

The current campaign for energy conservation can strongly affect the availability of materials by influencing the cost, demand, and relative use of materials. Metals refining consumes about 9 percent of the total U.S. energy budget; ail materials 20 percent. The energy intensity (1,000 Btu/$) at each stage of the materials cycle is shown in figure 30. Refining and fabricating require several times the national industrial average. Thus, materials and energy are intimately associated.

Theoretically, with unlimited energy, any material could be obtained from common rocks as low-grade ores or from nuclear chemistry. In more practical terms, the "energy materials' '—such as natural gas, oil, and coal, on which the United States has come to depend—are being depleted at rates greater than the materials from which products are made. For the foreseeable future, therefore, energy conservation will be more important than materials conservation because energy availability is a prerequisite for materials use, and energy sources are almost universally in shorter supply than materials for making products. A more detailed discussion of the energy-materials relationship is included in *Working Paper Six. (vol.* 11-F.)

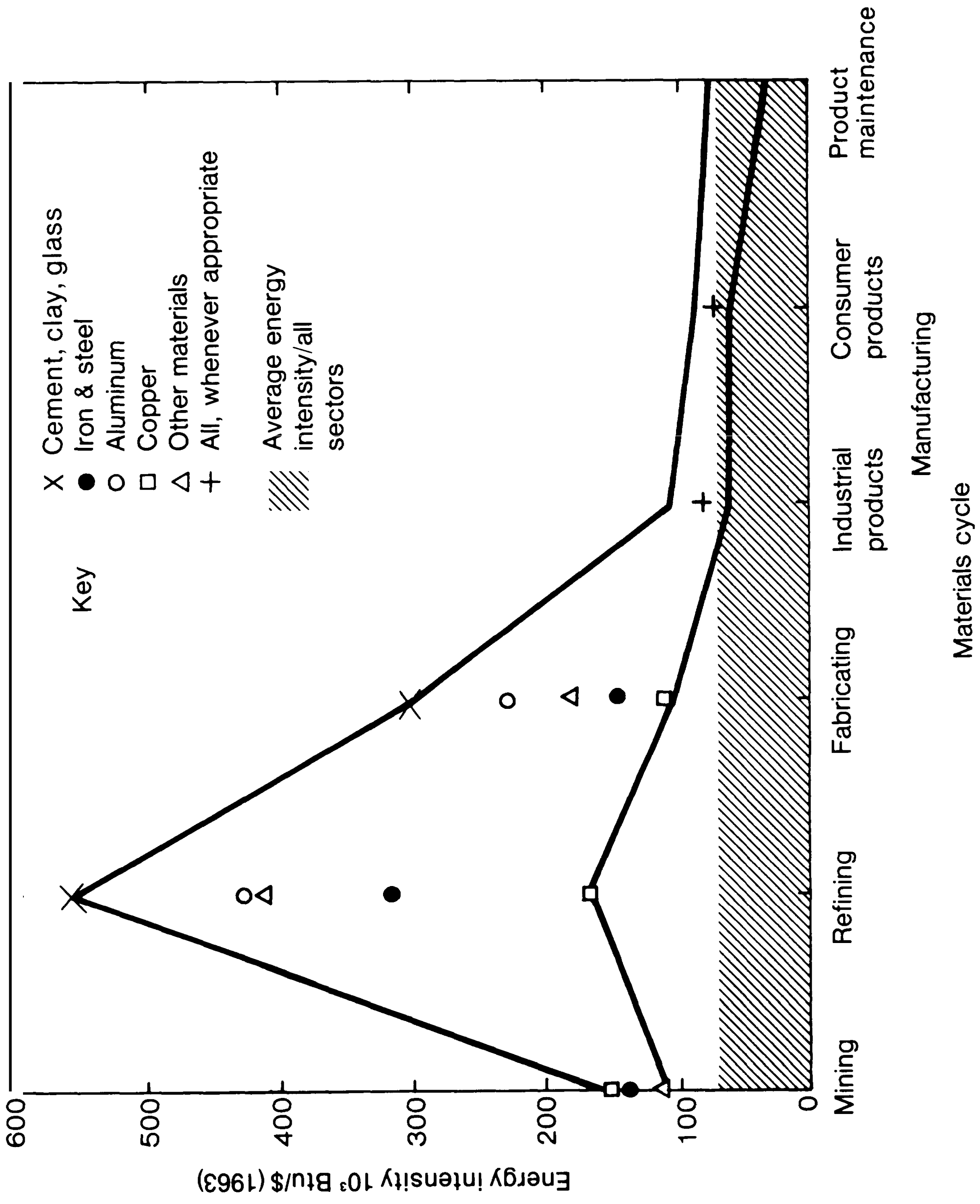
In the short run, energy conservation, as well as the effort to increase energy supplies, will lead to a greater use of materials rather than reduced demand. This will happen in spite of increasing materials prices, and will aggravate other problems such as import dependency. Further reduction of materials losses from industrial processes would in many cases be energy intensive. On the other hand, recovering materials by recycling and preventing loss of sunken energy investments in products and their components through remanufacturing promises to save large amounts of energy while simultaneously conserving materials.

Finally, the flexibility offered by materials substitutions will likely be necessary to improve overall energy efficiency and meet the changing demands for energy supply while maintaining reasonable standards of environmental quality. Materials substitution will more likely be driven by the need for energy conservation than for materials conservation or the reduction of materials "waste."

Cyclical Instabilities

Short-term availability problems occur as supply shortages and/or price fluctuations. In 1973, a

Figure 30.—Energy ntens ty at Each Stage of the Materials Cycle



SOURCE: Working Paper Six.

combination of factors made cyclical shortages unusually severe. At that time, contrary to the popular notion, certain metals were not available to some customers at any price. Because of over-commitment, these suppliers would not take new orders. Since shortages can manifest themselves within relatively short periods of time, the normal market responses are not available and severe impacts can occur. Unlike the other problems, this one is less predictable and could occur at any time, with any metal.

During the period from 1946 to 1977, interruptions in supply were constantly occurring for the eight metals analyzed in this study. Factors affecting the supply of such metals include: governmental regulations, capacity limitations, raw materials shortages, strikes, transportation disruption, import limitations, unusual demand surges, and acts of nature, for example, severe weather conditions. While a tight supply situation can result solely from the general fluctuations of the business cycle, the occurrence of supply disruptions adversely affecting industry usually involves the combination of several factors, for example, unusual demand combined with capacity limitations, and/or demand surges combined with raw materials shortages.

Tight supply situations or actual disruptions in supply occurred as follows:

- aluminum was in tight/short supply in 1950-53, 1966, 1972-74, and early 1976;
- ferrochromium alloys were insufficient to meet peak steel demand in 1973-74;
- copper was in tight/short supply in 1946-48, 1954-56, 1959, 1965-68, and 1972-74;
- nickel was in short supply during 1950-57, 1966, and 1974;
- supply shortages of scrap were apparent in 1948, 1952, 1955-57, 1969, and 1973-74;
- steel was in short supply in 1947-57, 1959-60, 1969-70, 1972-74, and the first quarter of 1977; and
- the supply of tungsten was interrupted during 1972-74.

Thus, the facts indicate that tight/shortage situations in regard to these seven metals did constantly occur over the past 30 years. Since the factors that combined to cause such supply disruptions were not metal specific or time specific, the probability of shortage conditions occurring in the future in regard to such metals is quite high. (See appendix C for further discussion.)

Environmental Restrictions

Concern for the environment may favor the use of certain materials and restrict the use of others. Some metal-processing techniques discharge more pollutants to the atmosphere than others. Since the damage done to the environment is often not reflected in the metal cost, conservation may be mandated. The environment is a major consideration and any conservation options should be evaluated for environmental impacts. Municipal solid waste is a special environmental and economic problem. Any options that could effectively reduce the amount of material entering the waste stream would be beneficial, both from an environmental as well as a conservation standpoint. Thus, the reduction of the amount of municipal solid waste is a strong driving force for conservation of those materials that find their way into this waste system.

Long-Term Depletion

The depletion of natural resources is an area of major materials concern. However, there is little danger of actual physical exhaustion over the next 20 to 50 years. This is not to say there are no problems. Old mineral deposits are being worked out and new ones are being discovered, But levels of ore quality are declining. If new mining technology does not increase the accessibility of low-grade ores, then prices will rise and supply shortages may develop. This will come sooner for materials such as gold, mercury, silver, tin, lead, and tungsten than for other metals such as iron, aluminum, and nickel.

Technological Change

Technological changes will require shifts in materials usages. No unusual technological changes are expected to radically alter demand over the next 25 years. However, these estimates are based primarily on historical data and expected growth in the gross national product (GNP) and population. Probably the major technological change, other than in energy, would be the widespread use of composite materials. This would reduce demand for structural metals such as steel and aluminum. Deep sea mining, if it becomes economically feasible, could increase the supply of certain metals by an order of magnitude.

MATCHING CONSERVATION OPTIONS TO MATERIALS AVAILABILITY PROBLEMS

If a specific materials problem arises (for example, a threat to the supply of nickel), then specific technical conservation options to address the problem could be selected from table 24 (reducing losses) or table 36 (reducing excess metal usage). These tables identify options with the greatest potential to save metal, but do not indicate the applicability of the options to specific materials availability problems. Given the many possible materials availability' problems, a technique or approach is needed to match conservation options to materials problems.

The approach used in this assessment was a systems analysis that classified the problems and the possible solution (options) in terms of their overall impact on the parameters that describe the behavior of the system. [n this case, the system is the materials cycle, and the parameters are efficiency, stability, and adaptability.

Thus, the systems analysis concepts of materials efficiency, stability, and adaptability were used to establish a linkage (or matching) between technical conservation options and materials problems. These concepts are summaried below and in table 37, and discussed in more depth in *Working Paper Six, (vol. II-F).*

Improved efficiency means better utilization of resources or making the best use of what one has. It means making products with a minimum expenditure of materials consistent with other accepted values of society. Efficiency does not rate materials saving as the only priority, but tries to optimize usage based on a whole spectrum of criteria. Options to improve efficiency attempt to reduce the total material usage and usually deal with losses. Efficiency is one appropriate response to resource depletion, that is, a gradual reduction in losses and usage over the remaining resource life.

Improved stability is an attempt to assure a more adequate and consistent amount of materials in the material cycle to satisfy demand. It means

Table 37.—Systems Analysis Concepts of Materials Efficiency, Stability, and Adaptability

	Efficiency	Stability	Adaptability
Goals"	*Optimize* according to recognized goals and objectives.	Make sure that all actions will *suffice* in satisfying recognized goals.	*Evaluate* appropriateness of existing goals under changing conditions; *identify* new goals or objectives.
Resource emphasis	Reduction of wastes; make sure all resources are fully utilized (labor, equipment, energy, capital, materials).	*Protect/on* against all possible failure modes or malfunctions; build in redundancy and safeguards.	*Rapid adjustment* to change, capability to cope with variability, innovation, search for new opportunities.
Resource management	*Reduce operating margins (excess* capacity, labor, inventory, and stockpiles).	*Increase operating margins* to allow for errors or contingencies; provide standby capacity.	*Provide substitutes* and alternatives (materials, processes, facilities, sources of supply).
Resource flows (along cycle)	Assume predictable controlled transactions; establish minimum number of source: and markets.	Reduce variability and diversity; establish overlapping but stable sources and markets.	Provide fall-back options and decision mechanisms for rapidly redirecting flows under changing circumstances.

SOURCE Working Paper SIX

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taking actions to protect market participants against possible failure modes, to reduce the cyclical variabilities, and to remove market instabilities. Options consistent with stability are increasing standby capacity, use of multiple sourcing, economic stockpiling, and improved information on materials supply and demand.

Improved adaptability, on the other hand, means more rapidly adjusting to change and coping with problems as they arise. It means developing the capability to deal with and overcome problems, difficulties, threats, or conditions as they occur.

Unfortunately, some options can lead to conflicts among materials efficiency, stability, and adaptability. That is, all-out efforts to improve efficiency can reduce the slack in the system and lead to a destabilization of the market and reduced ability of industry to cope with materials problems as they arise. Moves by the Government to stabilize markets can reduce efficiency and adaptability. Finally, efforts to become more adaptive may compromise both efficiency and stability.

For example, options to improve efficiency will reduce the amount of material used. But as a result, there will be less slack in the system to absorb unforeseen shortages, and companies will be less able to adapt. As companies exercise the limited number of options to reduce the amount of material used in product manufacture, these options are then no longer available to stabilize supply/demand or cope with unforeseen events,

On the other hand, actions to become adaptive include developing substitutes, establishing a variety of sources, multiple ordering, having extra material on hand, and, in general, developing a pattern of usage that gives the user a variety of choices to cope with all uncertainties. All of these actions are, by nature, materials inefficient. Furthermore, this ability to adapt can be exercised at the discretion of the materials user for any reason he chooses. If he is a major user, his action and the counteractions by other stakeholders might cause a very unstable market. Materials suppliers might not be able to predict from year to year what the demand would be and plan production. They would either overproduce or underproduce. Overproduction would lead to lower prices and inefficient use. Underproduction would lead to shortages and greater instability.

As indicated earlier, materials problems can be classified as requiring improved materials efficiency, stability, and/or adaptability. As shown in table 38, all problems cited—except for chronic lack of capacity and long-term depletion—appear amenable to options that improve adaptability. Balance of payments, energy conservation, environmental restrictions, and long-term depletion problems call for options to improve efficiency. Finally, lack of capacity and cyclical instabilities suggest options to improve stability.

Table 38.—Materials Problems Require Improved Efficiency, Stability, and/or Adaptability

Materials problems	Improved efficiency	Improved stability	Improved adaptability
Chronic lack of capacity. .	—	✓	—
Import dependency			
Balance of payments . . .	✓	—	✓
Threat of disruption . . .	—	—	✓
Energy conservation.	✓	—	✓
Cyclical instabilities			
Stable prices/shortages	—	✓	✓
Unstable prices/steady demand.	—	✓	✓
Environmental restrictions	✓	—	✓
Long-term depletion	✓	—	—
Technological changes . .	—	—	✓

SOURCE: Working Paper Six.

