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.

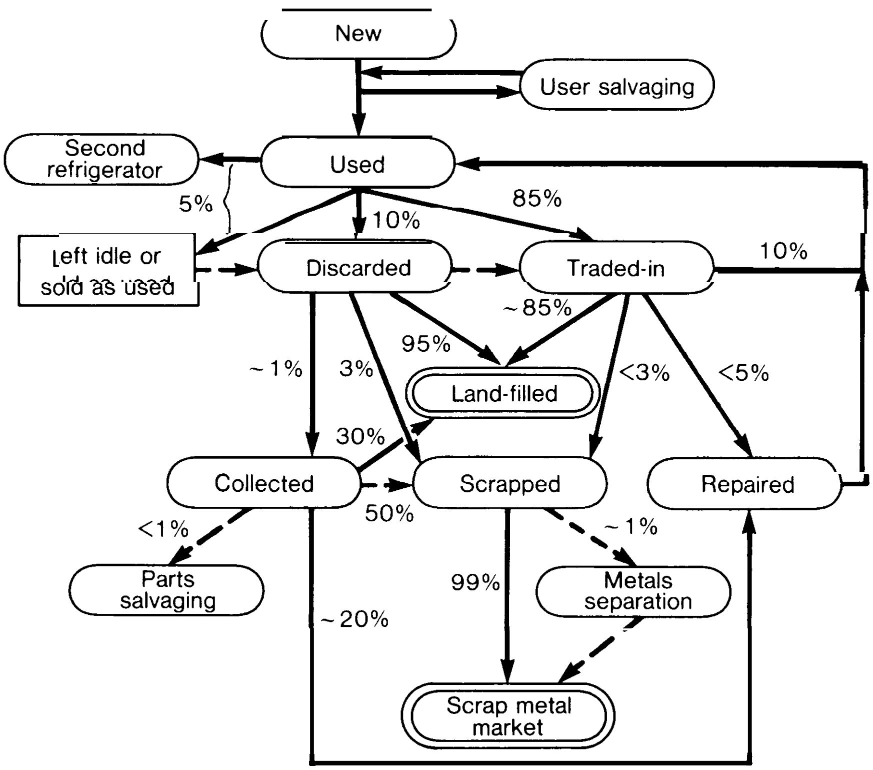
Another impediment is the consumer's desire for new products. This barrier was identified in a survey of consumers carried out by Corm where "25 percent of the respondents disposed of their products because they preferred new ones."[1] This consumer behavior pattern is in part encouraged by Government 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	1/2
	Plating	1/.
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.

