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Increased Aluminum Use and Its Impact on the Life-Cycle Energy Cost of Automobiles

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Abstract

This paper examines the life-cycle of a passenger automobile including ore refining, manufacture of components, assembly, driving and recycling to provide a general computerized model to be used in evaluating the impact of various material substitution rates and recycling policies on the total system energy consumption. The emphasis is on the use of increased aluminum to replace iron and steel

1. INTRODUCTION

An examination of the 1976 National Energy Outlook, Executive Summary (1) prepared by the Federal Energy Administration is sufficient to convince even the most skeptical reader that this nation has a significant energy problem. This situation has attracted a lot of attention since the events of 1973 and the following changes in the patterns of availability, costs and consumption of fossil fuels. Many excellent reviews of the energy problem and its general impact in the American way of life have already been published.(2)

The passenger automobile has been a typical American phenomenon. It constitutes perhaps the most significant component of American Industry as well as the American way of life. Its mass scale production since early twentieth century has shown a steady growth. This growth has caused an accompanying increase in the energy consumption of the passenger automobile. Today the passenger automobile consumes 13 percent of all the energy used in the United States. (3)

Thus it is clear that some drastic changes are due in the design, manufacture, operation and the salvaging of cars in this country in the next few years. The growth patterns based on the assumption of the availability of cheap and inexhaustible energy sources in the form of gasoline or similar fossil fuels can no longer be sustained.

Signs of these changes are already upon us in the automotive industry. The most prominent ones are that the cars are averaging more miles per gallon of fuel and that they are shrinking insize and weight.

Car producers seem to have no choice but to cut hundreds of pounds of weight from all new cars to fit the new realities of fuel economy. Reducing the weight of a regular size passenger car may not be easy without reducing its size. The automakers' dilemma is a real one. On the one hand there is the superior profitability of larger cars and on the other they achieve better fuel economy by making smaller cars. Their obvious solution is to make regular size cars without sacrificing passenger comfort and profitability while reducing the weight through substitution of lightweight materials to achieve fuel economy.

This has indeed been the new direction since 1976 in the U.S. automotive industry. (4) The substitution of aluminum in place of steel has been one of the ways the newer cars are made lighter and more efficient in the use of fuel. However, this substitution may cause an increase in the overall energy requirement when the life cycle of an automobile is examined.

Thus it is apparent that there is a need to develop a general life-cycle model of an automobile from an energy accounting view to examine the impact of material substitution rates and recycling policies on the total energy consumption. This paper describes such a model.

First, it reviews the literature to provide a sound basis for construction of a descriptive life-cycle model of a passenger automobile. The main emphasis is on the evaluation of the substitution of aluminum for steel and its impact on over-all energy requirements. Then the estimates for energy requirements at each of the phases of the life cycle are provided. These phases consist of ore refining, manufacturing, assembly, driving and recycling. The energy values are then used in a computerized model to calculate the energy requirements according to the total auto weight under a given recycling policy.

2. LITERATURE REVIEW

Concern with the energy requirements of some consumer products go back to pre-energy crisis days of 1973. In 1972 Hannon published a study of the beverage industry in which the emphasis was on estimating the total system energy requirements of various methods of packaging and showing that recycling is desirable. (5)

In this study a thorough energy analysis was performed on the soft drink, beer and milk container systems. It was shown that the energy required to deliver a unit of beverage to the consumer is about three times more in throw-away glass containers than in returnable bottles or bimetallic cans. This study required the thorough examination of the metal (aluminum and steel), paper, glass and plastics industries and paved the way for our attempts to consider the automobile industry in a similar way.

Hannon's study was originated due to environmental concerns and did not intend to develop a complete model to be used under different policy assumptions to determine the optimum recycle policy or material substitution rates.

Also it is interesting to note that the soft drink containers consumed nationwide was about 0.17 percent of the nation's total energy in 1970. (6) If we include the energy consumed by beer containers and the rest of the beverage industry we obtain that the total 1970 container system energy consumption amounts to only 0.48 percent of the overall U.S. energy demand. Compared with the 13 percent figure for the automobile industry the figures for the beverage container industry clearly are not as significant.