Thus, based on this analysis, most future materials problems seem to be more amenable to improved industrial adaptability rather than to improved efficiency or efforts to stabilize the materials markets. This does not mean that industry should become less efficient or that markets should be destabilized. It also does not mean that adaptability should be stressed to the exclusion of efficiency and stability. Rather, it does suggest that a balance between efficiency, stability, and adaptability should be maintained. And at this time conservation options that increase adaptability require primary consideration. However, at the same time, care should be taken that this increased adaptability does not sacrifice efficiency or stability to any great degree.

Thus, the analysis suggests that competition among organizations and alternative technologies will continue to produce relatively great efficiency, including materials conservation. The greater need at present is for options to better anticipate societal vulnerabilities, to devise strategies to cope with recognized uncertainties, to establish norms for orderly interactions among organizations, and to assess the need for better adaptability in the face of future contingencies. Under these conditions, private stakeholders would be able to plan for efficiency with a clear understanding of the opportunities and attendant risks.

In table 39, some of the more promising technical conservation options are classified according to their ability to improve materials efficiency, stability, and adaptability. These options—with the exception of major savings (allocation) —apply to improving efficiency and/or adaptability. Also included in table 39 are illustrative methods of implementing some of the technical options. These implementation options are discussed in the next section.

Table 39.—Ability of Conservation Options to Improve Efficiency, Stability, and Adaptability

Improved efficiency	Improved market stability	Improved adaptability
Technical Options		
Increased metal recycling	Metal savings (e.g., through allocations)	Major savings (e.g., through allocations)
Increased product remanufacturing		Metal substitution
Increased product reuse		Use of stocks
Reduced dissipative uses		Export controls
Illustrative Implementation Options		
Public data base	Public data base	Public data base
Improve product after-market	Contingency planning	Contingency planning market for contingency shares certificates
Establish scrap inventory	Market for contingency shares certificates	R&D on metal substitution.

SOURCE: OTA, based on Working Paper Six

ILLUSTRATIVE IMPLEMENTATION OPTIONS

In the previous sections, preliminary consideration was given to options with respect to their ability to solve materials problems that may arise in the future. The purpose of this section is to briefly present illustrative methods of implementation applicable to the most promising options.

However, this report does not assess in detail the impacts of the options on the economy, energy conservation, environmental quality, employment, and other important impact areas.

A more detailed discussion of the implementation options can be found in *Working Paper Six, (vol. II-F)*. The implementation options listed below are illustrative of the range of options that could be considered.

Establish a Governmental Contingency Planning Function

Periodic shortages and oversupply along with price variation have been a part of the materials supply system since the beginning of the industrial age. Industry and consumers have learned to live with this condition and in some situations to take advantage of it. In most of these shortage situations, warning has been adequate. In the materials field, suppliers and users maintain a close working relationship and the suppliers are usually aware of developing threats. [n addition, the Bureau of Mines, the State Department, the Defense Department, and the Central Intelligence Agency monitor materials supply and in most cases provide an adequate alert. Materials users whose business depends on a given material initiate their own information network independent of the suppliers and are often the first to anticipate a problem. Through trade publications and the technical literature, this information is available to those who choose to avail themselves of it.

The primary difficulty comes in responding to the threat. Each organization moves independently to cover their own position and often overreacts, which tends to make the situation worse. When the supply does become limited, the suppliers invoke an allocation system that provides for an orderly distribution to current customers. But this system locks out other customers and provides little incentive to increase capacity. In addition, certain industries are more dependent on critical materials than others and will suffer more during times of shortage, with a greater negative impact on the economy and total employment. The question is: What could the Government do now, if anything, to be ready for such a situation?

One option available to Congress is to assign a materials contingency planning function to one Government organization. This organization would be responsible for evaluating the severity of perceived threats in materials supply and to develop contingency plans to cope with these problems should they arise. Such a function could bean extension of the scope of work now provided by various existing offices and bureaus. The main advantage of this option is that it would provide, at a small additional cost, a continuous appraisal of the seriousness of the threats to be faced and the ability of current mechanisms to counter those threats.

Establish a Public Data System

Decisionmaking with regard to materials management in both the private and public sectors appears to suffer from a lack of comprehensive information and integrated analysis, insufficient R&D on generic problems, and lack of a long-range holistic view of materials problems.

The Federal Government is the only participant in the process with the scope of concern and the authority to collect, integrate, and disseminate information necessary to compensate for imperfections in market mechanisms and inequalities in resources of the various actors. It may also be the only participant with the resources, capabilities, facilities, and long-range interest to fund the research necessary to solve the technical problems inherent in the transition to an economy of finite resources.

A public data base would help to improve the quality and quantity of information available to Government and to industry for better analysis and forecasting of materials supply and demand problems. It would also help identify R&D needs for solving or alleviating technical problems in the materials cycle (e.g., substitutions for temporarily or chronically scarce materials, techniques for separating and reclaiming scrap materials). Some R&D support needs were discussed in an earlier section.

New Government sponsored and operated information systems are favored by nearly all academic observers and professional societies, by labor, by Government experts (with a few exceptions, noted below), and by some industry representatives. Such actions have been opposed by the Departments of the Interior and Commerce. They maintain that existing systems, such as that of the Bureau of Mines, are adequate. Some industries oppose such systems on the grounds that they would be a step toward a "nationally planned economy" and an infringement on proprietary information rights.

A public data base would be the foundation stone for many forms of private planning, public policy review, and contingency planning. All the basic public implementation options would require specific evaluative information in the formulation, operation, and modification of standards and guidelines. The greatest need is for additional information on the end uses of materials and the total quantities of a given material used in any given product. Supplier inventories would also be valuable information to assist in assessing the need for implementing contingency plans and to assist industry in locating scarce materials.

These two implementation options, contingency planning and public data base, have been studied in detail in an earlier OTA report *Assessment of Information Systems Capabilities Required to Support U.S. Materials Policy Decisions* (December 1976). Option 3 in that study, known as the Bureau of Materials Statistics and Forecasting, encompasses these two options. Chapters VII and VIII of the *Information Systems* report provide a detailed discussion of the impacts and issues associated with implementation of such a Bureau with contingency planning and public data base capabilities.

Establish a Market for Contingency Shares Certificates

In this implementation option, a private sector market for contingency shares certificates would be established between materials suppliers and industrial customers of basic materials. This option would be a private allocation system. The Government would not be involved in-these private sector transactions. This market would be an extension of the emergency allocation scheme that the metals suppliers use now during shortages in which shares are based on the previous year's proportion of total orders. In the contingency shares market, customers would have to pay in advance for the privilege of obtaining a share of limited supply capacity during periods of shortage.

The contingency shares certificates sold in a private marketplace between suppliers and users would designate the fraction of available production capacity allocated to the certificate holder (and guaranteed by the supplier) under the contingency condition that all orders could not be met on schedule.

Furthermore, the certificates would designate a priority for the filling of the order. Those with the highest priority would have their orders filled first. But, unlike the successful wartime priority scheme, lower priority orders would automatically receive a higher priority following a specified period of delay (possibly 1 month). In this way, all orders are eventually filled because even those orders with the lowest initial priority will eventually arrive at the highest level and receive attention.

The period of incremental increasing of priorities would be calculated according to the number and size of the contingency shares sold. In this way, the fact that a fraction of capacity is allocated to each certificate holder and that those holding lower priorities eventually receive attention prevents the highest priority certificates holders from usurping the total supply by placing a large number of orders.

The major effect of using these certificates to allocate available capacity during periods of shortage would be to allow materials buyers to realistically assess their needs for an assured supply in anticipation of possible shortages. The assessment is based on a price mechanism, that is, the recognition that they will have to pay more for large capacity share and high priority.

The contingency shares arrangements allow' market participants to anticipate the relative competitive pressure for materials under shortage conditions in order to make intelligent decisions about substitutions while there is time to implement a substitute, or to reconsider whether the material is so important that their needs could not be deferred in time of shortage. Revenues from the contingency shares would enable suppliers to attract investment capital for expansion if demand were running high. Movement in the contingency shares market could give suppliers warning of shifts in demand enabling them to stockpile in advance or sell potential surplus. Also, speculators would receive much better price signals from the technically astute stakeholders and would thereby be much more likely to act to stabilize the market.

During periods of plenty, all orders would be filled as they come in with no change from business as usual. Only during shortages would the provisions and privileges of the certificates be important. The competition among various buyers would determine the specific selling price of the certificates, as in any securities or futures markets. Speculators could buy certificates and gamble on a shortage occurring to produce high profits in reselling these privileges and offering latecomers entry into the market even though it may be tight. Brokers would hold certificates and resell their privileges in smaller blocks to make it easier for small, intermittent, or new buyers to gain market entry.

Additional provisions may be necessary for very small customers so that they are not locked out of the market as happens today during shortages. The normal fraction of the market going to the many small users (probably 10 percent of the total market) could be set aside for bids during the shortage—with only the small or intermittent user or new entrants being qualified to place orders on this fraction. This provision would require oversight inspection to prevent resale and speculation. It remains to be seen whether brokers and speculators could provide this function better than the formal provision of set-aside capacity and the costly oversight to go with it.

The prices for contingency shares certificates would be a valuable indicator of "criticality" for metals under abnormal market conditions; it would also indicate beforehand which sectors would be most hard hit (those bidding highest for shares). Both public and private organizations could benefit from these price signals to improve their planning and coping strategies.

The contingency shares certificates market would virtually eliminate the cause of materials markets' imperfections during periods of shortage. Double ordering would be impossible without having paid for the privilege through the purchase of certificates; this would reestablish the rates of ordering as a useful indicator of real demand to the materials suppliers.

Increasing private stockpiles leading into and during periods of shortage would be impossible unless the purchaser had also bought sufficient certificates to gain the capacity to be able to stockpile. In either case, the certificates would be a useful indicator of real demand. The decision to buy enough shares to stockpile would help to pay for a needed expansion of productive capacity by bidding up certificate values.

Price signals for shortage conditions would operate in advance of shortages or true contingency events. They would thereby reduce the advantage of "quick response" by major corporations. There would be real penalties (one cost of the certificates) for using materials for less essential applications during shortage periods. By reducing hoarding and double ordering, the glut following past shortages would be moderated. In addition, increases in the certificate prices would induce compensatory actions to cope with anticipated shortages rather than increase materials prices per se.

Research and Development on Metal Substitution

Substitution promises substantial savings for specific metals. Approximately one-third of the possible substitutions would use other metals; one-third, coatings (metallic and nonmetallic); and the remaining third, nonmetals. Substitution can provide flexibility in the face of specific materials shortages. In the long run, substitution is a principal means of coping with shortages.

The Paley Commission in 1952, the National Materials Board in 1972, and others have recommended greater design efficiency and substitutability. However, Government implementation policies have been proposed only in general terms such as "tax policy" and international standards. The options available for harnessing materials substitutions as an instrument of national policy warrant further investigation.

Substitutions are a strategy selected by management to fit conditions of technical desirability, especially in product performance; efficiency of operations; and price or availability. Evidence suggests that price is usually not the most critical factor. One industry representative has noted that material costs represent only 5 percent or less of the final product cost of an aircraft, although it may be responsible for 75 percent of Iifecycle costs. Thus, Government taxing or price control can only be effective in major applications for mature industries in which small cost differences exert considerable materials selection leverage.

Some have suggested designers and manufacturers make materials choices on the basis of "true relative value" rather than cost. This "true relative value" could include disposal costs and long-term marginal costs of replacement. These policies would not lead to greater materials substitution flexibility because the true relative value is an average market price, not a reflection of the uncertainty of supply and limitations of capacity during periods of high demand.

Discovering the available substitution options is in part a product of Government-sponsored R&D. This should be done within the industries where substitutions would be desired based on high-volume usage. Congress could establish a research program to develop practical substitutes for critical materials, with particular emphasis on products with high metal use, nonmetallic coatings for corrosion and wear resistance, and dissipative uses. This would encourage additional private sector R&D.

Improve Product Aftermarket

Product remanufacturing, reuse, and repair (collectively known as product recycling) offer the greatest leverage for saving materials and energy. Improved aftermarket (the market for recycled products) would prevent the mixing of scarce materials with the landfill waste stream as well as improve the recovery of the major metals—iron, steel, aluminum, and copper. The aftermarket changes that could improve efficiency resemble vertical integration in their managerial and technological efficiency but do not necessarily lead to centralized control. For example, the following trends are toward vertical integration in the aftermarket but not by new product manufacturers: the growth of automotive jobbers and mass merchandisers in repair markets, greater leasing of products (new or used) by retail outlets, more efficient diagnostic and rework procedures in support of these integrated service groups, and greater willingness to offer guarantees on reworked products.

Improved product recycling to capture the residual value in products through a strengthened aftermarket would eventually have implications for the entire materials cycle. Table 40 systematically enumerates the functional requirements that apply to each step of the materials cycle, if recycling is to increase. The table also lists the benefits to the Nation and stakeholder groups, the corresponding disbenefits, possible Government options, and likely impacts of implementing the options.

in all, there are 20 possible Government options listed. Fifteen of these would dovetail with improved efficiency; eight directly support improvements in the aftermarket.

The results of this preliminary study of the product aftermarket indicate that four of these options should receive primary consideration.

