AN ASSESSMENT OF ENERGY AND
MATERIALS UTILIZATION IN THE U.S.A.

by

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Memorandum No. ERL-M310 (Revised)

22 September 1971

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ABSTRACT

An Assessment of Energy and Materials Utilization In the U.S.A.

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The amounts of energy needed for the processing of unit weights of basic materials (such as steel, aluminium, glass etc.) are calculated. These data, in conjunction with industrial and statistical data are used to compute the amounts of energy and materials required for the production, consumption and/or use of specific items such as food, cars, housing construction, cans, heating, machinery manufacture and so on. These quantities are tabulated along with the corresponding total and per capita quantities.

It is shown that although an order of magnitude relationship exists between standards of living, GNP and energy consumption, little correlation exists between these quantities if comparisons are restricted to the developed nations. This assertion is substantiated by a study of GNP and energy consumption statistics and by a detailed comparison between New Zealand and the United Kingdom which have almost equal per capita GNPs, very similar material standards of living but vastly different levels of energy consumption.

Paper presented at the Department of EECS, UC Berkeley, Seminar on the Ecology of power production.

Research sponsored by the National Science Foundation, Grant GK-27538.

A model of energy and materials consumption assuming the same (or in some areas such as housing and urban transportation larger) availability of material goods and comforts, the recycling of metals, the limited application of solar power and better insulation to household and commercial usage and the use of reusable containers is presented. It is shown that per capita energy consumption can be reduced to 62% of the 1968 levels. The demands for nonrenewable resources such as mineral ores and fuels are also greatly reduced.

Today, there is a general consensus that the betterment of the human condition in the U.S.A. is intimately correlated with increases in per capita energy consumption. Since the utilization of energy and material resources has provided us with diverse necessities and comforts while at the same time contributing to the deterioration of the environment, it is felt that an evaluation of the efficiencies of the use of energy and materials is necessary. Upon analysis, it is shown that the present efficiencies of utilization of both energy and material resources are low and that there improvement is possible. This results both in the maintenance of current material standards of living and in the enhancement of the environment or at least a prevention of its deterioration at the current rapid rate.

I. The Reduction of Pollution and the Conservation of the World's Resources

Pollution can be reduced by two methods:

(a) Control and reduction of the waste products of fuel and materials consumption

and (b) Reduction in materials consumption (including fuels) and reuse of non-fuel resources where possible.

These methods are regarded as complimentary, though the emphasis here is on the latter method.

The effects of energy and materials consumption appear in the various forms of waste discharged to the environment. Air, thermal, water, radioactive nuclide, sound and solid wastes pollution are some of them. Fig. 1 [1]*

* [1] refers to the number of the reference in the reference list at the end of the study.