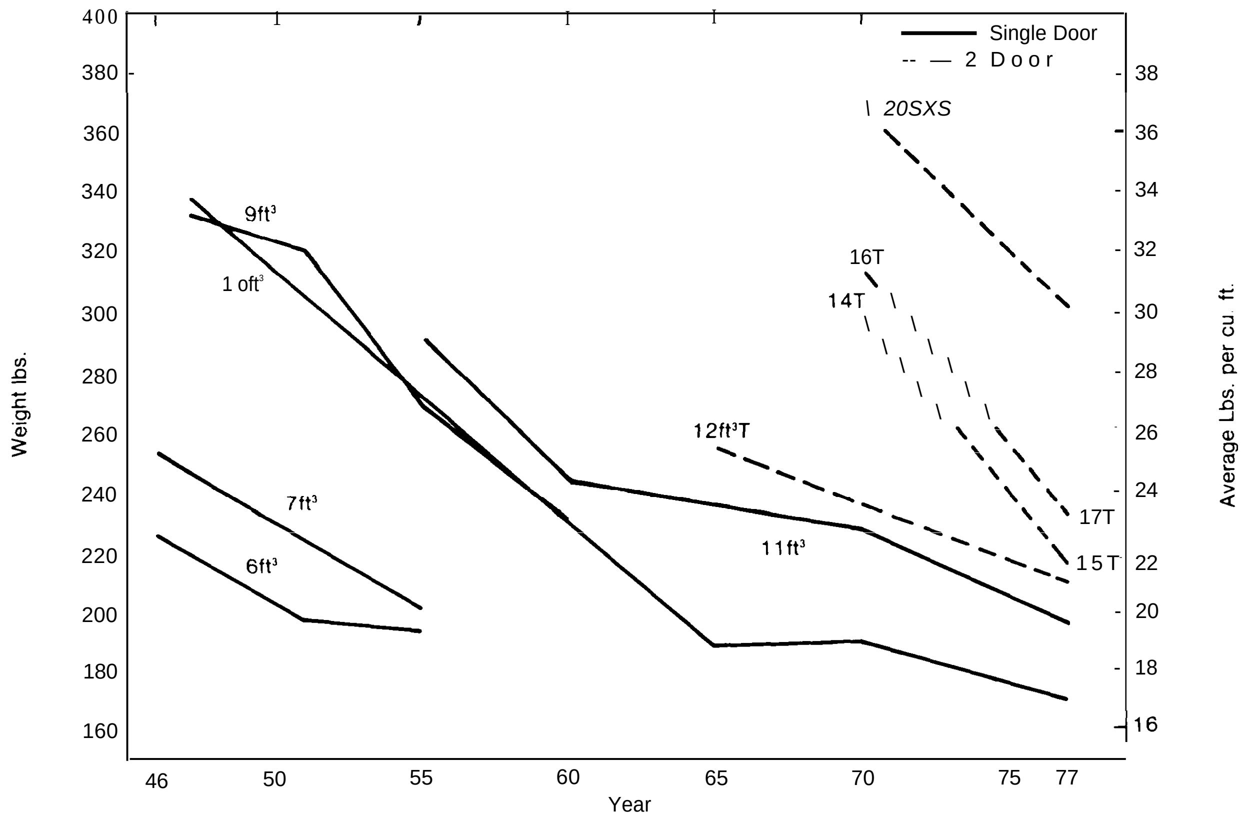
The results presented for refrigerators apply generally to the other products of this report. That is, although elimination of some excess metal is possible, the difficulties include increased manufacturing costs, increased cost of investment in engineering and equipment, decreased durability, and reduced 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	15%
Automobile.	9%
Aluminum vans	25%
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

51-680 O - 79 - 6

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	23[a]	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	

[a]Percentage of aluminum used in construction Industry
[b]Determlned 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.

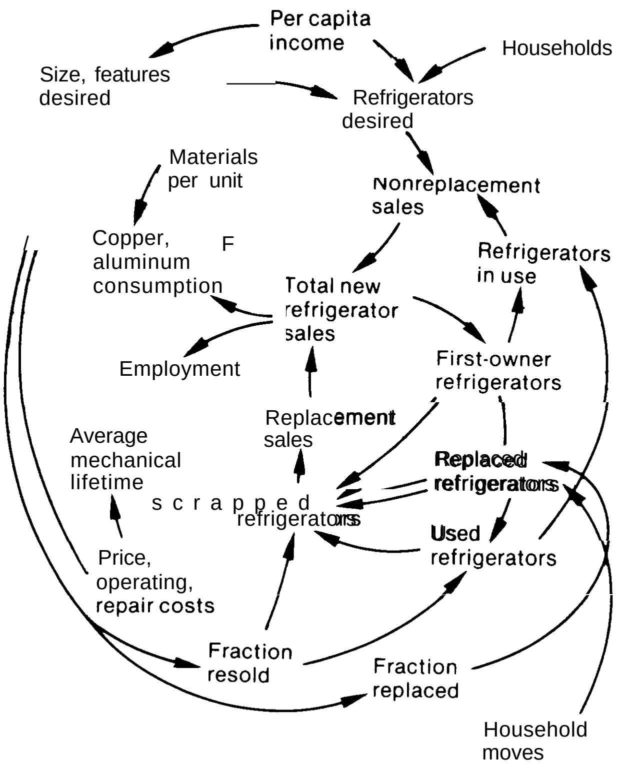
EXTEND PRODUCT LIFE OF REFRIGERATORS: AN EXAMPLE OF SYSTEMS DYNAMICS METHODOLOGY

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:

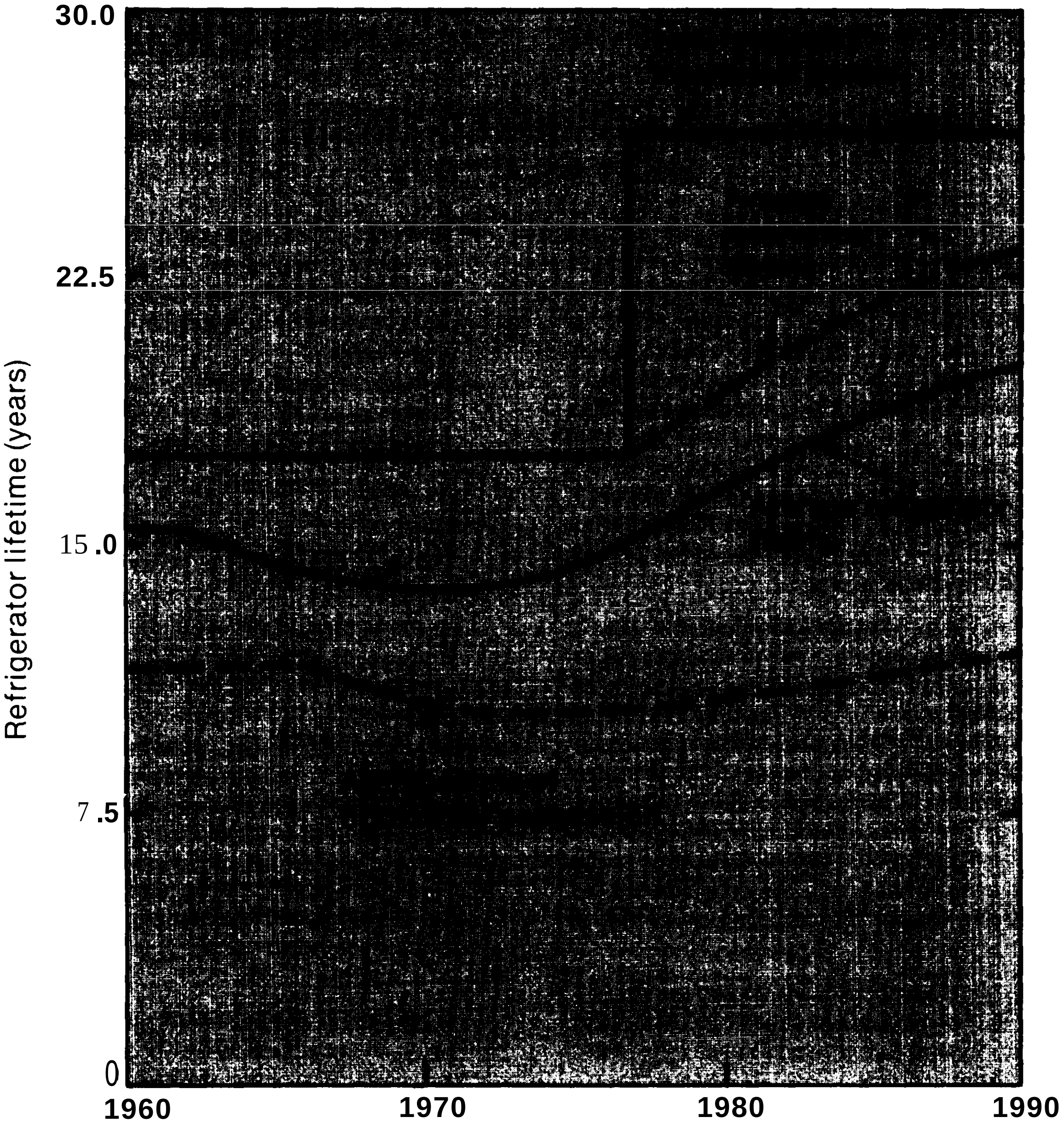
- The amount of metal used in any given alloy is small. Only under very critical circumstances would it be justifiable to conserve the alloy in order to conserve a few percent of its ingredients.
- A large amount of metal is used with steel, either as an alloy or as a coating; the total percentage is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