- **Encourage product leasing through tax deductions.** —Tax deductions could be used to provide an incentive for leasing of major products, such as automobiles, appliances, and machinery. At the end of the lease period, the products would be returned to the supplier who would have product recycling capability, rather than being discarded into the waste stream.
- **Provide loans to establish aftermarket business.—Low-cost** loans could be provided to assist product recycling firms in attracting the necessary investment capital. At present, most major products are discarded rather than recycled, in large part because very few firms are in the business of product recycling.
- **Provide funding to establish a scrap inventory.**-Another likely prerequisite to effective product recycling is improved information about the amount, form, and location of residual scrap and its flow in the aftermarket. Funding could be allocated to establish a scrap inventory for this purpose. See the following section for further discussion of a scrap inventory.
- **Increase public confidence in recycled products.—Another** major barrier to product recycling is lack of consumer acceptance of used or remanufactured products. Government regulations (e. g., with regard to product testing, labeling, specifications, and procurement) could be modified so as to increase consumer confidence in the quality of recycled products.

A direct substitution of recycled products for new ones would probably have a short-term impact of reducing net jobs and replacing unskilled jobs with those requiring somewhat greater skill. However, the long-term impact would be to increase consumer buying power and generate even greater product flows and even more jobs in other nonmanufacturing sectors. Engineering skills and talent would have to shift toward the aftermarket. Following this shift, unskilled employment opportunities would likely improve.

Product recycling would also save energy. As shown earlier in figure 30, metal refining and fabricating are several times above the national average

Table 40.—Implications and Impacts of Recycling on the Materials Cycle

Functional requirements if recycling is to be increased	Application to national goals; benefits to stakeholder groups	Disbenefits to . stakeholders and Nation	Government options, role, and imple-mental ion strategies	Impacts of implementing Govern-ment options
		1. EXTRACTION		
Constant and rapid feed-back of information be-tween extraction of pri-mary materials and re-cycling to assess scarci-ty and value of materials in order to adjust and balance rate of depletion and rigor of recycling. Toxicity or other dangers from primary materials, which will eventually enter recycling process, must be understood and tracked to avoid hazards during reprocessing, reuse, or disposal. Rare materials which are byproducts from extrac-tion of other materials must be preserved for future use regardless of current value (e. g., helium).	Future needs and uses protected, balanced against today's needs and likelihood of future technological develop-ment, substitutions, or changes in usage/de-mand, Occupational safety of recycling, reprocessing labor force and consum-ers; reduced landfill re-quirements, reduced en-vironmental degradation. Avoidance of irreversible losses of materials valuable in the future	Errors in forecasting supplies and shortages have economic and se-curity risks Extraction industry bears costs.	Establish commission to continually assess scar-city, provide feedback between recycling and extraction. EPA research and standards develop-ment for problem materials, tracking through cycle.	Competition between re-cycled and raw materials may destabilize either or both: who absorbs costs of market variability? Basic materials markets become more sensitive to Government policy decisions regarding safety, forecasting needs. and recycling.
		II. PROCESSING, FABRICATION		
Assure energy conserva-tion benefits from using recycled metal instead of primary raw materials, Trace element contam-ination of recycled ma-terials may require mod-ification of processing equipment, new equip-ment, and/or higher costs in processing. Some modification in fabrication.	Reduced energy costs in production, reduced energy sensitivity. Better understanding of true costs of small alloy contamination in re-cycled materials, Greater flexibility in meeting materials demands, reduced fluc-tuation in supply cycle	Coupling of materials in-dustry energy needs to availability of recyclable materials. Either reduced certainty about materials quality or Increased materials testing. Could lead to lower quality primary materials and higher production/ manufacturing costs because some forming/ bonding applications now require higher quality.	Tax credit or other subsidy of differential costs of processing equipment for handling contaminated/mixed re-cycled materials (invest-ment tax incentive?), Joint sponsorship of R&D for processes to handle mixed/contam-inated materials or to ex-tract valuable trace elements, Procurement Incentives for use of scrap, Establish standard of metal quality for recycle.	Increased capital re-quirement by industry. Standards may restrain materials development and innovation.

= Indirectly Improved efficiency of reworking, repair, and resale of products in the aftermarket
• = Directly supports improvements in the aftermarket activities

SOURCE Working Paper SIX.

Table 40.implications and Impacts of Recycling on the Materials Cycle—continued.

Functional requirements if recycling is to be Increased	Application to national goals; benefits to stakeholder groups	Disbenefits to stakeholders and Nation	‘Government options, role, and implementation strategies	Impacts of implementing Government options
		III. MANUFACTURING		
Modularize designs so that components can be replaced, refurbished, or Interchanged. Design for ease of repair, diagnostic evaluation, and recycling. Build in diagnostic checks and/or electronic monitoring. Develop production-line compatibility with used components. Market research on reasons for discard/ replacement of nonobsolescent products.	Reduced costs for product/component repair or replacement (consumer satisfaction). Easier/less expensive diagnostics, facilitate do-it-yourself repair Easier to meet specific consumer/user needs through modularization. Economies of scale in reliability studies.	Without vertically integrated companies (or sophisticated purchasers), additional design costs are borne by manufacturers for good of the repair industry. Higher priced new products due to higher resale value compensates manufacturer *but* new and used products compete and tend to destabilize the market for both. Greater volatility in demand for new products if buyer choice between new/used products is dependent on fluctuations in disposable income. Some additional constraints on design/ marketing decisions; some reduction in consumer choice and convenience.	I Government procurement standards favoring reuse/rehabilitation of products, components. • Establishment of standards for design and repairability through officially designated evaluation laboratories.	Repair industry is largely captive of manufacturers; creation of new conflicts of interest. Constraints on product design may compromise optimality of design in terms of energy efficiency, substitution of materials, rates of innovation.
		IV. DISTRIBUTION		
Share new product distribution system and outlets with recycled products, or devise new distribution systems/ outlets. Use distribution system for consumer in formation/education and for collecting data on product failure/obsolescence etc. Equitable transportation costs for recycled trade-In products from dealers.	Create new small business opportunities. Reduce costs of collection, transportation—principal barriers to recycling. Improved relationships between manufacturer, seller, buyer, repair industry. New customers for railroads, truckers.	Distributor may be caught in conflict of interest: higher profits on new goods than on rehabilitated goods. Better informed buyers may gain advantages over poorly educated or poorly informed. Buyers may be victimized by misrepresentat ion of recycled products, components.	[Review/revise ICC regulations on transportation rates; end discrimination *or* subsidize recycling. • Encourage leasing rather than sale of products[a] through tax advantages and insurance protect ion ● Government procurement through leasing rather than purchase. □ Assistance to small business to build distribution system and outlets: guaranteed loans, training, etc.	Consumer's control, independence, autonomy reduced by leasing. Prolonged product life through better maintenance from leasing, or reduced user care of leased devices/vehicles. Government leasing. Issues of financial/ legal liability resulting from leasing.

[a]Leasing of vehicles large appliances, and equipment usually provides more systematic maintenance, greater intensity of utlization aggregated collection for eventual recycling, and greater motlvation for recycling
= Indirectly Improved efficiency of reworking, repair, and resale of products in the aftermarket
• = Directly supports improvements in the aftermarket activities

SOURCE Working Paper SIX

Table 40.—Implications and Impacts of Recycling on the Materials Cycle—continued.

Functional requirements if recycling is to be increased	Application to national goals; benefits to stakeholder groups	Disbenefits to stakeholders and Nation	Government options, role, and implemental ion strategies	Impacts of Implementing Government options
		V. USE AND REUSE		
Better information about patterns of obsolescence, discard, etc. Better knowledge of durability, safety of rehabilitated, resold items. Building of consumer confidence through standards, warranties, labeling, etc.	Extended use, avoidance of premature obsolescence. Improved customer confidence in buying decisions. Improved discretionary income. Less pressure on individuals and households for excess consumption.	More labor requirements, lower profits for retailers. Possibly lower GNP due to reduced markup between purchase of used product and sale of reworked product; i.e., less value added which mostly goes to wages. Possibly reduced customer choice and satisfaction.	ı R&Don durability, safety. [Public education and persuasion. • Manpower training for rebuild ing/rehabilitation. • Development of diagnostic/repair techniques. • Development of insurance warranty systems.	Resistance from manufacturers/distributors, wholesalers/retailers because of competition New product manufacturers may move into the aftermarket in competition with existing repair/rework companies or new part manufacturers; conversely aftermarket firms could develop more sophisticated units and encroach on new product manufacturing.
		VI. DISPOSAL		
Collection systems for materials, products, components. Sorting/evaluating systems for products and components. Residual disposal system. Product design for easier recycle. Knowledge of availability and locational access to obsolete discarded material items.	Reduced municipal solid waste disposal problem: land and environmental degradation, costs. Preservation of items of value Enhanced international image. General encouragement of prudence, conserving society. Establish learning curve for recovery of additional material under increased scarcity. Reduced costs of retrieval through better information.	Esthetic/environmental insults from collection, sorting, transportation, stockpiling (local). Inhibit substitution of composite material, special alloys, and complex designs because it makes recycle more difficult.	Encouragement of MSW[b] resource recovery centers (technical aid). Disposal deposits based on testing, lab evaluation of recyclability. • Inventory of obsolete, abandoned, discarded materials (in large or concentrated deposits) available for recovery. • Requirement for manu - facturers/distributors to buy back. Disposal charges.	(MSW centers) requires changes in State laws/ constitutions; may undercut present secondary suppliers and destabilize prices; requires heavy State/ local investment in rapidly evolving high technology; requires steady flow of waste, may undercut longer range conservation in initiatives; centers also produce energy. Disposal charges promote roadside dumping Deposits add to consumer prices, reduce sales volume, high administrative costs. Inventory may undercut scrap dealers basis for business (knowledge of location and accessibility y of material for recycle).

[b]Municipal solid waste
= Indirectly improved efficiency of reworking, repair, and resale of products in the aftermarket
. = **Directly** supports improvements in the aftermarket activities.

SOURCE: Working Paper Six.

in energy intensity. Therefore, recycling of metal products and components—which involves the maintenance and manufacturing stages of the materials cycle—is more energy-efficient than building products from scratch with newly mined, refined, and fabricated metal parts.

In sum, improvement of the product aftermarket would provide the institutional mechanism to achieve many other important objectives such as energy conservation and environmental protection, as well as contribute to materials conservation.

Establish Scrap Inventory

A complementary approach to recycling would be to inventory the unused products or abandoned materials available for recycling when needed. Discarded products form a large reservoir of materials that has never been accounted for in detail. Estimates of the magnitude of this resource have been made, but to support recycling, the types of metal and their location, physical accessibility, and unit sites would be needed. A periodically updated inventory might provide an ongoing assessment of available resources sufficient to reduce the need for direct Government action. The inventory would also provide accurate estimates of true product life and reuse patterns. Many "obsolete" products are in fact acting as backup units or serving as second systems (refrigerators and machine shop lathes are clear examples of this).

The most valuable metals (other than common steels) are found in specialized applications and may or may not be accessible. By balancing the books on obsolete products, one could: 1) determine the amount of accessible scrap (scrap that is not corroded and within a reasonable distance of a recycling center), 2) the flows of material products in the aftermarket, 3) the reserves the Nation has to fall back on in case of shortage, and 4) products performing nonessential functions or materials that could be removed from working products and replaced with substitutes in the event of an emergency.

One objection to such an inventory of unused products would be the high administrative cost of the inventory, especially for materials not owned by organizations with readily available inventory records. Some form of sampling procedure would be needed to obtain estimates and focus further study to keep administrative cost down. Existing scrap dealers might object to losing the proprietary information needed to match sellers and their customers. New metal industries may feel their market would be undercut in the short-term, reducing their capacity, but when the scrap ran out there would not be enough capacity. Such instabilities or overreaction would have to be eliminated.

Owners of the scrap might fear that proprietary information would be released to competitors by revealing the amount of material or equipment in current inventory. The data base would need some security protection; this would raise costs. If owners of products lost some control over these products—as in a recall during a materials shortage—this would complicate the present owners' planning for future needs.

Summary

The illustrative implementation options presented were selected so as to avoid Government intervention in private decision processes to the greatest extent possible. Instead, they enable the private sector to more efficiently deal with their own needs while reducing the uncertainties and vulnerabilities for all parties. These means of implementation are to a great extent self-correcting. They do not require constant Government adjustment of standards or regulations in order to achieve a balance of interests.

These options were also selected so as to maximize the potential for reducing materials losses, and to increase the adaptability, stability, and efficiency of the materials cycle.

The set of illustrative options discussed are mutually reinforcing. The public data base supports all the other options. Contingency planning primarily strengthens adaptability and stability. The contingency shares certificate market would moderate the extremes of tight materials markets and diminish the frequently self-defeating responses of stakeholders during short-term crises. Substitution is very much the result of a private decision process, but it also can be an important instrument of national materials and energy policy. Improvements in the aftermarket will contribute to greater efficiency but will also provide the institutional mechanism to achieve many other goals such as energy conservation and environmental protection.

These options if implemented would depend on cooperative action by the private and public sectors. By initiating a private/public sector partnership now, when crisis conditions do not yet exist, all parties could fully assess these and other options without the overriding pressure of emergency situations obscuring their underlying and long-term needs. Through such a partnership, options like those illustrated in this section could strengthen the ability of the United States to avoid crisis conditions in materials such as now exist with regard to energy resources.

Appendixes

Appendix A.—Proceedings of a Workshop on Wear Control to Achieve Product Durability*

BACKGROUND

The Office of Technology Assessment, U.S. Congress, is analyzing the potential for materials conservation in the manufacturing and use of products. This assessment will determine at which stages in the materials cycle materials can be conserved and the potential economic and other impacts of such conservation.

One possible strategy for conservation would be to increase product life through improved corrosion, wear, and fracture control. To explore the conservation potential of increased product life, a workshop was held in Washington, D. C., on the 23rd, 24th, and 25th of February 1976. This document presents the proceedings of that workshop. (See table A-1 for Agenda.)

Wear control was chosen as an example of a technology which can increase product durability. Experts from the field of wear along with representatives from industry discussed the status of wear control technology and its application in the design and maintenance of a range of products (railroad equipment, automobiles, aircraft, propulsion, naval aircraft structures, metal-cutting machinery and tools, and heavy construction equipment).