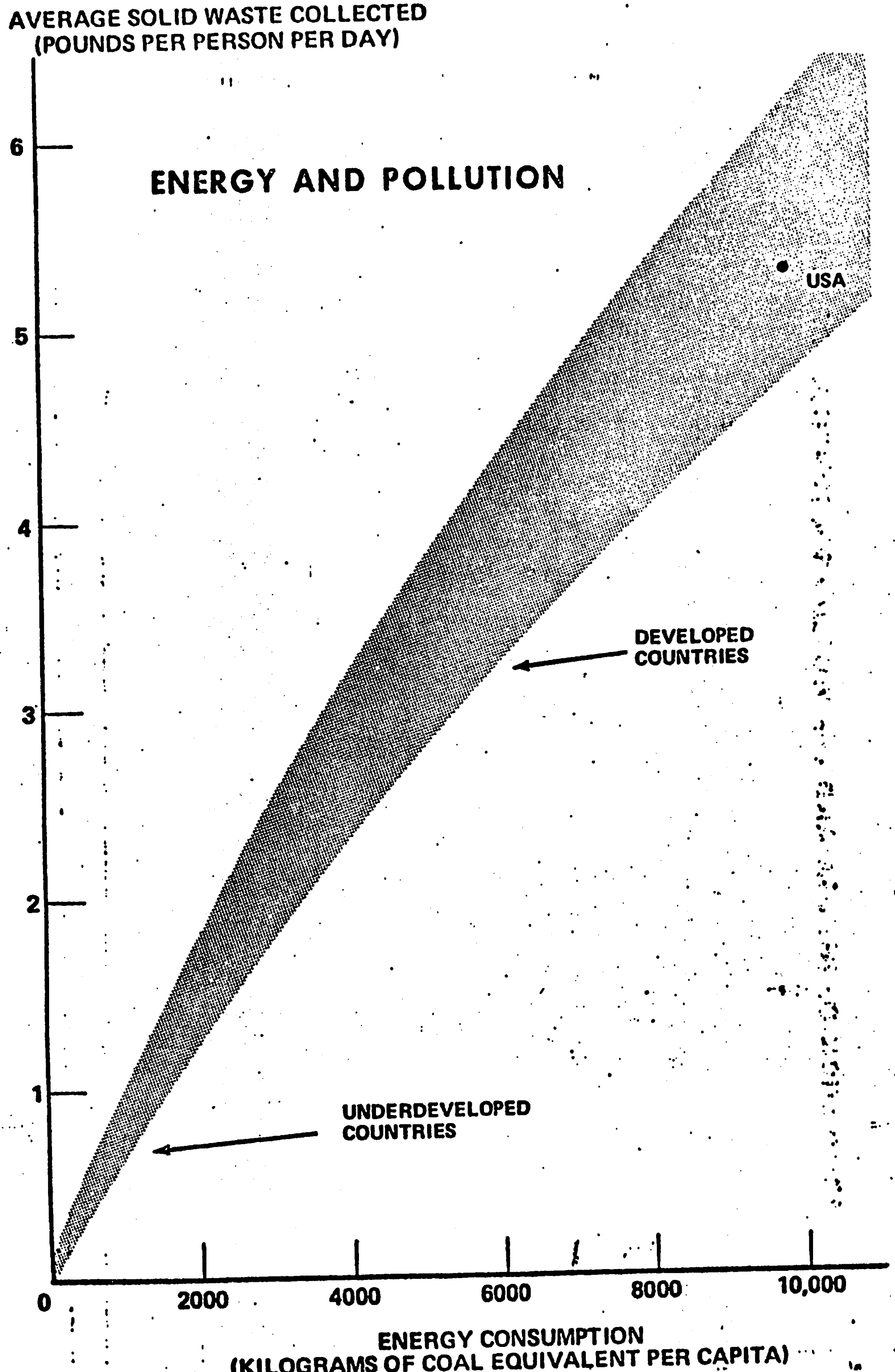
AVERAGE SOLID WASTE COLLECTED
(POUNDS PER PERSON PER DAY)
ENERGY AND POLLUTION
USA
DEVELOPED COUNTRIES
UNDERDEVELOPED COUNTRIES
0
1
2
3
4
5
6
2000
4000
6000
8000
10,000
ENERGY CONSUMPTION
(KILOGRAMS OF COAL EQUIVALENT PER CAPITA)

Figure 1

shows an approximate relation between energy consumption and solid waste generation. In Fig. (2) [1] we see that per capita production of solid wastes increased 84% between 1920 and 1970. In this same period energy consumption increased 90% per capita. To some extent this extremely close correlation is fortuitous, since not all components of solid wastes require artificial energy for production (e.g. leaves) and not all the wastes represented by energy consumption appear as solid wastes (e.g. air and thermal pollution). Nevertheless, a large portion (75% excluding food) of today's solid wastes are industrially processed materials [1]. Their abandonment is a measure of our disregard for the finiteness of our resources. A quantification of this finiteness is shown in Fig. 3 [1].

Increasingly, the raw materials and fuels used in the U. S. and developed nations in general are being imported ([2], [3]), chiefly from the underdeveloped nations of the world. This does to some extent mitigate the short term foreign exchange problems in poor countries ([4], [5]), but viewed from the point of their own development, if and when this occurs, a continued drain on irreplaceable mineral and fuel resources from these countries can hardly be considered desirable, especially if these resources are utilized in such a manner as to make their reutilization ver difficult or impossible.*

*The roles of trade, capital investment and flows and foreign aid are fully discussed in references [4] and [5]. No attempt is being made here to describe the complexity of the problems involved. However, it is pertinent to note that in recent years, the net flow of capital (including the value of goods traded) between South America and the U.S. has been to the U.S. - ref. [5], Chapter 9.

REFUSE PRODUCTION PER PERSON IN THE U.S.