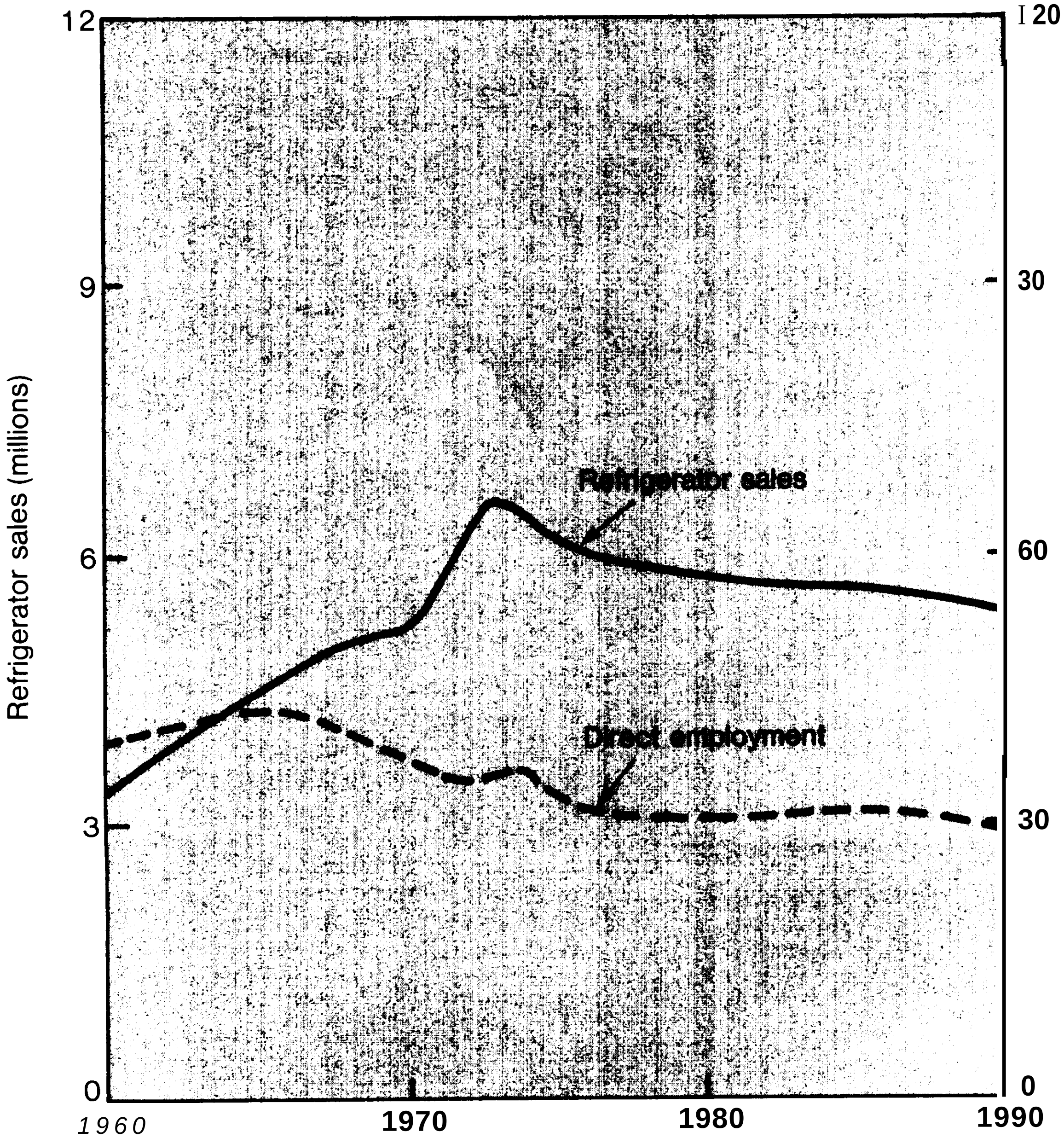
A wide variety of nonmetallic coatings are used for corrosion and wear resistance, although they do have certain technical limitations such as brittleness, lack of electrochemical effects, etc. A major benefit of the use of substitute coatings is flexibility. It is much easier to change a coating than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