The earliest study concerning the energy cost of automobiles was conducted by Berry and Fels. (7) In this study, the use of materials and energy from a thermodynamic point of view in the automobile industry was examined. Total free energy change per ton of finished metal for iron and steel as well as non-ferrous metals in terms of kwh/ton are calculated. Free energy consumed in every step of steel production is determined. Recovery of non-ferrous metals from scrap is emphasized. Energy consumed for secondary aluminum production is compared with primary aluminum production.

A complete system description showing all of the materials and processes with corresponding free energies which go into the manufacture of a new automobile from primary metals is provided. Total free energy change is estimated at 37275 kwh/car. Recycling procedures are explained in detail and savings of energy using different assumptions are calculated. It is concluded that we ought to find ways to improve all aspects of auto manufacture in a thermodynamic sense.

This study is extremely important as a pioneering effort in a new field of energy analysis applied to automobile production. Its conclusions specifically deal with only the environmental aspects of recycling junked autos which scar our landscape. Considering that the immediate purpose of the study was to provide the Institute of Environmental Quality of State of Illinois with assistance in making decisions on the disposal of automobile hulks and of solid waste in general, its objectives were well achieved. However, the life-cycle driving energy or the increased aluminum substitution in place of steel were not considered in the total energy system.

An updated version of this study was published in 1974 under the title of "A Thermodynamic Valuation of Resource Use: Making Automobiles and Other Processes". (8) This paper identified the materials related problems not in terms of materials availability but of their flows. A flowchart of overall process of automobile manufacture, discard and reuse is given, as well as overall energy requirements. The statement to the effect that it is worth-while noting that the energy cost of manufacturing a car is roughly equal to the energy cost of operating it for one year, indicates some concern over the life-cycle energy impact.

The Report of the Aluminum Association task force on automotive energy saving is the first comprehensive study on the effects of aluminum substitution in place of steel in auto manufacture. (3)

Three different publications of the same article were found essentially providing the same analysis, evaluation and conclusions. The common theme is that if we are to come to grips with our energy dilemma, we must use gasoline fuel more efficiently. This is an obvious conclusion when we realize that today's cars use 30 percent of the U.S. annual petroleum supply in the U.S. Since there is a direct connection between vehicle weight and fuel mileage the weight reduction is an attractive solution to the problem. The use of one pound (0.45 kg) of aluminum in an auto part produces a primary and direct weight saving of one and one-half pound (0.68 kg) on the average when substituted for traditional materials. In addition, this weight reduction allows use of lighter structural supports which result in additional weight reduction.

Thus, use of one pound of aluminum can reduce total car weight up to 2.25 pounds.

The concept of the life-cycle energy investment for the U.S. transportation system and its importance are reiterated in the report. It is pointed out that ground transportation also accounts for 75 percent of rubber, 56 percent of petroleum, 29 percent of steel, 20 percent of aluminum, 53 percent of lead and the passenger automobile consumes a significant portion of these materials.

It is concluded that reduced car weight will improve fuel mileage but there will be no net savings in the total energy consumption if it takes more energy to produce the materials responsible for lighter vehicle weight to operate a car over its life. The paper does provide much insight into the aluminum substitution for weight reduction in automobile manufacture but no comprehensive life-cycle model is provided.

The paper by Cochran on the use of aluminum in cars and its influence on energy consumption is an analytical study similar to the report of the Aluminum Association. (9) It provides a well-supported case for increased aluminum use in transportation vehicles.

The most reliable source of information on the energy use patterns in metallurgical processes can be found in the Phase 4 Report of Energy Data and Flowsheets, High Priority Commodities. (10) This report was prepared by the Battelle Columbus Laboratories for the Bureau of Mines. It covers 14 high-priority commodities including aluminum and iron and steel. All of these commodities are important basic industrial materials and, therefore, this energy appraisal is very important in assessing the national energy requirement patterns.