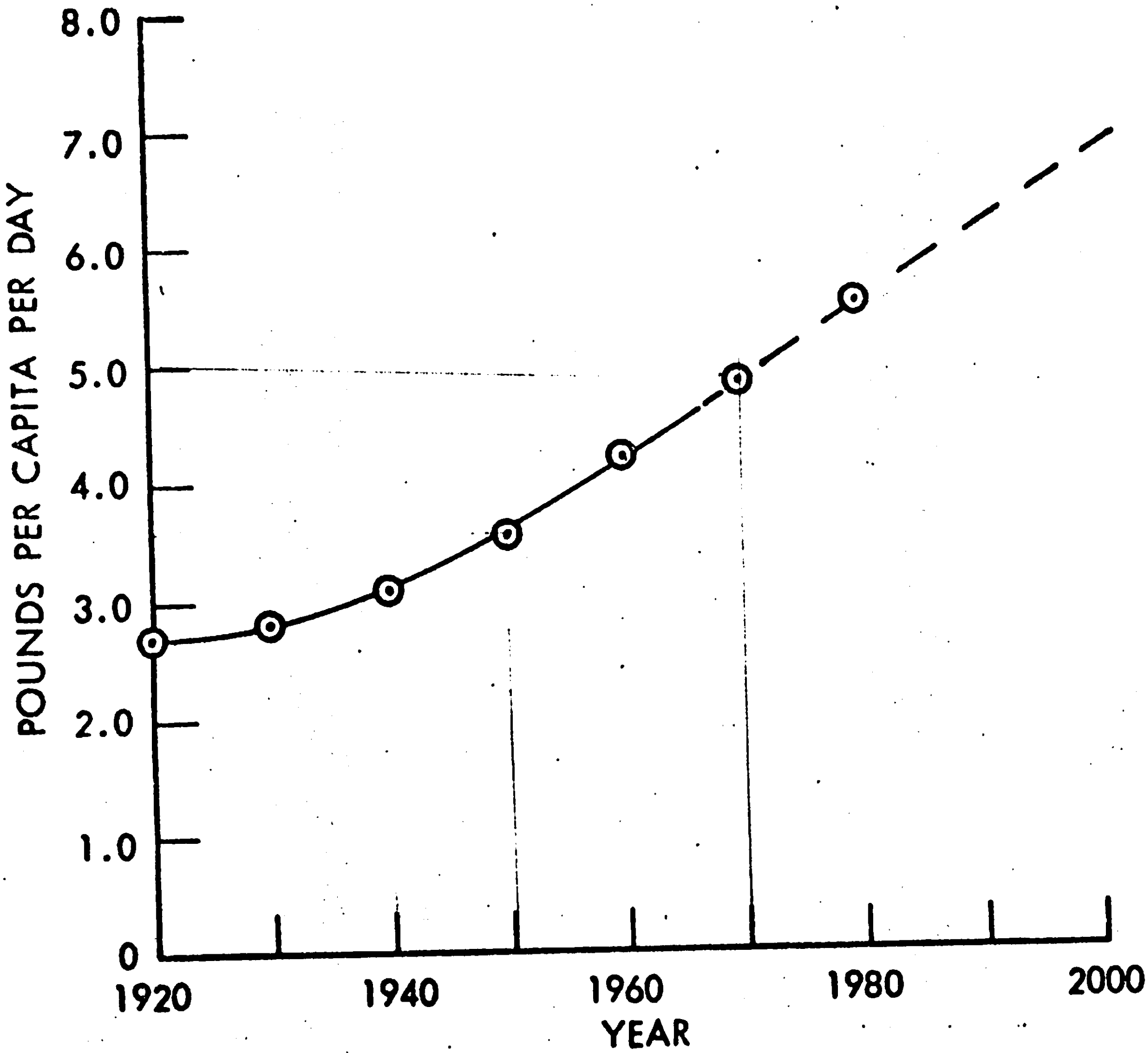

Figure 2

2. The Marginal Relationship* of Standard of Living, GNP and Energy Consumption

In studies on energy consumption, the terms "standard of living" and "Gross National Product" are often used interchangeably. Both of these terms are imprecise ([3], [4]), although for different reasons. The idea of a "standard of living" as related to consumption of goods is highly personal. However, it is possible at least to some extent to quantify this personal idea by the examination of the availability of food supplies, housing, clothing, medical, recreational, transportation and communication facilities and the like. To the extent that the GNP measures these facilities it is an indicator of this quantified standard of living [4]. GNP, however, includes such items as defense and government spending. Part of the nondefense government spending is in the form of direct monetary redistribution in the form of social security, G.I. bills and the like. These parts are counted twice in that the government only serves as the redistributing agent for the money, the "goods and services" are actually purchased by the recipients and counted in the item on consumer expenditures. In relation to trade, net exports are added to GNP, whereas net <u>imports</u> should be added since imports represent the items actually consumed.

One must be very circumspect in comparing the GNPs of different countries and inferring relative standards of living primarily since the

*Marginal relationship is defined as an order-of-magnitude relationship.