*Excerpted from Martin J. Devine, Editor, *Proceedings of a Workshop on Wear Control to Achieve Product Durability, 1977,* Analytical Rework/Service Life Project Office, Naval Air Development Center, Warminister, Pa. 18974. The workshop was sponsored by the Office of Technology Assessment, U.S. Congress.

Table A-1.—Agenda for the Workshop on Wear Reduction
(Sponsored by the Office of Technology Assessment, U.S. Congress, February 23-25, 1976)

Theme: "Materials Conservation—improved Product Durability by the-Application of Wear-Control Technology"

Morning Session, Monday, Feb. 23, 1976
Chairman— Dr. Elio Passaglia

Opening Remarks— Purpose
M.J. Devine
Office of Technology Assessment

Welcome
Emilio Q. Daddario, Director
Office of Technology Assessment

Materials Program Overview
A. E. Paladino
Office of Technology Assessment

Workshop Background
E. Passaglia
National Bureau of Standards

Session A.1

Session Chairman:
Dr. J. B. Wachtman, Jr.
National Bureau of Standards

Wear Technology
M. Peterson
Wear Sciences

Incentives for Longer Product Life
W. *Flanagan*
Center for Policy Alternatives
Massachusetts Institute of Technology

Manufacturing Technology for Materials Conservation
R. Matt
Aerojet General

Economic Factors in Product Durability
C. *H. Madden/R. S. Landry*
Chamber of Commerce of the United States

Technology for Estimating Product Durability
J. John
IRT Corporation

Financial and Taxation Implication of Equipment Replacement
P. Lerman
Fairleigh-Dickinson

Safety Aspects of Improved Product Durability
H. *Azzam*
Interrad Corporation

Automobile Durability
D. Barrett
Ford Motor Company

Economic impact of Tribology (U.K. Experience)
D. Scott
National Engineering Laboratory/ Wear Publications

Improved Product Durability Navy Program
A. Koury
Naval Air Systems Command

Bell Systems Wear Control Program
G. *Kitchen*
Bell Laboratories

Life-Cycle Costing
T. Brennan
Naval Air Development Center

National Science Foundation Tribology Program
M. Gaus
National Science Foundation

Advanced-Research Projects Agency Wear Program
E. Van RuethlR. Miller
Advanced Research Projects Office
Office of Naval Research

Maintenance Improvements Within the Airlines
T. Matteson
United Airlines

Session A-2 (Evening)

ASME Wear Control Handbook
W. *Wirier*
Georgia Institute of Technology

ASLE Replacement Costs Survey
R.L. Johnston
Rensselaer Polytechnic Institute

ASTM Wear Program
K.C. *Ludema*
University of Michigan

MFPG— Wear Control
E. Klaus
Pennsylvania State University

Session B—Seminars

1. Automobiles/automobile spare parts
2. Naval aircraft structures/ materials/components
3. Aircraft/aircraft propulsion systems
4. Metal cutting machinery and tools
5. Railroad rolling stock
6. Construction equipment
   a. Track-laying tractors
   b. Rubber-tired earth-moving equipment

SOURCE: OTA.

The workshop explored whether product life could be extended by improved wear control and what would be the cost and other consequences of such extension. These questions were explored from various viewpoints: 1) the status of technology to support increases in durability, 2) economic considerations, 3) current policies and programs, and 4) the methodology and information available.

The fact that only a few products were studied limits the conclusions. However, these products are sufficiently representative of a cross section of industry so that the question of product durability could, indeed, be qualitatively explored.

FINDINGS

Methodology of Economic Appraisal

A large amount of economic data was presented at the workshop establishing that the real cost of wear can be evaluated for a range of products and/or industries. Such information is essential to judge the need for and the significance of new technology.

No standard techniques for acquiring the real costs of wear are available. It is not apparent that a standard technique would suffice; each product might require its own separate analysis.

Standard methodologies are available for economic appraisals, and these could be applied to wear, corrosion, or any other degradation process. Some illustrative procedures are: 1) National Association of Corrosion Engineers (NACE) standards for corrosion economies, and 2) lifecycle costing.

Wear Costs and Consequences

It is clear from information provided during the presentations and seminars of the workshop that: 1) data on the cost of wear in several different product areas are available, and 2) that cost appraisal standards or techniques have been developed for this purpose. As expected, the greater part of this information is available from Government sources. However, further contacts with representatives from other product sectors are expected to yield additional cost data.

At the workshop, examples of specific cost data were presented. These data, if shown to be generally applicable, would in themselves provide strong economic incentives for improved product durability and therefore, for increased materials conservation. It is recommended that such data be collected. A major data source would be the military, which retains computerized malfunction maintenance records. Some examples of specific cost data discussed at the workshop include:

- **Data on Wear Costs in Naval Aircraft.** Data provided on the wear costs in naval aircraft show that the scheduled maintenance for wear for one aircraft amounted to $67 per flight hour, unscheduled maintenance $140 per flight hour, and overhaul $36.87 per flight hour. Thus, the total cost of wear is $243.87 per flight hour. This can be compared with the cost of fuel of $376 per flight hour. Data was also provided on the lifecycle costing of naval aircraft tires. The Navy uses 20,500 tires per year at a cost of $3.48 per landing for a total yearly cost of $1,853,200.
- **Data on Wear Cost of Diesel Engines.** Data provided on the diesel engine maintenance and repair for 20 ships (120 engines) indicated that wear costs were $38.92 per ship per hour. Fuel costs were $75.00 per ship hour.
- **Data on Wear Costs of Tools.** The purchased cost of high-speed steel tools (U. S. A.) was $470 million per year; carbide tools $435 million per year, It was also learned at the workshop that the best estimates of the cost of wear came from users rather than manufacturers of products. The relationship of these costs to manufacturing design decisions was not defined. However, where responsibility is divided between the user and the manufacturers the chief concern of the latter is marketability with durability being an indirect consideration.

It is clear from the data presented that ignorance as to the wear control costs a significant amount not only from the resultant necessity to overdesign but also from the discard of components. Another important factor regarding wear costs was that few product areas use lifecycle costing. And those areas that do use lifecycle costing employ it only at certain stages of decisionmaking. Also, there is little agreement as to how the appropriate interest rate should be calculated in order to compare different development and procurement plans from the present-worth point of view. Present high rates of interest tilt decisions to labor-intensive rather than capital-intensive projects, with a resulting loss in concern for product durability and hence wear control. The possibilities of technological obsolescence further aggravate the problem. Those responsible for development and procurement are frequently career people who will move on and whose current responsibility is to keep down capital cost, not to assure succeeding low-cost maintenance programs.

Thus, the above findings, which are but representative of the material that was covered during the workshop, all point to the fact that wear considerations cannot be isolated from the other considerations that go into the design of consumer products. Wear control simply does not appear to be a primary goal anywhere. Since responsibility for wear control changes hands as the product changes hands during its lifecycle, lifecycle costing will not be used. The heart of the analysis of wear and wear programs, or the lack of them, lies in the understanding of the objective functions of the producers and the consumers as well as the constraints under which they operate.

State of the Technology

It was pointed out at the workshop that tribology, the branch of science concerned chiefly with improvements in wear control for greater product durability, has not received sufficient attention in U.S. academic, industrial, and Government institutions. The benefits of increased emphasis have not been defined sufficiently by the scientists involved. Further research in the field of wear could result in improved techniques to control damage resulting from sources such as contamination, vibration, misalignment, etc. Thus, the most pressing need is for a centralized source of information on wear control technology which can be effectively used in product design.

At the same time, technology does not limit product durability, since many newly developed techniques are now currently used by industry. implementation of this technology in design and maintenance varies from one product to another and one industry to another and is generally limited by many other factors such as cost-effectiveness.

At present, several professional and technical societies sponsor activities which contribute to and facilitate efforts to control wear. Some examples of these societies are as follows:

- American Society of Lubrication Engineers (ASLE) documentation of wear and failure costs;
- American Society for Testing and Materials (ASTM) Committee G-2 on erosion and wear;
- Mechanical Failure Prevention Group (MFPG) sponsored by the National Bureau of Standards; and
- American Society of Mechanical Engineers (ASME) Lubrication Division and Research Committee on Lubrication.

Existing technology is shared by various manufacturers or industries by communication with each other through these societies.

It was also noted that support programs oriented toward tribology and wear control are sponsored by the National Science Foundation, the Advanced Research Projects Agency of the Department of Defense, the Office of Naval Research, the National Bureau of Standards, and the National Aeronautics and Space Administration.

Product Durability

Concise definitions of product durability are not available; however, it relates both to the maximum life achieved and the ability of the product to survive both normal and abnormal usage. High product durability appears desirable from the point of view of reliability and materials conservation. In practice this is usually achieved at a higher purchase price. Secondly, longer life products may have a tendency to reduce the application of technical innovations.

The conclusions of this workshop indicate that considerable improvement in the durability of some products can be achieved if desired. The question which ultimately must be answered is whether increased durability *is worth the added costs* to the consumer and whether it *can be effectively achieved.* Product durability is the prerogative of the consumer. It is available if he wants and demands it.

During the workshop several different actions were discussed which could lead to improved durability.

- Industries with close working relationships between manufacturer and user, e.g., the Bell System and the heavy construction equipment industry, could provide an active feedback system yielding improved durability of products.
- Inspection requirements and inspection frequency may be utilized to achieve increased useful life of products, e.g., based on data from Sweden, and comparison of States in the United States, with and without periodic motor vehicle inspection (PMVI), median car life was shown to be extended as a result of PMVI programs.
- At the workshop, active product-durability programs were reported by the Navy Department. These programs, which have been designated the analytical-rework and service-life programs (ARP), are concerned with: 1) reducing the cost of aircraft maintenance; 2) applying new technology to aircraft repair-rework aimed at increasing service life and improving performance/safety /quality; 3) conducting the optimum strategy for a more efficient application of materials and processes generated under ARP; and 4) increasing component and product durability through the application of the rapid and precise nondestructive inspection techniques (with the minimum disassembly of components) currently available.

However, product life is often not limited by product durability. For example, many products are removed from service which still have some remaining useful life, Among the reasons for early product retirement are: 1) cost of operation or repair, 2) productivity or functionality, 3) esthetics, 4) accidents, 5) physical loss, and 6) style preferences. Nevertheless, the extent to which useful product life can be extended without decreased product durability is not known. The primary factors that can affect useful product life are: 1) use, 2) environment, 3) maintenance, 4) procedures, 5) personnel qualifications, 6) inherent durability, 7) design, 8) manufacturing process, and 9) material characteristics.

In addition, product durability is only one approach to materials conservation. Due consideration should be given to other approaches. At this workshop, reducing materials wastage in manufacturing was frequently cited as one means of achieving materials conservation and should be investigated.

Capital and Labor

From the manufacturer's point of view there are many factors in the development of a product: performance, safety, development cost, schedule, energy consumption, maintenance costs, first costs, appearance, styling, and durability. These factors must be balanced in such a way as to find widespread consumer acceptance. Where durability has a high value to the consumer, that attribute will be accentuated in the product. Even without this demand, the manufacturer has compelling reasons for maintaining high durability standards. First and foremost, a good service record for durability helps to *ensure* that the *customer will return.* This is particularly true for industrial consumers who maintain detailed maintenance records and perform component evaluations.

The manufacturers in general cannot design for a given product life. However, they do know and keep records of service problems (warranty or otherwise) and strive to eliminate these. Where there is a close *working relationship* between the manufacturer and the user, more success and greater durability result. However, the manufacturer is limited in this regard since he seldom has information on the life of a product or a component based upon the service condition in which it operates. Thus, it can be concluded that the acquisition and distribution of such data would provide a necessary base to initiate the engineering development actions for achieving increased product durability.

The results of this workshop suggest that it is primarily the consumer who determines product durability. First of all, in a free-market system, products reflect consumer demands. Secondly, evidence presented at the workshop suggests that many failures are service-related and that product durability is often a function of the kind of usage and maintenance it receives rather than its design-related deficiencies. Market surveys have shown that product durability is very high on the list of customer wants. However, consumers are generally not willing to pay more for increased durability and often when given the choice, they select the lower cost, less durable items (e.g., power tools are often made in different quality lines; even professionals often select lower cost quality). It was further pointed out at the workshop that even sophisticated corporate "buy" decisions of capital equipment are based on maximizing the immediate cash flow (net present value computation) to the company. Thus, longer life at increased cost achieved by greater durability will not be sufficient justification for purchase. The incentive to buy must be lower operating or maintenance costs since these directly influence cash flow.

Thus it seems clear, based on the conclusions of this workshop, that one point of action for increased durability is the consumer, and two areas of appropriate investigation concern maintenance cost reductions and improved durability at equal cost. Programs which identify and correct service related malfunctions, for example, Navy's ARP, should be encouraged since they achieve the above mentioned goals as well as provide reciprocal information to the manufacturer.

Another incentive for the consumer would be the further acquisition of cost data. At this workshop, wear costs were shown to be surprisingly high in a variety of product areas. The same can undoubtedly be said for corrosion, fatigue, and other durability factors. If consumers realized these costs, they might be prompted to take remedial action. It was also pointed out at the workshop that there are acceptable techniques (e.g., cost modeling, economic system analysis) for both assessing durability (wear) costs and in determining how changes in durability would result in system cost savings for a number of products.

The Lifecycle

Product life is not a clear concept. As an individual product reaches the end of its useful life (as determined by its owner), it is not necessarily scrapped. A product may be reconditioned or rebuilt. Or, when a product is finally considered unusable, it may be used as a spare part for a similar model. Thus, it is possible to recycle parts as well as materials. It was also learned at the workshop that scrapped products and components could not be considered waste. For example, the majority of workshop participants felt that for those products considered, the recycling of materials reached 80 to 90 percent. Thus, while recycling can sometimes result in a combination of materials having different properties, it cannot be considered waste. Furthermore, scrapped products often find value as completely different products.