The study includes estimated energy values for mining and beneficiation of consumable raw materials, transportation and miscellaneous fuels and electrical energy in the production of these materials. No attempt is made to provide a general life-cycle model for energy use in automobile industry.

A paper based on source data obtained from the Chrysler Corporation gives energy estimates for the production of compact, intermediate and full-size cars in BTU/car units. (11) This document provides some help in estimating energy requirements for manufacturing automobiles but does not appear to be very reliable and thorough. Nevertheless, it provides a cross check for values obtained from other sources.

A number of other articles dealing with the use of lightweight materials, especially aluminum in the auto industry, and some of the specific manufacturing, design and technology problems were also reviewed. (12, 13, 14, 15, 16, 17, 18, 19, 20) The overall conclusion reached by the author is that there is a need for a descriptive, comprehensive, computerized life-cycle energy accounting model for the passenger automobile.

Such a model would consider the substitution of various materials to reduce the overall energy consumption, and would allow the simulation of the effects of various recycling policies.

In the next section a preliminary model in this direction is developed. It must be understood that this model is in no way claimed to be the solution of the problem stated above. It should only be considered a first attempt towards such a goal.

3. MODEL DEVELOPMENT

The basic Life-cycle Energy Model (LEM) is shown in Figure 1. In this figure square boxes are used to show processes, elliptical shapes are used to describe a product and the triangles to transform it from one state to the other. This flow chart has been used to develop the computer program to calculate energy needs at a given aluminum substitution rate and recycling policy. The basic car was assumed to be the average 1974 car weighing 4000 pounds and containing 3000 pounds of steel and only 80 pounds of aluminum. It was assumed that it would be desirable to hold the general size of the car at the 1974 levels for passenger comfort and customer appeal. In other words, the proposed aluminum substitution would not necessarily be accompanied by reduction in size of the regular passenger car. It is obvious that this would provide additional energy conservation, but this situation was deemed to be too complex to lend itself to reasonable treatment and for simplification the car size was assumed to remain constant.

The energy and fuel consumption figures were gleaned out of several sources, most of which were already presented in the literature review. In areas where information was lacking, estimates were made to provide the basis for model operation.

Another simplifying assumption was that aluminum substitution occurs at a continuous rate. This is clearly not a theoretically correct assumption since such substitutions can only occur in discrete quantities such as making the engine block, the transmission housing, doors, etc., from aluminum in place of iron and steel. Each case would cause an equivalent and discrete amount of weight saving and corresponding energy requirement. However, given the complexity of the possible combinations of substitutions the continuous assumption is a simplifying one and does not reduce the value of the model significantly.

Fuel economy vs inertia weight is shown in Figure 2. Figure 3 shows the energy values used in the model.

4. RESULTS AND CONCLUSIONS

Figures 4 and 5 show the results which can be obtained from the use of the computerized model.

Starting with an average automobile size, increased aluminum substitution in place of steel causes the auto weight to decrease. At approximately 3400 pounds the total energy requirement for the production of a car is minimized at 10 percent steel and aluminum recycling assumption. This was used simply to demonstrate the use of the model and does not represent the optimum recycling policy. However, it is important to note that the main energy consumer is the driving energy in the life of a car. Thus, it is clearly shown that fuel economy of a passenger car must be increased by technological improvements in the engine and carburation as well as reducing the total weight. The model shows that manufacturing energy is increasing as more and more aluminum is substituted in place of steel at the 10 percent recycling rate. Since recycling aluminum requires only one-tenth of the energy required to refine it, increased recycling is a must when more aluminum is used.

As stated earlier, the model developed here was intended to be only a preliminary attempt to provide a descriptive, comprehensive computerized life-cycle energy accounting model for the passenger automobile.

The results have shown that this attempt was successful at this stage. It now remains to be refined and applied to the problem at hand as a tool to provide more definitive and urgently needed answers.