DEPLETION OF WORLD RESERVES OF COMMERCIAL GRADE ORES IF WORLD POPULATION HAD U.S. LIVING STANDARD

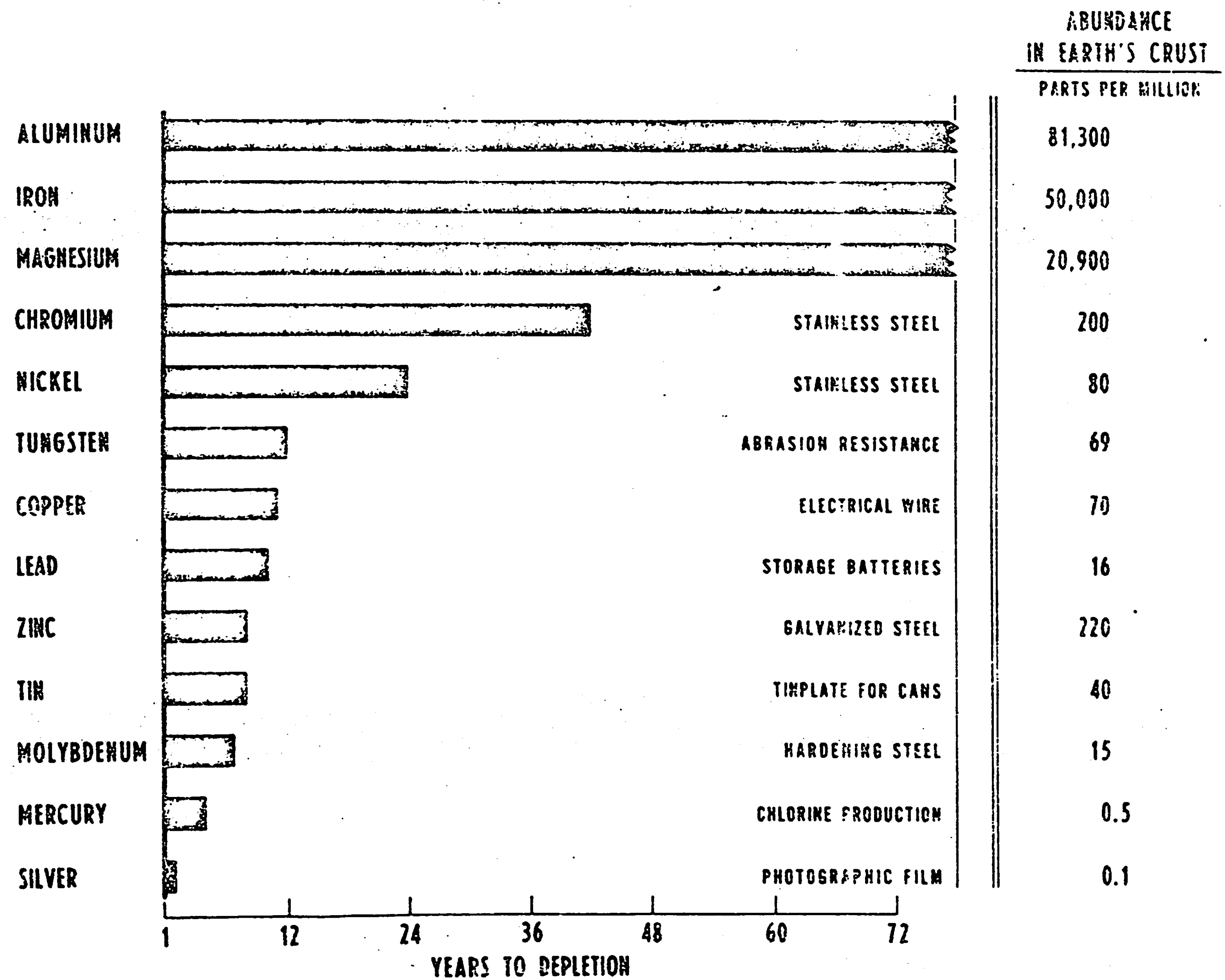

Figure 3

local buying power of currencies varies greatly from country to country.*
Since some form of energy (natural or artificial) is required to produce many of the items relating to these needs and comforts, energy consumption appears to have an order of magnitude relationship with per capita GNP.

It is manifest that in the poor countries of the world, the items that go to make up a "good" standard of living listed above, are in scarce supply. Simultaneously, the per capita energy consumption is low compared to that of the developed countries. One concludes therefore that energy consumption and the availability of human needs and comforts are at least qualitatively related and since GNP has an order of magnitude relation to energy consumption, GNP is at least marginally related to standards of living.