It should also be noted that the workshop participants expressed one area of concern regarding product life. It was reported that inventories for spare parts often reach a high of 20 to 1. Such an excess in inventory could cause severe economic loss. It was decided that this subject should receive careful consideration in the final assessment on materials conservation.

Materials Wastage

It was also found at the workshop that except for spare parts, wastage due to poor product durability seemed small for those products considered. Those products that do not enter the spare parts inventory are often recycled. And, as the supply of material decreases, one would expect more use of spares and more recycling. It was felt by the workshop participants that specific areas of possible wastage should be identified and corrections should be made when possible.

Significance for Research

Although this workshop was called to explore the questions of wear, product durability, and materials conservation, certain implications for research become obvious when that work is taken in its broadest context. A great proportion of the research undertaken in this country has been related to innovation, that is, finding new ways to accomplish a stated objective. Composite materials are a good example of this type of research. Much less attention has been devoted to disciplines such as wear, mechanical failures, corrosion, fatigue, etc., which affect our knowledge of such factors.

It is clear from the results of this workshop that the wearing of materials produces significant costs in the overall materials cycle. And even more particularly, wear degrades performance so that much of the original value of the product is lost. An emphasis on wear research, particularly those studies which emphasize predicitve capability, would be desirable. This emphasis need not be limited only to wear but to all life-limiting technologies. Product durability and life prediction are basically the same concept and increased durability will not be attainable without better concepts of component life.

Improved knowledge of component life and the factors which affect it would not only lead to improved durability but allow tradeoff decisions to be made relative to such factors as materials conservation, lifecycle costs, reimbursement for defective products, maintenance costs, net value, and depreciation. At the present time, these are largely guesses.

Life prediction need not be *a priori*. Diagnostic techniques such as those being used on naval aircraft should be further developed. Estimates of product life remaining allow "use" decisions to be made which result in longer life and improved utilization. Research emphasis on this subject could lead to considerable improvements in materials utilization.

A greater priority could be given to research that extends product life. That is,

1. Improved research and knowledge on what malfunctions actually limit product service life.
2. Increased research on those technologies responsible for life determination such as wear, fatigue, etc.
3. Increased support of research that allows estimates or predictions to be made of product and component life.
4. Expanded research on the subject of diagnostic instrumentation that will allow residual life estimates to be made.

Appendix B.—Conservation in World War II: 1933-45

INTRODUCTION

Over 35 years ago, the United States had to mobilize for a global war. The demand for war material such as aircraft, ammunition, ships, and tanks, plus the loss of foreign sources of supply, created threats of shortages for materials such as: aluminum, chromium, copper, iron and steel, manganese, nickel, tungsten, and others. Strong production and conservation measures had to be established to meet the threats of shortage. This appendix examines the production and conservation strategies and their implementation, and the technical and institutional impediments and associated impacts. This appendix is developed in a scenario format to allow for easy comparisons with future scenarios of materials shortages, and is based primarily on information from the historical publication *Industrial Mobilization for War, Vol. I, Program and Administration,* Bureau of Demobilization, U.S. Civilian Production Administration (1947).

ELEMENTS OF THE WORLD WAR II SCENARIO

Table B-1 provides basic information describing the World War 11 period. War production rose from 2 percent of total output in 1939 to 40 percent of total output in 1943 and 1944, as shown in figure B-1. Expansion of total output was so great that consumer purchases of goods increased by 12 percent. The impact of the war on civilians, in spite of the human misery, was an economic improvement over the great depression.

Strategic and Critical Materials

Table B-2 lists the materials "strategic" to the Nation's military needs in World War 11. Listed as "critical" are other materials that were less difficult to procure than the strategic materials. Table B-3 shows the materials stockpiled just before the war erupted.

Military Requirements for Selected Materials

Table B-4 list the maximum percentages of selected materials allocated to military and foreign requirements. Although 90 percent of the aluminum was used to meet military and foreign demands, sufficient capacity was reached in 1943 to make aluminum more generally available than it was before the war. The high use of copper for the military did not seriously harm the civilian sector, although supply fluctuations were a source of irritation. Originally, drastic cuts for iron and steel were proposed in the civilian sector, but the actual maximum amount used by the military never exceeded 57 percent.

National Objectives and Policies

The general war objective was to supply the United States and its allies with war materials as a first priority. Second priority went to basic civilian needs for public services, food, clothing, and health care. The remainder went to other civilian consumer needs. Table B-5 lists major national objectives based on the January 1942 Address of the President. For comparison purposes, the actual production of munitions in 1945 dollars for the war period is shown in table B-6. Table B-7 describes the production of selected materials prior to 1942. At the beginning of the war in 1942, expansion of production capacity was of greater importance than conservation.

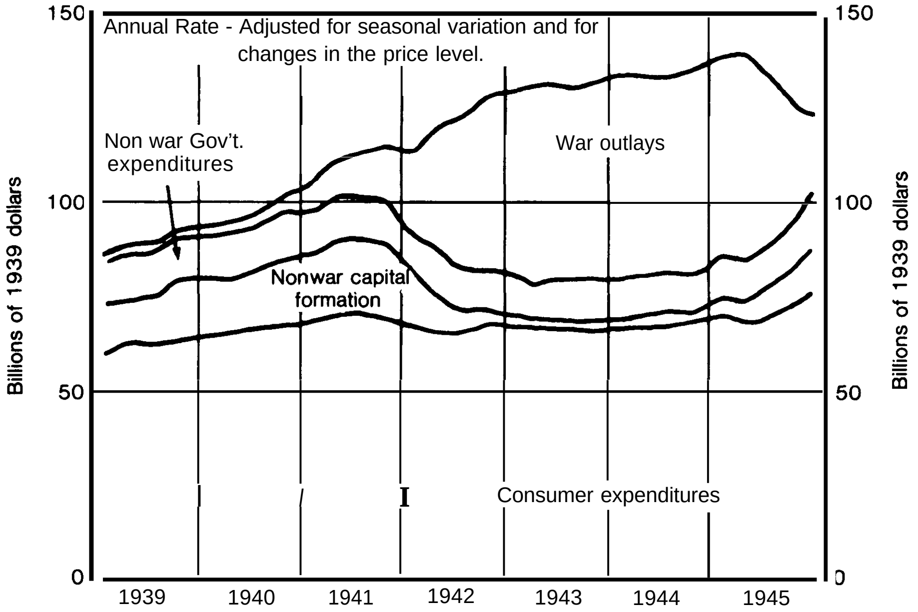
Table B-1 .—Elements of the World War II Scenario

Elements	Remarks
Overall economic conditions.	Recent turnaround from the Great Depression.
Availability of materials,	Critical (see table B-2).
Energy	Generally abundant except for 100-octane gasoline.
Weather/climate.	Favorable (some droughts affected hydroelectric power supply).
Labor	Full employment, labor scarce.
Patterns of social values	Strong group achievement efforts to meet war needs.
GNP	(See figure B-1.)
Inflation.	Inflationary pressures held down by price controls with some two-tier pricing.
Interest rates.	Low-rate Government financing (60-percent private financing).
Population.	137,000,000.
Population distribution	Northeastern States concentration.
Concentration of businesses	Northeastern States with emerging aircraft industry on the West Coast.
Leisure and recreation. .	Limited by long work weeks and military service.
Crime.	Limited by high employment and military service.
Domestic policies.	Recently established social security and labor laws. Isolationist pressures before the war were followed by strong war emphasis with attempts to maintain civilian democratic relationships in war production efforts.
Environment concern. . .	Little concern, smoke, etc., meant product ion.
Education trends	Crash training programs in war-related areas. Education for veterans followed the War.
Technology trends	Steel industry was healthy before the War. Synthetic rubber was in pilot plant status. War needs spurred innovation. Atomic energy unleashed. Radar introduced and expanded. Basic materials industries generally expanded with known technology.
Foreign relationships. . .	Strong ties with England to supply war goods. Conquest of friendly countries changed supply relationships. Russia became an ally.

SOURCE: OTA, based on data supplied from Civilian Product Ion Administration

Figure B-1.— Gross National Product, World War II

[Total output of goods and services]



SOURCE: Civilian Production Administration.

Table B-2.—Strategic and Critical Materials (World War II)

Strategic (essential to defense)
Aluminum for aircraft
Copper for ammunition
Carbon steel for weapons
Alloys steel for weapons

Also: Antimony, chromium, manganese, coconut shell char, manila fiber, mercury, mica, nickel, quartz crystal, quinine, silk, tin, tungsten

Critical" (less difficult to *procure* but essential to *the* Nation)
Steel in the form of shapes, plate, tubing rail, shell, tin plate
Zinc
Aluminum (other than aircraft purposes)
Magnesium
Copper (other than for ammunition purposes)
Brass
Bronze
Tin
Nickel
Rubber
Also: asbestos, cork, graphite, hides, iodine, kapok, opium, optical glass, phenol platinum, tanning materials, tolunol, vanadium, wool

"Conservation controls were Imposed on all materials critical enough to war. *rant* stockpiling

SOURCE: OTA, based on data supplied from Civilian Product Ion Administration

Table B-3.—Status of Government Stockpiles (12/27/41)

Commodity	Objective	Percent of objective on hand 12/27/41
Metals and minerals		
Antimony	27,000 short tons	***29***
Beryllium ore	3,000 metric tons	0
Cadmium	6,000 short tons	1
Chrome ore	1,950,000 long tons	16
Cobalt	2,500 short tons	0
Iridium	7,750 troy ounces	0
Lead	200,000 short tons	9
Manganese ore	3,300,000 long tons	16
Mercury	25,500 flasks	25
Tin	207,434 long tons	24
Tungsten ore	27,209 short tons	28
Zinc concentrates	150,000 short tons	59
Asbestos	30,700 short tons	2
Corundum ore	3,000 long tons	0
Diamonds, industrial	6,410,000 carats	13
Graphite	34,000 short tons	1
Kyanite	3,000 short tons	0
Mica	13,850 short tons	20
Nitrate of soda	300,000 short tons	67a
Quartz crystals	702,000 pounds	?b
Miscellaneous		
Rubber	1,200,000 long tons	*30*

aStored in Chile
bConsiderable quantity delivered, but not yet tested against Government specifications.
SOURCE: WPB Dec. 30, Feb 24, 1942, file 025

Table B-4.—Supply to the Military and Relevant Materials Policies

Material	Maximum percent to military and export	Relevant materials policies
Aluminum	90	Policy of production expansion solved basic supply problem by 1943 with some remaining shortages in shapes and forms.
Copper	*90*	Policy of heavy foreign purchases from South America. Little U.S. expansion made until a premium price system established. Erratic supply problems.
Iron and steel	***57***	Policy of expansion relieved shortages later in the war with a 30-percent increase in capacity.
Alloy materials:		
Chromium	60	Policy to buy as much ore as possible from all sources. Domestic low-grade production established as an insurance policy, but less than 2 percent of that produced was used.
Manganese	Same as steel	Policy of stockpiling worked well with l-year supply available throughout the war. Manganese was used as a substitute for more critical materials. Conservation attention only to high-grade ores.
Nickel	Approximately all to military	Policy of strict conservation controls on use and distribution. Overconfidence in Canadian supply resulted in early shortages. Substitutions, leaner alloys, and recycling improved materials flow.
Tungsten,	Same as steel	Policy of expansion in domestic mining plus price supports and assistance to foreign producers. Miscalculations resulted in excess of supply and inventory surpluses at the end of the war.
Rubber	60	Policy of expansion of synthetic rubber production as 90 **percent of natural rubber was unavailable.**

Other important metals not included in the chart: magnesium, cobalt, molybdenum, vanadium; an important fuel was 100-octane gasoline.

SOURCE: OTA, based on data supplied from Civilian Production Administration

Table B-5.—National Objectives (1942), Presidential Goals

1. To increase our production rate of airplanes so rapidly that in this year, 1942, we shall produce 60,000 planes, 10,000 more than the goal set a year and a half ago. This includes 45,000 combat planes—bombers, dive bombers, pursuit planes. The rate of increase will be continued so that next year, 1943, we shall produce 125,000 airplanes, including 100,000 combat planes.
2. To increase our production rate of tanks so rapidly that in this year, 1942, we shall produce 45,000 tanks; and to continue that increase so that next year, 1943, we shall produce 75,000 tanks.
3. To increase our production rate of antiaircraft guns so rapidly that in this year, 1942, we shall produce 20,000 of them; and to continue that increase so that next year, 1943, we shall produce 35,000 antiaircraft guns.
4. To increase our production rate of merchant ships so rapidly that in this year, 1942, we shall build 8 million deadweight tons as compared with a 1941 production of 1.1 mill ion. We shall continue that increase so that next year, 1943, we shall build 10 million tons.