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6. BIOGRAPHY

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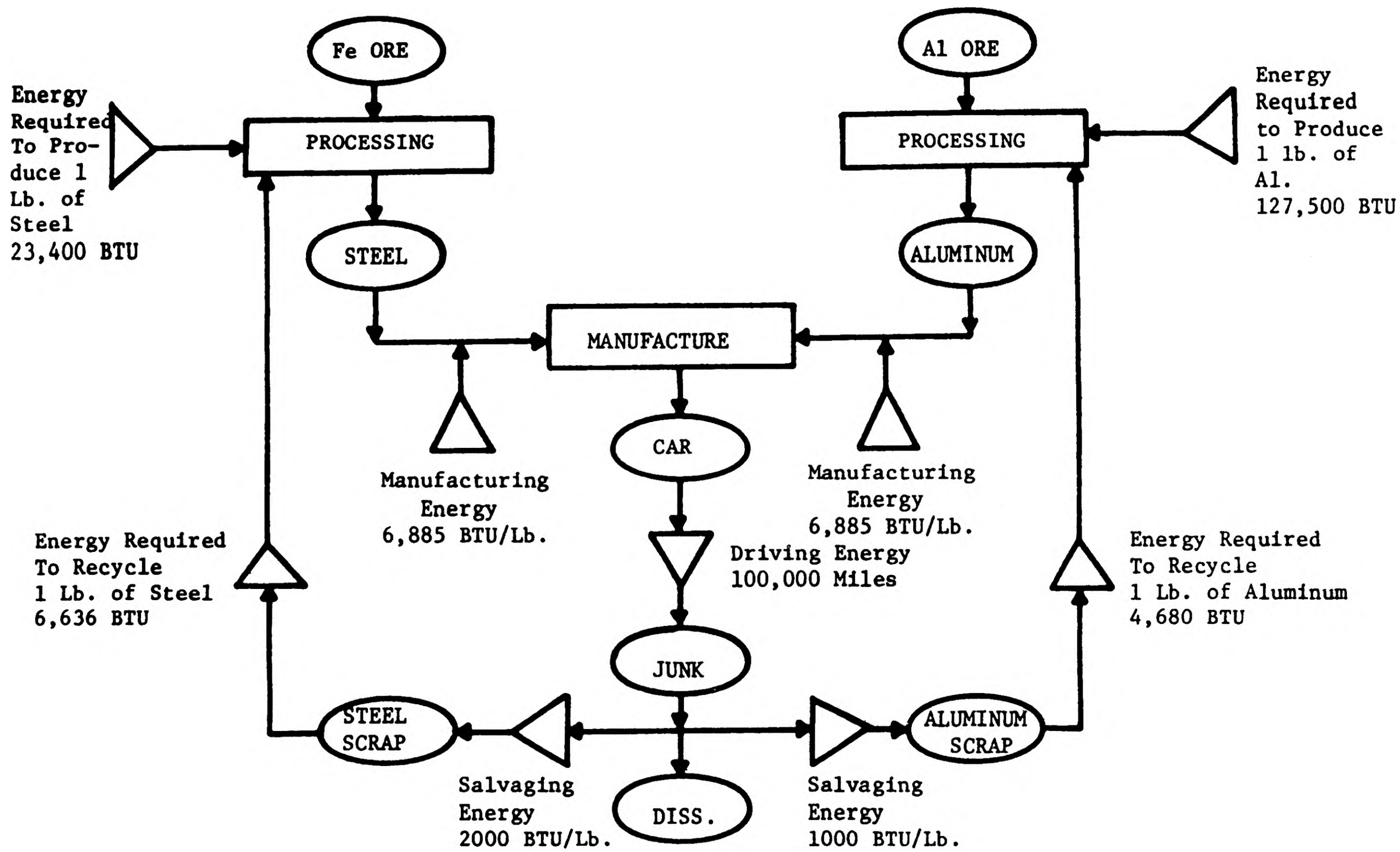