We now show that in comparing the developed countries, it is not possible to relate GNP with energy consumption to a degree of precision better than that indicated above. In Fig. 4 [2], we see that the U.K., Belgium, Australia, Germany, Denmark, Norway, France and New Zealand had GNPs within 10% of each other while the per capita commercial energy consumption (including industry, commerce and transport, but excluding household and miscellaneous uses) varied between 110×10^6 Btu (U.K.) and 45×10^6 Btu (New Zealand). In section III a brief comparison is made between these countries from the points of view of standards of living and structure

*If the average annual per capita income in India was $72 in real U.S. money with U.S. prices, there would not be very many people alive in India! Even the relative value of goods varies from country to country as this depends on social attitudes, availability of materials, trading position vis-a-vis other countries, government controls and taxation and relative value of materials versus labor.

of the economy. Yet is is this same figure that has been used as a justification for the statement: "high energy consumption levels and high income levels go hand-in-hand" (reference [2], p. 4), thus implying a strong positive correlation between the two. In the light of the above comments it can be seen that that is an erroneous statement.

It is also pertinent to note that per capita GNP and per capita income represent averages and say nothing of the distribution of income levels. If a wide disparity in income levels - and consequently a large population segment that is poor - exists in any country than per capita GNP can hardly represent the standard of living in that country. South Africa is a good illustration of this non-correlation.

Whether reductions in per capita energy consumption will be accompanied by a decline in the per capita GNP is beyond the scope of this study to answer. However, as noted above, this study demonstrates that reductions in energy consumption need not be accompanied by reductions in the availability of material goods and comforts.

II. Analysis of Energy and Materials Usage.

In this section, an analysis of the energy and materials consumption according to the goods consumed in the U.S. is made. The raw data were obtained largely from the various U.S. and U.N. statistical reference books listed in the reference section. Where such data were insufficient or not available, consultations with individual industries and design firms were made to determine the energy content of a given product.

The amounts of energy to produce unit amounts of basic materials (generally short tons) such as steel, aluminum, glass, cement, etc. are