SOURCE: 77th Cong., 2d sess , *Address of the President of the United States,* H. Doc. 501, pp. 3-4, Jan, 6, 1942

Table B-6.–Munitions Production by Type (July 1940 to August 1945) (in millions of standard 1945 munitions dollars)

Item	1940 (July-December)	1941	1942	1943	1944	1945 (January-August)	Total	Percent of total
Munitions total[a]	2,047	8,442	30,168	51,745	57.594	33,153	183.149	100.0
Aircraft	370	1,804	5,817	12,514	16,047	8,279	44,831	24.5
Ships	391	1,852	6,957	12,498	13,429	6,011	41,138	22.5
Guns and fire control	78	355	1,794	3,180	2,926	1,471	9,804	5.3
Ammunition	87	427	2,743	4,908	5,768	4,173	18,106	9.9
Combat and motor vehicles	238	1,285	4,778	5,926	4,951	3,138	20,316	11.1
Communicant ion and electronic equipment	27	226	1,512	3,043	3,739	2,212	10,759	5.9
Other equipment and supplies	856	2,493	6,567	9,676	10,734	7,869	38,195	20.8

aExcludes net increases in naval stock fund value of goods in store and stock in transit between supply offices, as follows: July-December 1940 (28); 1941 (194); 1942 (320); 1943 (613); 1944 (148); 1945(68); cumulative, July 1940-August 1945 (1,326)
SOURCE: War Production Board, Program and Statistics Bureau,

Table B-7.–Production of Selected Metals (July 1940 to December 1941)

Metal	Total	Third quarter 1940	Fourth quarter 1940	First quarter 1941	Second quarter 1941	Third quarter 1941	Fourth quarter 1941
Aluminum (thousand pounds)	848,254	108,390a	121 ,553a	127,085[b]	147,888[b]	164,939[b]	178,399[b]
Copper (tons)	1,596,750	254,089	276,394	282,816	267,637	253,858	261,356
Lead (tons)	954,971	143,651	176,432	177,782	164,819	145,049	147,238
Steel (tons)	120,416,094	17,967,529	19,609,306	20,277,275	20,592,070	20,622,050	21,347,864
Zinc (tons)	1,120,050	178,620	190,154	186,604	188,277	188,198	188,197

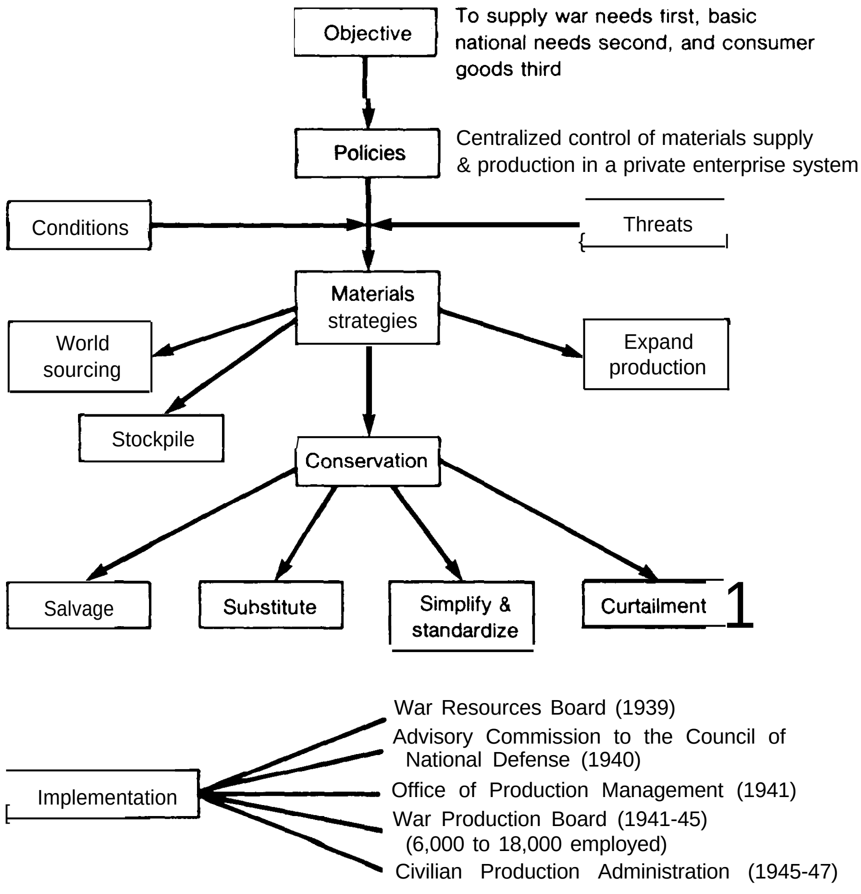
aLetter J. L. Honey to G. C Bateman, Apr. 29, 1941, file 523.4.
bReport "The Aluminum situation, " table Vll, files 523.01 and 523.4.
SOURCE. Metal Statistics, 1945, New York: American Metal Market, 1946, except where otherwise noted.

CONSERVATION APPROACHES

Figure B-2 presents a schematic flow of conservation policy in World War II. Although the policies varied as the war emerged, peaked, and subsided, the general conservation policy was centralized Government control of materials supply and production in the basic framework of a private enterprise system. Conservation was just one tool among several for meeting the objectives of supplying the United States and its allies with needed goods for war as well as providing basic needs for the civilian sector. The prominent conservation options implemented were substitution, simplification and standardization, curtailment, and salvage.

Conservation options such as design efficiency, life extension of products, reducing exports, and reducing dissipative uses were not given much attention because of the crisis conditions and lack of leadtime and advance planning.

Figure B-2.—Conservation Policies During World War II



SOURCE OTA, based on data supplied from Civilian Production Administration

Substitution

The largest substitution project in World War 11 was the substitution of synthetic rubber for natural rubber. Ninety percent of the supplies of natural rubber were cut off. Just before Pearl Harbor, the synthetic rubber process was in a semiexperimental state. Six companies hoped to produce 10,000 tons by 1941. For war expansion, businessmen estimated that each 100,000-ton requirement would involve a 12- to 18-month leadtime and $50 million in costs. In 1942, a rubber "Czar" was given production and conservation powers to increase production and meet supply requirements. By early 1943, 241,000 long tons were produced. By late 1943,850,000 long tons were produced. By March 1944, 50 plants had been either built or converted to rubber production. Table B-8 shows the estimated economics of the substitution of synthetic for natural rubber.

Conservation was emphasized in greater degrees as the war progressed and resources became taxed to the utmost, In the early stages of the conservation program, substitution was the method most commonly used. Excessively heavy demands on certain materials, for which there was insufficient supply, frequently made substitution the quickest and easiest way to relieve the problem. Many of the substitutes used in these crisis times proved unsatisfactory.

Three substitution methods were prominent: (a) complete materials change, for example, steel cartridge cases substituted for brass cartridge cases, (b) changes to reduce the use of the critical material, for example, substituting a different production process, and (c) downgrading the same material for the same product, for example, downgrading the use of compositions in production of tube bushings.

Simplification and Standardization

Simplification was the elimination of items, types, sizes, and colors of products that might hinder the flow of essential products in periods of

Table B-8.—Estimated Economics of Substitution

Material or product.	Synthetic rubber for natural rubber World War II period.
Make v. buy	The choice to buy was not possible because of the loss of Asian sources during the war. Only 10 percent of the natural rubber supply was available.
Required capital investment.	Before the war, in 1940, the synthetic rubber process was in a semiexperimental state requiring new process development including learning curve experiences with input materials and operating characteristics. Existing capacity was 5,000 tons/yr. Six companies expected to have a combined capacity of 10,000 tons/yr by 1941. Financial estimates were $50 million for providing each 100,000 ton/yr of capacity with 12- to 18-month leadtimes. Ultimate production desired was 877,000 long tons/yr including: 40,000 tons neoprene rubber (raised later to 60,000) 132,000 tons butyl-rubber 705,000 tons buna-S-rubber (raised later to 877,000) In early 1943, there were 241,000 tons/yr. produced. In later 1943, there were 850,000 tons/yr. produced. By early 1944, the program was complete with 50 plants in operation. Assuming $50 million/100,000 tons time approximately 1 million tons gives an estimate of total expansion cost of one-half billion dollars (1945 dollars).
Operating and maintenance costs.	Assuming 50 plants were in operation with approximately 1,000 employees estimated per plant making $3,000 per year, then the annual operating costs were probably around $150 million per year.
Cost increase/decrease due to the substitution.	Standard tire cost—Approximately the same to the buyer but he couldn't get a natural rubber tire. Total cost of the synthetic rubber—The Defense Plant Corporation provided the financing and the costs were subsidized making comparisons difficult. Total cost to the customer—The cost is mixed because of the amount directly paid does not include general taxes to the war effort.

SOURCE: OTA, based on data supplied from Civilian Production Administration short supply. It was a means to break the wasteful use of critical materials and facilities. It was also a means to protect the buying public against excessively low quality. Standardization included building in the feature of interchangeability. As an example, through standardization, electrical indicating instruments could be transferred from one combat vehicle to another with substantial increases in production and elimination of waste.

Simplification and standardization were not effective early in the war because of the hurried startup production efforts. Around 1943, the production efforts smoothed sufficiently to allow the refinements necessary to simplify and standardize. The driving force for simplification and standardization was the taxing of nearly every type of resource to the utmost, in order to meet the enormous war production goals and maximize facilities, manpower, and materials usage.

The Office of Civilian Requirements took the leadership in establishing minimum standards of essential consumer goods and limiting production of higher priced luxury goods or unnecessary models and sizes that were wasteful of scarce resources. Attention was given to: (a) the quantities and types of goods and services needed by civilians; (b) the materials required to produce them; and (c) the broad price ranges in which the bulk of production would be sold.

Curtailment

In a war time mood, it was possible to have a program of direct orders from Washington for conservation by curtailment. Curtailment involved preference rating orders, allocation orders, conservation orders, limitation orders, and inventory control.

a. **Preference Rating Orders.** The preference rating order was a priority rating given to manufacturers whose products were vital to the defense program, but entered only indirectly into military items. Some examples of industries receiving blanket preference ratings were building materials, mining machinery, farm machinery, chemicals, and health and medical supplies. Military production had an A-1 rating. The preference rating system was difficult to administer for two basic reasons: 1) quantities were not included in the ratings and hence only A-1 really meant anything; and 2) the paper work was excessive. Over 7,000 pieces of mail came in each day, and applications arrived at about twice the rate at which they could be processed.

b. **Allocations.** Allocations were a mandatory form of distribution. Manufacturers were directed to fill all defense orders in preference to nondefense uses. Rating provisions were included, but went further toward actual allocation by requiring that complete booking of orders be submitted once a month from manufacturers. Nondefense uses were divided into categories, and each was allowed a quantity of metal equal to a percentage of an amount used for the same purpose before the war. Deliveries were contingent upon receipt of a sworn statement of inventory and a sworn statement that no other order had been placed with another supplier for metal for the same purpose. The system did not work well because of the extensive paperwork involved.

The system later evolved into primarily focusing on three key materials: 1) carbon and alloy steel, 2) copper, and 3) aluminum.

Seven claimant agencies dealt directly with the War Production Board: the War Department, the Navy Department, the Maritime Commission, the Aircraft Scheduling Unit, the Office of Lend Lease, the Board of Economic Welfare, and the Office of Civilian Supply. The claimants broke down their requirements by major programs and related them to monthly production schedules. Requirements included not just raw materials, but also specific forms and shapes. The requirements were earmarked as to programs for: production, construction, and maintenance. The sum of the materials requirements of all the agencies were to make up the total demand. On receiving their allotment, each claimant agency had to bring its programs and schedules into line with its allotment. Allotment numbers were then given to contractors and were in effect a “certified check” to obtain materials needed.

c. **Limitation Orders.** These orders were curtailment directions to the civilian manufacturers to limit the production or use of consumer goods and services. There were two reasons for the curtailment: 1) to add pressure on industry to convert to war production, and 2) to conserve scarce materials. For example, a truck manufacturer would be given assistance by the Government in getting scarce material if the manufacturer would agree to cut back on the amount of civilian vehicles producd. A percent of the average annual output of a selected prewar period might be the quota set in the limitation order. These limitation orders applied not only to manufactured goods like vehicles and refrigerators, but also applied to energy conservation. Drought conditions, for example, reduced the amount of hydroelectric power for aluminum production. Limitation orders had to be issued to restrict electrical consumption.

d. **Conservation Orders.** These were orders to eliminate scarce materials in products or to reduce the amount of such natural use in products. As an example, in order to conserve copper, the use of copper in building construction was prohibited and specific articles containing copper were given quotas based on 60 percent of previous usage before the war. In the case of tool steels, substitution compelled the use of molybdenum alloying element in place of scarce tungsten alloying element.

e. **Inventory Control Orders.** Inventory control orders attempted to curb overbuying of materials and hoarding in anticipation of future scarcities. Under the orders, suppliers were forbidden knowingly to deliver any of the named metals considered critical in amounts that would increase the customer's inventory for any calendar month beyond the quantity necessary. The basis for determining quantities was the customer's usual method and rate of operation, and his required deliveries for products produced.

Salvage

The War Production Board had a Salvage Group in its Conservation Division. The group conducted campaigns for the salvage of cutting tools, cordage, twine, fuel, and paper. Salvage was encouraged for all critical materials. As the war began to wind down, the Salvage Division watched only tin and paper, which were still in short supply.

IMPLEMENTATION OF PRODUCTION AND CONSERVATION POLICIES

The implementation of war production and conservation policies started slowly with limited contingency planning by advisers just before the war, building into a super operating agency during the war, and finally, shrinking to a demobilization agency for peacetime preparations. At its peak, 6,000 to 18,000 people were directly engaged in carrying out the national materials policies for the war effort. In 1939, a War Resources Board consisting of Government, industry, and labor advisers attempted to determine possible wartime needs. Through its efforts, a limited stockpile of material was accumulated to meet contingencies. In 1940, an attempt was made to create a stronger organization. Civilian isolationist pressures allowed only a modest change with the establishment of an Advisory Commission to the Council of National Defense. This council had no single leader. Efforts were geared at converting segments of industry to producing war goods. Resistance was met from industry, labor, and local government, for example, when curtailment of civilian automobile production hurt brisk sales.

In 1941, a stronger organization was formed with two leaders, one from industry and one from labor. The organization was called the Office of Production Management (OPM). Large orders from England were coming into the United States for war goods when the lend-lease program was initiated. The OPM had to balance production for these war goods against civilian requirements. Efforts were aimed at increasing productive capacities and building the stockpile. This organization had the authority to apply priorities for needed materials and goods.

After the war broke out in late-1941, the Nation was in total war effort mood, and a centralized superagency was established, called the War Production Board (WPB). By 1943, the superagency was in firm control, and production and conservation procedures were fairly well established except for conflicts concerning military estimates of needs. Most of the discussions in this paper cover the activities and policies of WPB. After the war changed from a two front to a single front, pressures formed to eliminate WPB and reduce Government controls. The Civilian Production Administration replaced WPB and carried out the transition task. The Civilian Production Administration was finally phased out in 1947.