Figure 1. Life-Cycle Energy Model For Automobiles

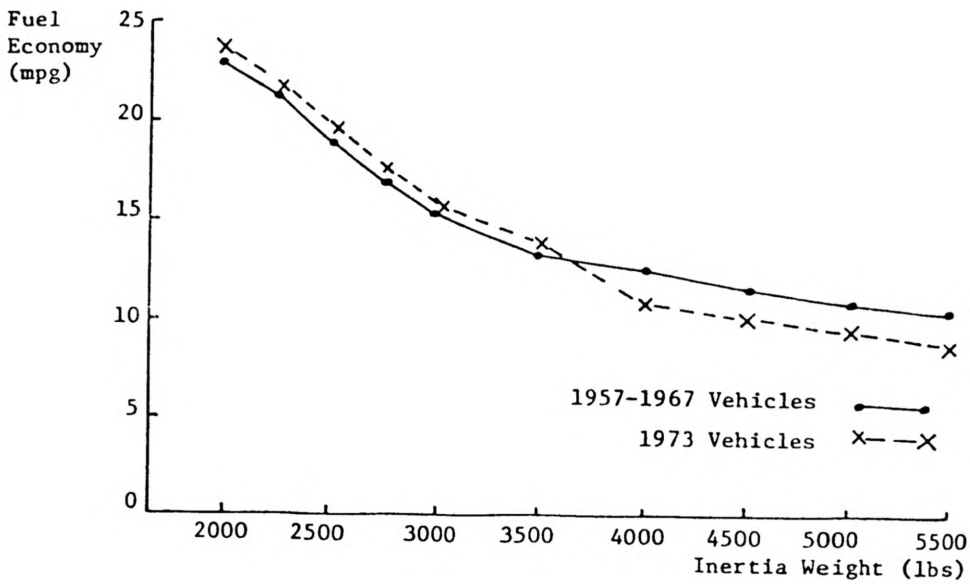

Figure 2. Fuel Economy vs. Inertia Weight

ENERGY QUANTITY (BTU/LB)	SOURCE				USED
	ALCOA	BERRY, FELS, MAKINO	CHRYSLER	MISC.	
Energy required to produce steel	13,800.- 25,800.	23,358.- 38,034.	21,000.- 34,000.	12,000.-21,000.	23,400.
Energy required to produce aluminum	43,300.-152,400.	107,179.-125,398.	10,000.-110,000.	122,000.	127,500.
Energy required to manufacture parts	--	7,978.	6,885.	--	6,885.
Energy required to scrap steel	--	1,707.- 3,415.	--	--	2,000.
Energy required to scrap aluminum	--	1,707.- 3,415.	--	--	1,000.
Energy required to recycle steel	1,600.- 6,636.	6,714.	--	--	6,636.
Energy required to recycle aluminum	2,400.- 4,680.	2,168.	--	--	4,680.

Figure 3. Model Energy Parameters

WEIGHT (LBS)			ENERGY CONSUMPTION AT 10% RECYCLE POLICY (BTU)			
TOTAL	ALUMINUM	STEEL	BY ALUMINUM	BY STEEL	BY DRIVING	TOTAL
4000.	80.	3000.	10,758,800.	91,454,992.	695,499,008.	797,712,384.
3850.	180.	2750.	22,521,120.	77,034,640.	669,417,728.	768,973,056.
3700.	280.	2500.	34,672,560.	70,004,608.	643,336,192.	748,013,056.
3550.	380.	2250.	46,824,016.	62,974,576.	617,255,168.	727,053,312.
3400.	480.	2000.	58,975,456.	55,944,560.	591,174,144.	706,093,824.
3250.	580.	1750.	71,126,912.	48,914,528.	565,093,120.	685,134,336.
3100.	680.	1500.	83,278,352.	41,884,496.	539,012,096.	664,174,336.
2950.	780.	1250.	95,429,776.	34,854,480.	512,930,560.	643,214,336.
2800.	880.	1000.	107,581,216.	27,824,464	486,849,536.	622,254,848.
2650.	980.	750.	119,732,688.	20,794,448.	460,768,512.	601,295,104.