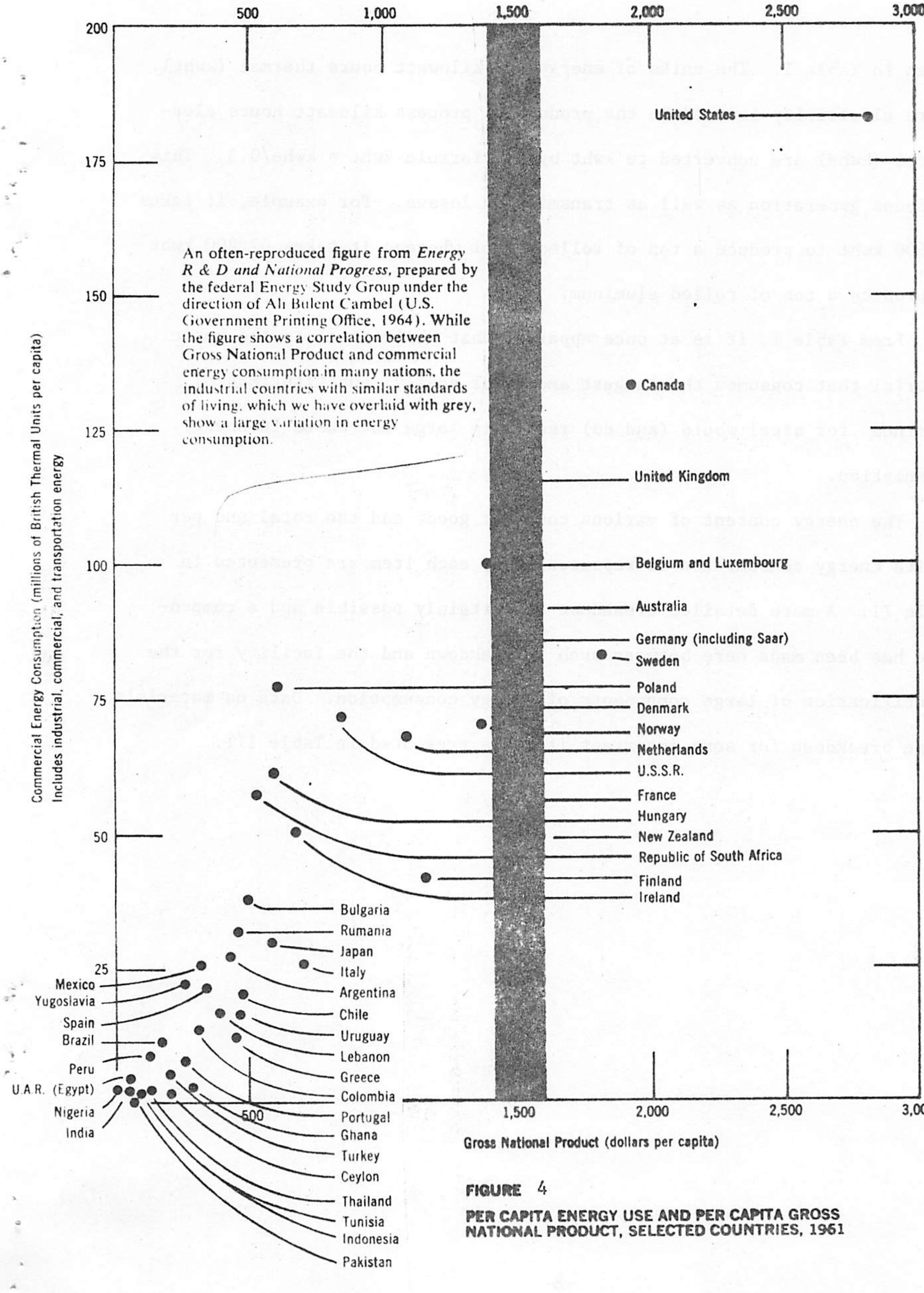

FIGURE 4

PER CAPITA ENERGY USE AND PER CAPITA GROSS NATIONAL PRODUCT, SELECTED COUNTRIES, 1961

given in Table I. The units of energy are kilowatt hours thermal (kwht). Where electricity is used in the production process kilowatt hours electrical (kwhe) are converted to kwht by the formula kwht = kwhe/0.3. This includes generation as well as transmission losses. For example, it takes 12,600 kwht to produce a ton of rolled steel whereas it takes 67,200 kwht to produce a ton of rolled aluminum.

From Table I, it is at once apparent that while steel is the basic material that consumes the largest amount of energy, substitutions of aluminum for steel would (and do) result in large increases in energy consumption.

The energy content of various consumer goods and the total and per capita energy consumption as represented by each item are presented in Table II. A more detailed breakdown is certainly possible and a compromise has been made here between such a breakdown and the facility for the identification of large components of energy consumption. Data on materials usage breakdown for some important items is presented in Table III.

TABLE I[5] (ALL TONS ARE 2000 LBS.)

ENERGY CONSUMPTION IN BASIC MATERIALS PROCESSING

ITEM #	MATERIAL	ENERGY FOR UNIT PRODUCTION[1] kwht/ton	MACHINERY DEPRECIATION[1,2] kwht/ton	TRANSPORTATION[1,3] kwht/ton	TOTAL[1] kwht/ton	# OF TONS CONSUMED (1968)	TOTAL ENERGY (kwht)	% OF TOTAL ENERGY CONSUMPTION(1968)
1.	STEEL (rolled)	11,700	700	200	12,600	90×10^6 (excluding alloys)	1.13×10^{12}	6.2
2.	ALUMINIUM (ROLLED)	66,000	1000	200	67,200	4.07×10^6	2.74×10^{11}	1.49
3.	COPPER (Rolled or hard drawn)	20,000	800	200	21,000	2×10^6	4.2×10^{10}	0.228
4.	SILICONE METAL & HIGHGRADE STEEL ALLOYS	58,000	1000	200	59,200	2×10^6	1.19×10^{11}	0.65
5.	ZINC	13,800	700	200	14,700	1.5×10^6	2.2×10^{10}	0.12
6.	LEAD	12,000	700	200	12,900	0.467×10^6	6.05×10^9	0.035
7.	MISCELLANEOUS ELECTRICALLY PROCESSED METALS	50,000	1000	200	51,200	$\approx 2 \times 10^5$	1.02×10^{10}	0.056
8.	TITANIUM (rolled)	140,000	1000	200	141,200	$\approx 16 \times 10^3$	2.24×10^9	0.012
9.	CEMENT	2,200	50	50	2,300	74×10^6	1.7×10^{11}	1
10.	SAND & GRAVEL	18	1	2 (Short distance hauling)	21	918×10^6	1.83×10^{10}	0.10
11.	INORGANIC CHEMICALS	2,400	100	200	2,700	67×10^6	1.8×10^{11}	0.985

TABLE I continued

ITEM #	MATERIAL	ENERGY FOR PRODUCTION	MACHINERY DEPRECIATION[1,2]	TRANSPORTATION[1,3]	TOTAL[1]	# OF TONS CONSUMED (1968)	TOTAL ENERGY (kwht)	% OF TOTAL ENERGY CONSUMPTION (1968)
12.	GLASS (plate finished)	6,700	300	200	7,200	$\sim 10^7$	7.2×10^{10}	0.394
13.	PLASTICS [4]	~2,400	300	200	2,900	$\sim 6 \times 10^6$	1.74×10^{10}	0.095
14.	PAPER (FINISHED, AVERAGE)	5,900	300	200	6,400	50.7×10^6	3.24×10^{11}	1.77
15.	LUMBER	1.47 per board ft.	0.02 per board ft.	0.02 per board ft.	1.51 per board ft.	3.75×10^{10} board ft.	5.66×10^{10}	.309
16.	COAL	40	2	-	42	556.7×10^6	3.3×10^{10}	0.2