IMPACTED STAKEHOLDERS AND THEIR RESPONSES

Table B-9 shows a selected listing of stakeholders and their problems in the World War II period. The conflict between the military and the civilian needs was the most prominent of stakeholder problems. The civilian sector lost out to the military as the war approached. When the war was ending, the civilian influence grew as evidenced by the isolationist pressures on Congress and the President to slow the shift to war production. An example of military influence was the strength of the Army-Navy Munitions Board in demanding that its needs be given priorities during the heat of the war. An example of reemerging civilian influence, as the war ended, was the pressures to let price do the allocation rather than formal Government controls.

The second prominent stakeholder problem involved industry, which had to look to the superagency for its needed materials and product quotas. Industry representatives were very vocal about the delays, confusions, and contradictions of the new Government bureaucracy. Special interest groups in the industrial sector would also push for gains that would put them in a favorable future competitive position.

The third prominent stakeholder problem involved management and labor. Before the war, labor had just accomplished a great deal of gains through labor legislation and confrontations with management. Labor was afraid that gains would be lost under wartime emergency actions. The President and Congress were pressured to include both labor and management people on the wartime boards involved with materials policies.

The fourth prominent stakeholder problem involved the established executive agencies and the wartime superagency. Overlapping of functions and power caused confusions and strained relationships. As an example, both the Department of the Interior and the Federal Power Commission wanted more say in the development of hydroelectric sources.

England and the allies were also important stakeholders that placed demands on the war agency. Supplies had to be portioned out. England's huge demands had to be reduced to a balance with U.S. needs. Russia's needs had to be portioned in the light of possible collapse of that nation. South America had to have sufficient goods to remain good neighbors. The War Production people in the United States did not always see the global picture of resources and alternatives and risks. As an example, British Empire resources around the world were still available in many cases and the English had to point this out to WPB.

Internal stakeholders emerged within WPB. The field organizations differed with the central organization on how to work with industry. Often the field groups were left confused without information or authority while having to meet the industrial user face to face.

Table B-9.–Examples of Impacted Stakeholders and Their Responses (World War 11)

Time period	Stakeholders	Nature of the problem	Stakeholder responses	Results
1939	Military v. civilians	Amount of military influence in production plans	Isolationist pressures	Hesitancy of President to establish War Resources Admin.
1940	Industry v. antitrust units	Firms reluctant to accept defense contracts involving negotiated	industry delays	Attorney General promises freedom from prosecution
1941, ...	Military v. civilians	Consumers worried about new priorities extended by Congress	Consumer complaints	Vice President had to intervene to resolve conflicts
	Industry v. Govt. production agency	Overlapping functions by new agency	Pressures by industry for less confusion	Delays, contradictions
	U.S. v. foreign	Aid to England, Russia, South America	U.S. concern over loss of vital goods	Lend-lease program and closer foreign cooperation
1942	Military v. civilians	Overlapping authorities	Production Agency disturbed over free hand of the military	Production agency reorganization but problem persists
	Civilian v. Production Agency	Appeals by civilians for materials	Civilian demand for democratic treatment	Appeals Board established
	Interest groups v. interest groups	Oil groups wanted rubber from oil, Agriculture wanted the synthetic rubber from alcohol	Interest groups pressure on Congress	Synthetic rubber made from alcohol
1943, ...	Joint Chiefs of Staff v. WPB	Lack of production control	Inability of War Production Board to validate military claims for materials	Paper committee set up but resolved. Dislocation in materials flow.
1944 -45.	Free enterprise v. Govt. control interests	Pressures for allocation by price v. Government determination of need	Interagency arguments over consumer quality and price problems	Trends to decontrol as war wound down. Reorganization favored less Government involvement

SOURCE: OTA, based on data supplied from Civilian Production Administration

SUMMARY 1939945

In the World War II period, there were four basic conservation options: 1) substitution, 2) simplification and standardization, 3) curtailment, and 4) salvage. The major strategy for materials supply was not conservation, but increased production. Other materials supply strategies included stockpiling and world sourcing.

Strategic materials were those essential to defense, including aluminum for aircraft, copper for ammunition, and carbon and alloy steel for weap ens. Critical materials were those less difficult to procure but essential to the Nation.

Substitution was the conservation option used first and most frequently. Many of the substitutes used under crisis conditions were unsatisfactory. Users were eager to return to the original material or product. Three prominent substitution methods were: 1) complete materials change, **2)** changes to reduce use of critical materials, and 3) downgrading the material for a given product.

Simplification and standardization was a conservation-option that came later in the war as production began to smooth out and consumer demands for better quality increased.

Curtailment was a conservation option involving direct orders. The orders included: 1) preference rating orders, 2) allocation orders, 3) conservation orders, 4) limitation orders, and 5) inventory control.

Salvage was the recycling conservation option. Recycling of steels became an important part of reducing alloy element requirements later in the war.

Implementation of production and conservation policies was accomplished during World War 11 by a new superagency called WPB. At its peak, 6,000 to 18,000 people were directly engaged in the activity.

In addition to the production and conservation strategies, two additional strategies were applied: 1) stockpiling; and 2) world sourcing. Manganese was stockpiled successfully with a l-year supply available throughout the war. World sourcing of minerals like chromium and tungsten ores provided sufficient needed material to make subeconomic mining in the United States questionable in spite of foreign military occupations and hazardous transportation problems.

Two general observations can be made concerning materials conservation. First, availability of materials shifted in a short period of time, for example, steel was scarce and lumber abundant and then the reverse occurred within a couple of years as the war progressed. Policies had to be shifted with the mood of the people, for example, the people would accept controls of a “Rubber Czar” during the heat of the war, yet they objected to Government intervention and leaned to private sector allocation as the war was ending.

Appendix C.--Conservation and Shortages: 1946-77

INTRODUCTION

In analyzing whether the occurrence of materials shortages should affect the conservation of materials, one needs to look at all types of materials shortages, both general and specific. As most materials experts will agree, there have only been two major materials shortages of any duration from the end of World War 11 through 1977: the Korean War and the materials shortages occurring during 1973-74 (see figure C-l). However, at the same time, experts in both the public and private sectors note that interruptions in supply are constantly occurring on a short-term basis. As a result, industries are constantly having to adjust their supply decisions regarding production needs, etc., due to such factors as cartels, environmental regulations, fiscal and monetary policies, capacity limitations, and domestic and international demand pressures.

As illustrative of the types of materials shortages that have occurred in the United States, the following discussion[1] examines the supply of seven metals from 1946 to 1977. The metals that are examined include: aluminum, chromium, copper, nickel, scrap, steel, and tungsten.

SHORTAGES IN ALUMINUM SUPPLY

1. **Aluminum Supply in 1950-53.** Aluminum was in tight supply during this period as a result of the Department of Defense (DOD) requirements for the Korean War. Restrictions were placed on civilian use of aluminum until 1953, and the percentage of aluminum use by the military increased from 5 percent in 1950 to 28 percent in 1952.

During this period, the Government offered the aluminum industry financial incentives to increase production capacity. Under this program, 613,000 tons of new capacity were added between 1951 and 1954.

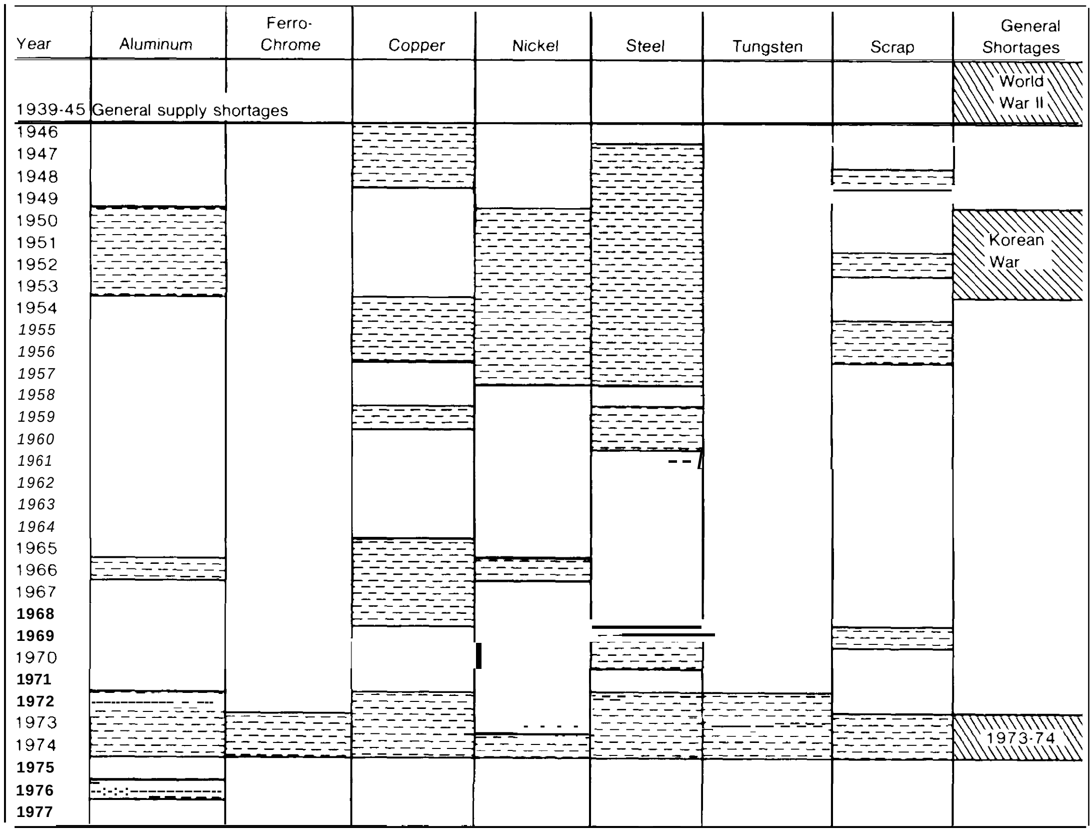
2. **Aluminum Supply in 1966.** During late 1965 and early 1966, aluminum supply was again in tight supply due to an increase in military activities as a result of the Vietnam War. The DOD requirements for aluminum increased from 2 percent in the second quarter of 1965 to 11 percent during the third period of 1966. A shortage situation was avoided by the release of aluminum from the Government stockpile.

3. **Aluminum Supply in 1972-74.** During the period 1972-74, aluminum was reported as being one of the major metal shortages. In the survey undertaken by the Senate Government Operations Committee regarding the industry perceptions of the materials shortages, 74 companies indicated that they had experienced aluminum supply problems. The survey indicated that aluminum mill products, for example, sheet, plate, rod, bar, tube, extrusions, casting, foil, forgings, etc., were all in short supply. The major problem the industries were facing was an increase in demand and a static supply of aluminum. An additional factor that affected production capacity was an electric power shortage which occurred in the Pacific Northwest in 1973. This shortage was responsible for reducing aluminum production capacity by 9.5 percent.

Other factors that aggravated aluminum production were: (a) the difficulties encountered in obtaining aluminum scrap and alumina catalysts from foreign markets (due to very high prices); (b) the unavailability of adequate metal and rolling capacity to produce aluminum foil; (c) the costs of compliance with environmental protection regulations; and (d) price controls.

[1]The data for this appendix is based on the following sources: (1) literature survey in the *New York Times, Wall Street Journal,* and *American Metal Market* newspapers; (2) working paper prepared by the Department of Commerce for the National Commission on Supplies and Shortages on "Shortages and Surpluses in Selected Commodities–1976;" (3) report prepared by A. D. Little for the Department of Commerce entitled, *Material Shortage Study;* and (4) hearings held by the Senate Government Operations Committee, August 1974, on *Materials Shortages, The Industry Perception.*

Figure C-1.— Metal Shortages 1939-77



Shortages, specific
General shortage periods

SOURCE: OTA based on data from references cited in footnote 1 p 118

It was found that independent fabricators and smaller customers were hit the hardest by the increase in prices, the shortages of selected types of aluminum products, and the allocations instituted by some producers and suppliers.

4. **Aluminum Supply in 1975-77.** At the beginning of 1975, the demand for aluminum dropped off due to the reduction of construction jobs. In response to this reduction in demand, aluminum producers began to curb their output. In addition, the General Services Administration further aggravated the situation by releasing 15 million lbs of aluminum from the Government stockpile. Thus, both the United States and Canada further limited their production of aluminum.

In late 1975 and early 1976, demand for aluminum was on the rise. The construction industry began to pick up, and the Ford Motor Company decided to expand its output of cars. As a result of these two factors, demand and increased supplies began to tighten (a result of reduced capacity during 1975). The tight aluminum supply situation was eased to a certain degree by the recycling of aluminum cans during 1976.

Articles indicate that while some spot shortages of aluminum occurred on the east coast due to unusually severe winter weather conditions, the overall outlook for aluminum supplies remained positive. However, it is possible that due to capacity limitations the production of aluminum might have been bottlenecked as economic recovery continued.

SHORTAGES IN CHROMIUM SUPPLY

The United States is dependent on foreign sources for its chromium requirements, either as chromite or as ferrochromium. Up until 1968, the United States imported a large amount of chromite. However, in 1968, the United States shifted its importation of chromite to the importation of ferrochrome. One reason for this shift was the United Nations sanction against Southern Rhodesia, which was the U.S. principal supplier of chromite. As a result, the United States shifted its dependence to the Soviet Union. While many companies expressed the fear that raw materials might be cut off from either Rhodesia or Russia—thus limiting production—such a shortage did not materialize.

At the same time, however, another type of shortage did occur during 1972-74. This shortage related to the ability of the United States to produce ferrochromium alloys at peak steel demand. Peak demand was reached in 1973-74 and could be reached again in any type of national emergency. Thus, the shortage in regard to chromium results not from the unavailability of the raw materials, but rather from the inability to convert the ore to ferrochromium alloys.[2]

[2] The conversion problem stems from the availability of electric furnaces. Apparently, industry switched its electric furnaces from the production of ferrochromium alloys to silicon ferroalloys, which are more profitable.