Figure 4. Increased Aluminum Use and its Impact on the Energy Cost of Automobiles (10% Recycling of Steel and Aluminum)

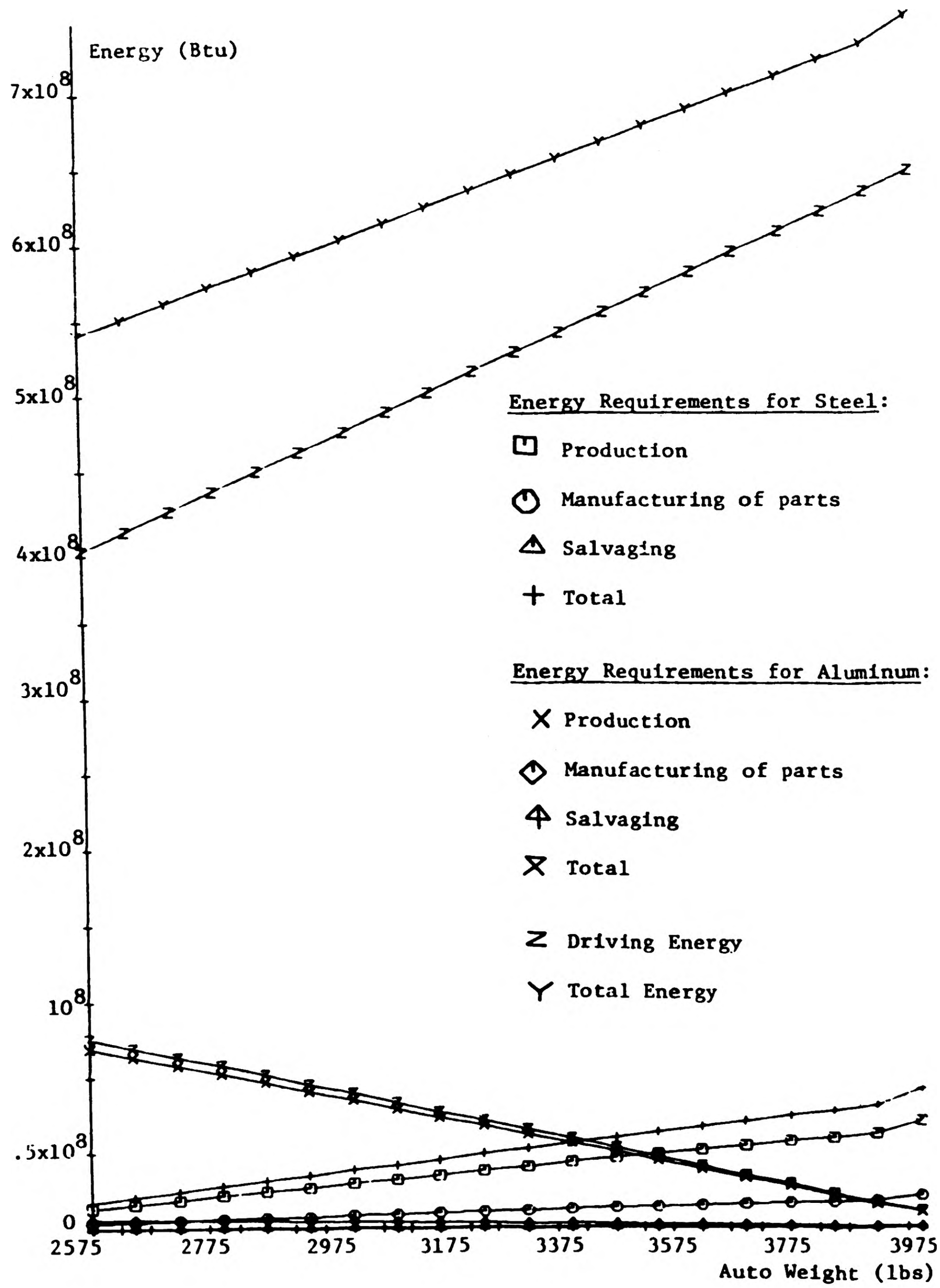

Figure 5. Auto Weight vs Energy Consumption Curve