NOTES FOR TABLE I

1. In kwht per short ton (2000 lbs.) unless noted. Throughout the paper tons means short tons.
2. <u>These are order of magnitude numbers derived as follows</u>: For steel calculations are on the basis of one ton of installed equipment excluding buildings) per annual ton of steel production. Depreciation is calculated on a 30 year straight line basis. For non-electrically processed metals the depreciation is taken to be equal to that for steel. Production facilities involving predominantly electrical equipment are amortized over 20 years and therefore the depreciation/ton is 1.5 times that for steel. For non-metals, the depreciation/ton allocation is about 5% of the energy required for producing one ton of product.
3. Figures are the sum of average railroad shipping distance (286 miles) + 200 mile trucking.
4. Assumed the same as inorganic chemicals for lack of information.
5. References [3], [6] through [12].
6. Accuracy is ±15% except as follows. Numbers prefaced with • should be within 50% of the correct values and those prefaced with ~ are order of magnitude estimates.

TABLE II[1]

ENERGY CONSUMPTION BREAKDOWN

Item #	Finished Product	Energy/ Unit Product kwht	Consumption (1968)	Total Energy kwht	Per Capita[2] Energy kwht/hr.	Comments
1.	Food (excluding beverages)	1600 / ton	2×10^8 tons	3.2×10^{11}	0.185	
2.	Beverages					
(a)	Carbonated	~ 3 / gallon	~ 5×10^9 gallons	1.5×10^{10}	0.009	Excluding containers
(b)	Distilled	~ 15 / gallon	~ 2×10^8 gallons	3×10^9	0.002	Excluding containers
3.	Textiles (Including Leathergoods)	(Note 5)		6×10^{10}	0.035 (Note 3)	Chlorine gas used in artificial fabric manufacture. Manufacture of Chlorine gas is <u>the</u> major cause of mercury pollution.
4.	Construction	(Note 5)				
(a)	Residential			3.02×10^{11} (Note 4)	0.175	
(b)	Non-Residential			8.7×10^{11} (Note 4)	.495	
5.	Roads			1.85×10^{11} (Note 4)	.107	Includes street lighting
6.	Trucks					
(a)	Manufacture	89,000 (Note 6)	1.896×10^6	1.69×10^{11}	0.098	
(b)	Operation	-	-	1.01×10^{12}	0.575	Excluding transportation for basic materials see Table I, column 5.

TABLE II contd.

Item	Finished Product	Energy per Unit Product kwht	Consumption (units) (1968)	Total Energy kwht	Per Capita Energy[2] kwht/hr.	Comments
7.	Passenger Autos					
(a)	Manufacture	31,000 (Note 7)	10.5×10^{6}	3.26×10^{11}	0.189	
(b)	Operation	-	-	2.67×10^{12}	1.545	
8.	Ships					
(a)	Civilian					
(i)	Manufacture	4500/gross ton (Note 8)	0.44×10^{6} gross tons	1.99×10^{9}	0.001	25% Oil Tankers
(ii)	Operation	-	-	1.7×10^{10} (Note 9).	0.010	
(b)	Military					
(i)	Manufacture	4500/gross ton	5.52×10^{6} (note 10)	2.5×10^{10}	0.015	Approximate values
(ii)	Operation	-	-	See Item 10(c)		
9.	Trains					
(a)	Manufacture	20,000/ton dead wt. (Note 11)	3.26×10^{6} tons dead wt.	6.52×10^{10}	0.038	
(b)	Operation	-	-	1.8×10^{11}	0.104	
10.	Aircraft (12)					
(a)	Civilian					
(i)	Manufacture					
	Single Engine	$\sim 2 \times 10^{6}$ kwht	9000 units	$\sim 1.8 \times 10^{10}$	0.010	Very approximate. Includes aluminium used. See Table III.
	Multi Engine	$\sim 18 \times 10^{6}$	1500 units	$\sim 2.7 \times 10^{10}$	.015	
(ii)	Operation	-	-	2.9×10^{11}	.168	Domestic traffic only
(b)	Military					
(i)	Manufacture	$\sim 18 \times 10^{6}$	~1000 units	$\sim 1.8 \times 10^{10}$	.010	As above for civilian aircraft manufacture except that titanium is included here.