SHORTAGES IN COPPER SUPPLY

1. **Copper Supply in 1946-71.** Table C-1 illustrates the periods of surplus and tight supply in regard to copper and the major factors influencing the supply from 1946-71.

Table C-1 .—Copper Supply

Period	Incident	Influencing Factors
1946-49 . .	Tight supply	Strong post-World War II demand and Government action.
1949	Excess supply	Weak demand.
1950-53 . .	Relative balance	Strong demand and production. Government price controls.
1954-56 . .	Tight supply	Strong demand and copper strike.
1957-58 .	Excess supply	Weak demand due to recession.
1959	Tight supply	Strike reduces available supply.
1960-64 . .	Relative balance	Demand and supply increase.
1965-68 . .	Tight supply	Strong demand. Government actions including Vietnam War and 8-month copper strike.
1969-71 . .	Relative balance	Supply able to keep pace with demand.

SOURCE: Department of Commerce

2. **Copper Supply in 1972-74.** Copper was considered to be in short supply during 1972-74. Sixty-two companies, as reported by the survey undertaken by the Senate Government Operations Committee on industry perceptions, indicated supply shortages. The reason most cited for the apparent shortage was an increase in world demand combined with limited production capacity.

Other factors that were mentioned as producing a tight supply situation included: (a) the exportation of domestic copper to foreign countries due to higher prices overseas, (b) price controls, and (c) the possibility of formation of a copper cartel that would restrict the sale of copper to the United States.

3. **Copper Supply in 1975-77.** Demand for copper began to fall during the first quarter of 1974 and plunged in 1975 due to a worldwide recession. As a result, copper production was cut back and prices fell. However, by early 1977 an oversupply of copper existed due to the very low level of demand.

SHORTAGES IN NICKEL SUPPLY

1. Nickel Supply in 1946-71. A primary nickel shortage was experienced in the United States from 1950 to 1957. This shortage was the result of rationing by Canadian producers, from which the United States imports about two-thirds of its nickel. This rationing caused U.S. steel producers (nickel is used in the production of stainless steel) to revert to the production of low-nickel steels. The Government continued to buy metal for defense stockpiles and placed nickel under allocation from August 15, 1951, to November 1953. The nickel shortage was less severe in 1955 due to the diversion of nickel, scheduled to be stockpiled, to the consumer sector.

In 1958, supply .exceeded demand and nickel producers reduced operating capacity. As a result, the Government terminated all contracts for nickel delivery, and DOD lifted all restrictions on the use of nickel.

During 1964, a nickel shortage would have occurred, due to an increase in demand for stainless steel, except for the fact that the Government released nickel from the strategic stockpile.

2. **Nickel Supply in 1972-74.** Nickel operations were fairly normal from 1972 through 1973. However, in early 1974, the nickel supply began to tighten due to a record consumption. In response to the tight market, many companies began to import additional nickel from the U.S.S.R. Additional responses to the demand/supply situation were the allocation of metal by nickel producers and the resistance by nickel producers to accept defense-related orders from new customers. The major industry that was adversely affected by the tightened supply of nickel during 1974 was the steel industry, that is, in the production of stainless steel.

3. Nickel Supply in 1975-77. Nickel was in excess during this period due to weakened demand.

SHORTAGES IN SCRAP SUPPLY

Ferrous Scrap Supply From 1946 to 1971

1. **Ferrous Scrap Supply From 1946 to 1949.** Steel production steadily increased from 1946 through 1948, thus increasing the demand for ferrous scrap. By 1948, ferrous scrap was in short supply. Also, price controls were lifted on November 10, 1946, thus allowing prices to rise.

A drive was begun by the Secretary of Commerce in November 1948 to assist in increasing the flow of scrap. The program was terminated in May 1949 as a result of an improved scrap situation. Also, imports of scrap during this period helped to ease overall scrap supply.

(b) **Ferrous Scrap Supply During 1950-53.** The demand for scrap increased during the Korean War due to increased steel production. Purchased scrap receipts increased between 1949 and 1950 by about 35 percent. Some spot shortages of scrap caused the closing of some open-hearth furnaces in early 1952. However, widespread closings of furnaces were averted due to the National Production Authority allocation program and by the maintenance of adequate flow of scrap from processors.

(c) Ferrous Scrap Supply During 1955-57. Ferrous scrap was in tight supply due to a record increase in the production of steel during this period. Also, scrap demand was especially high due to large export volumes.

(d) **Ferrous Scrap Supply During 1969-70.** Ferrous scrap again moved into a tight supply situation due to an increase in steel production. While steel production started to ease in 1970, exports increased the total scrap demand.

Scrap Supply From 1972 to 1974

(a) **Ferrous Scrap.** Tight supply of ferrous scrap is usually associated with a rising demand for steel. When steel demand increases, so does the price of scrap. Scrap prices are constantly changing, up and down, in response to changes in demand. A second factor that affects the supply and price of ferrous scrap is export demand. And in 1973-74, a rapid increase in scrap exports took place.

During 1972 and early 1973, the steel industry began to recover from the severe recession of 1971. The demand for domestic steel increased due to: (1) a lesser availability of foreign steel as a result of the devaluation of the dollar,[3] and (2) the overall increase in worldwide demand. Thus, the demand for U.S. domestic-steel and scrap sharply increased both domestically and internationally during this period.

Scrap prices began to increase and ranged from $48 per ton in January 1973 to $55 at the end of June, to a high of $81 per ton in November 1973. Also, scrap prices were not only high, but in some cases the supply of scrap was limited due to the exportation of scrap to foreign markets. Some small scrap companies were able to export their scrap for higher profits due to the fact that they were not affected by the wage/price control constraints. A further factor that aggravated the supply of scrap was the shortage of gondola cars that are used to ship the scrap to markets.

The situation was most serious in regard to the availability of scrap on the west coast. This was due to the large amounts of scrap being exported in proportion to the supply of scrap available for production.

(b) **Aluminum Scrap.** Aluminum scrap is the prime raw material used in the production of secondary aluminum ingot.[4] During this period, aluminum scrap was in short supply due to a number of factors: (1) as the demand for primary aluminum increased, so did the demand for aluminum scrap; (2) more scrap was exported due to increased worldwide demand and higher prices received for scrap on the foreign market; and (3) scrap that was normally available from fabricating plants of integrated producers was no longer offered for sale.

[3]Due to the devaluation of the dollar, domestic steel was priced about 25 to 35 percent lower than foreign steel.

[4]secondary ingot accounts for approximately 20 percent of the total U.S. aluminum supplied.

SHORTAGES IN STEEL SUPPLY

1. **Steel Supply in 1946-71.** The period following the end of World War 11 included periods of peak steel demand with tight supply or shortages of steel and periods of weak demand at the low point of the business cycle, as well as the more normal demand periods. Steel was in tight or short supply three times during 1946-71: (a) 1947-57 when the European and Japanese steel industries were rebuilding, (b) 1959-60 caused by the 116-day steel strike in the United States, and (c) 1969-70 due to a worldwide increase in steel demand.

2. **Steel Supply in 1972-74.** During the period 1972-74, one of the major shortages of materials experienced by industry was steel. Approximately 106 companies indicated to the Senate Government Operations Committee in their survey on "Industry Perceptions of Materials Shortages" that they were having difficulty obtaining steel, that is, stainless, castings, forgings, plate, sheet, and steel products.

Major factors to the tight demand/supply situation included: (a) a lack of adequate steel production capacity to meet demand, (b) wage and price controls, (c) a shortage of iron, and (d) an overall increase in worldwide demand for steel.

3. **Steel Supply in 1975-77.** During the first quarter of 1975, the demand for steel reached an all-time low. As a result, the production of steel was cut back drastically, However, by the end of 1975, the demand for steel began to improve, causing spot shortages to occur in various steel products. By the end of 1976, the demand/supply situation began to balance out.

Spot shortages also occurred in the availability of steel products during the first quarter of 1977 due to severe weather conditions and a lack of adequate fuel to operate the steel mills. However, as weather conditions began to ease, so did the tightened steel supply.

SHORTAGES IN TUNGSTEN SUPPLY

During the materials shortages of 1972-74, two companies indicated to the Senate Committee on Government Operations that tungsten was in short supply. The reason given for such a shortage was the lack of capacity. Factors influencing capacity, as with other metals, were wage and price controls, environmental protection regulations, and foreign competition.

SUMMARY 1946-77

From 1946 to 1977, interruptions in supply were constantly occurring in regard to the seven metals analyzed in this study. Factors affecting the supply of such metals include: governmental regulations, capacity limitation, direct raw materials shortages, strikes, transportation disruptions, import limitations, unusual demand surges, and acts of nature, for example, severe weather conditions. While a tight supply situation can result solely from the general fluctuations of the business cycle, the occurrence of supply disruptions adversely affecting industry usually involves the combination of several factors, for example, unusual demand surges combined with capacity limitations, and/or demand surges combined with direct raw materials shortages.

Tight supply situations or actual disruptions in supply occurred as follows: 1) aluminum was in tight/short supply in 1950-53, 1966, 1972-74, and early 1976; 2) ferrochromium alloys were insufficient to meet peak steel demand in 1973-74; 3) copper was in tight/short supply in 1946-48, 1954-56, 1959, 1965-68, and 1972-74; 4) nickel was in short supply during 1950-57, 1966, and 1974; 5) supply shortages were apparent in the supply of scrap in 1948, 1952, 1955-57, 1969, and 1973-74; 6) steel was in short supply in 1947-57, 1959-60, 1969-70, 1972-74, and the first quarter of 1977; and 7) the supply of tungsten was interrupted during 1972-74.

The above facts indicate that tight/shortage situations with regard to the seven metals constantly occurred over the past 38 years. Since the factors that have combined to cause such supply disruptions can reoccur, the probability of specific shortage conditions in the future is quite high. There is less certainty about the reoccurrence of general non-war-related shortages.

Appendix D.— Glossary of Terms

Corrosion and Wear Losses-Metal that is lost in the actual process of corrosion and wear (e.g., the gradual wearing down of saw blades or drills due to cutting friction) in the utilization of products; does not include metal lost because of a shortened product life due to corrosion and wear.

Dissipative Losses-Metal that is lost or consumed in use (e.g., used as catalysts and in paints and fertilizers) or dispersed beyond practical recovery (paper clips, nails, etc.).

Excess **Metal in the Material** Cycle—Material in use at each step in the material cycle that could be eliminated through applications of one or more conservation options.

Materials Cycle—The total flow of a material from mining to its ultimate return to the Earth (e.g., in landfills). Includes several steps or stages: mining, ore processing, metal production, transportation and handling, product manufacturing, distribution, use, storage, and disposal.

Metal Conservation Options–A technique by which metals can be conserved (their usage reduced). Example include: substitution of one material for another, prevention of losses in manufacture, making products smaller or with less metal, and recycling.

Metal Losses From the Materials Cycle—Residual metal from each step in the material cycle; examples include: the metal remaining in the ore that is not recovered, the slags of byproducts of metal processing, industrial scrap from product manufacture, material dispersed in use (e.g., pencil lead), and postconsumer waste.

Metal Processing Losses—Metal that is lost in the conversion of ore to metal, usually in the form of slags and dresses.

Metal Recycling-Recovering of metal from all sources including used products.

Milling and Concentrating Losses-Metal that is not recovered from the mined ore and remains in the mine "tailings."

Nonmetallic Losses-Metal that is lost when the ore is not actually converted to metal but is used in nonmetallic applications, such as abrasives, refractories, insulation, and ceramics.

Product Manufacturing Losses-Metal that is lost in the form of industrial scrap remaining from the manufacture of products: examples are chips, grinding dusts, unused metal, and product rejects.

Postconsumer Waste-Metal that is lost in household wastes discarded into the municipal solid waste stream.

Product After Market-The business of product recycling, resale, and reuse.

Product Recycling-All forms of recycling including metal recycling, product or component rework or remanufacture, or product or component reuse.

Product Rework or Remanufacture-The process by which an old product is restored to a condition approaching or equaling its original condition by replacing worn parts, cleaning, and refinishing.

Substitution-The use of one material or metal in place of another in a product or application.

Transportation and Handling Losses—Ore that is lost in transit between the mine and the mill.

Unrecovered (and Unknown) **Material-Metal** that is lost due to lack of recycling; calculated by subtracting the amount of scrap available from obsolete products in a given year from the amount actually recycled. The amount of scrap available is based on the products manufactured in previous years and estimates of their lifetimes.

Wastes-Metal losses or excess usage.

Appendix E.— List of Working Papers

Working Papers contain the complete texts of six working papers prepared by contractors in support of this assessment. The papers will be available in the near future from the National Technical Information Service (NTIS), Department of Commerce, Springfield, Va. 22161. Please call OTA's Public Affairs Office on (202) 224-8996 for NTIS availability and ordering information.

OTA staff have drawn heavily on these working papers for data and analyses. Their public release by OTA does not imply that OTA endorses the assumptions, data, findings, or conclusions of any of the papers or their authors. Neither OTA nor its contractors endorse specific named products, processes, or firms.

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Working Paper One
A Preliminary Assessment of Options for Reducing Wastage of Materials, Volume II-A
by Battelle Columbus Laboratories

Working Paper Two
Flows of Selected Materials, 1974, Volume II-B
by Battelle Columbus Laboratories

Working Paper Three
Identification and Evaluation of Metal Conservation Approaches for Products, Volume II-C
by Rensselaer Polytechnic Institute

Working Paper Four
Alternative Methods for Implementing a Recycling Policy, Volume II-D
by Battelle Columbus Laboratories

Working Paper Five
Analysis of the Impacts of Changing Product Service Life and Material Content, Volume II-E
by Pugh Roberts Associates, Inc.

Working Paper Six
Preliminary Technology Assessment of Materials Conservation Strategies, Volume II-F
by The George Washington University Program of Policy Studies in Science and Technology

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