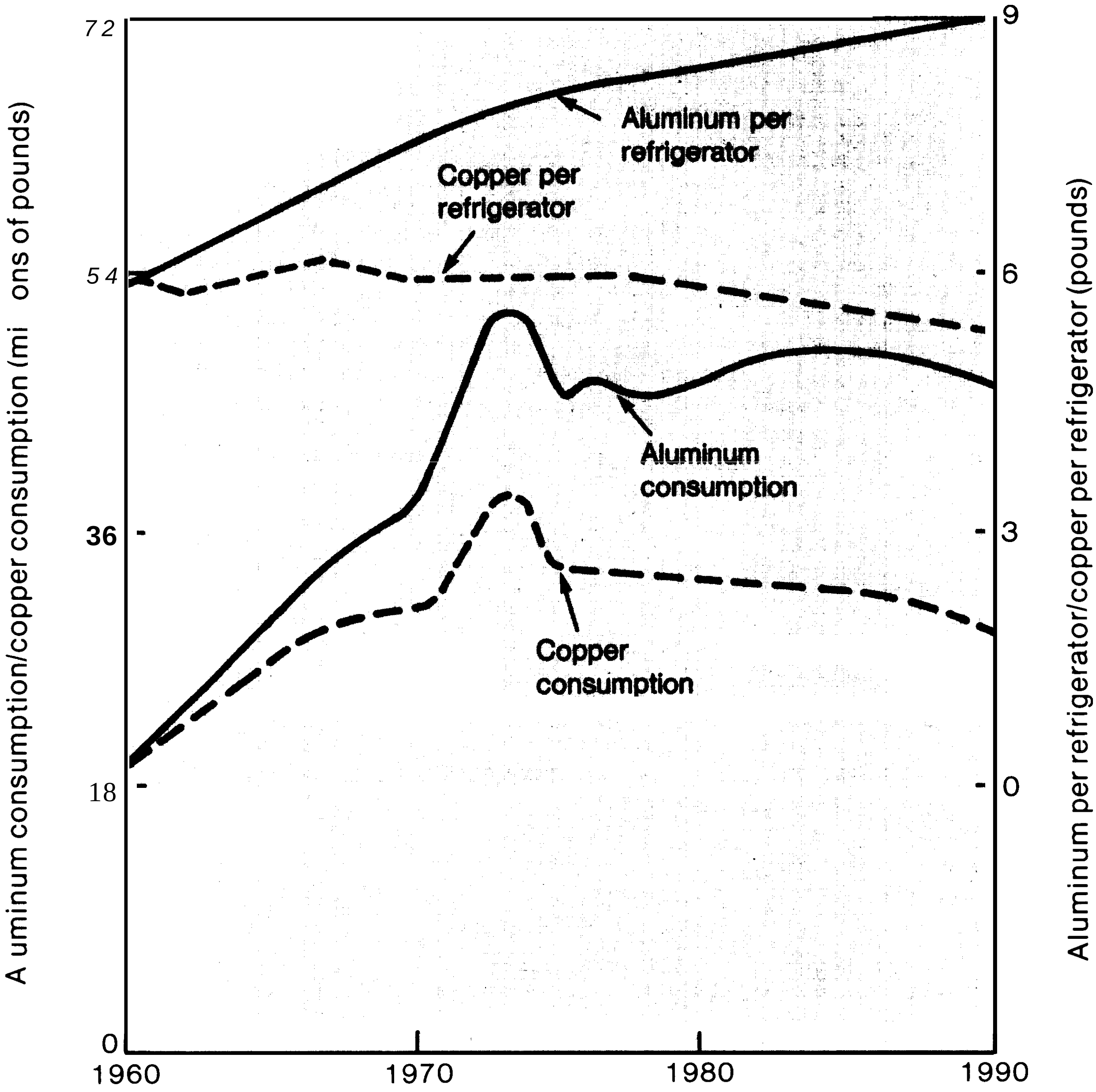
SOURCE Working Paper Five.

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	**5**	**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