TABLE II contd.

Item #	Finished Product	Energy per Unit Product kwht	Consumption (units) (1968)	Total Energy kwht	Per Capita Energy[2] kwht/hr.	Comments
(ii)	Operation	-	-	See Item 10(C)		
(c)	Military Vehicles Operation			1.42×10^{11}	0.082	Approximately 80% for Aircraft.
11.	Industrial Machinery	20,000/ton (Note 11)	8.4×10^6 tons	0.68×10^{11} (See comments)	.039	Steel (except high grade alloys), Lead, Zinc used -total excludes basic materials processing machinery - See Table I (i.e. excludes 10^{11} kwht)
		62,000/ton	4×10^6 tons	2.48×10^{11}	.144	High grade steel alloys & electrically processed metals (except aluminium). See Table III
		75,000/ton	0.5×10^6 tons	3.75×10^{10}	.022	Electrical Aluminium
		29,000/ton	2×10^6 tons	5.8×10^{10}	.034	Electrical Copper
12.	Household & Commercial Durables					
(a)	Steel	20,000/ton (Note 11)	4.4×10^6	8.8×10^{10}	.051	
(b)	Aluminium	75,000/ton	0.4×10^6	3.0×10^{10}	.017	
13.	Defense Related Steel	20,000/ton (Note 11)	2.06×10^6	4.12×10^{10}	.024	Direct Production Only.

Table II Contd.

Item #	Finished Product	Energy per Unit Product kwht	Consumption (units) (1968)	Total Energy kwht	Per Capita Energy[2] kwht/hr.	Comments
22.	Paper (Average, Including Paper board)	6400/ton	46.2×10^6 tons	2.96×10^{11}	0.172	43% in the form of paper board & 5.6% in the form of newsprint is recyclable. This probably has no advantages in energy savings but obvious ones in forest conservation.
23.	Non-energy uses	-	-	1.2×10^{12}	0.7	Excluding coke used for pig iron production. Includes carbon black production (NG), lubricating oils (lubricating oils for transport 4×10^{10} kwht for industry 4.9×10^{10} kwht) petrochemicals (1.73×10^{11})).
24.	Inorganic Chemicals	2400/ton	67×10^6	1.6×10^{11}	0.093	
25.	Commercial Lighting & Misc. Elec. (Airconditioning)	-	-	5.18×10^{11}	0.3	
26.	Household lighting & Misc. Elec.	-	-	8.64×10^{11}	0.5	
27.	Household Space Heating	-	-	1.97×10^{12}	1.14	
28.	Misc. Household Heat	-	-	5.7×10^{11}	0.33	Includes cooking.
29.	Commercial Space heat	-	-	2.24×10^{11}	0.13	

TABLE II contd.

Item #	Finished Product	Energy per Unit Product kwht	Consumption (units) (1968)	Total Energy kwht	Per Capita Energy[2] kwht/hr.	Comments
14.	Misc. Steel	20,000/ton (Note 11)	26.6×10^6 tons	5.32×10^{11}	0.31	Spare parts, nuts, bolts etc.!
15.	Agricultural Implements	20,000/ton (Note 11)	1.38×10^6 tons	2.76×10^{10}	.016	
16.	Steel Cans & Packaging	1.0/12 oz. can (20000/ton)	7.8×10^6 tons (note 13)	1.56×10^{11}	.090	55% cans & containers, 45% packaging. 10 cans/lb. Recycling energy approx. 0.5 kwht/12oz. or 5 kwht/lb.
17.	Aluminium Cans & Packaging	2.07/12 oz. can (82,800/ton)	0.4×10^6 tons (Note 13)	3.3×10^{10}	.019	Growth rate is 10% per year! (ref. [3]). 20 cans/lb. Recycling energy is approx. 0.5 kwht/12 oz. or 10 kwht/lb.
18.	Misc. Aluminium	70,000/ton	1×10^6 tons	7×10^{10}	0.041	
19.	Glass					
(a)	Containers	4/lb.	10^{10} lbs.	4×10^{10}	0.023	Recycling energy requirement is the same as for manufacture of new glass.
(b)	Miscellaneous	4/lb.	$\sim 2 \times 10^9$ lbs.	$\sim 8 \times 10^9$	~ 0.005	
20.	Wooden Crates	1.51/bd. ft.	10.5×10^9 board ft.	1.59×10^{10}	0.009	
21.	Plastics					
(a)	Packaging & Containers	$\sim 3.5 \times 10^3$/ton	$\approx 10^6$ tons	$\sim 3.5 \times 10^9$	0.002	} Mercury pollution due to use of Cl_2 gas. See Item #3.
(b)	Miscellaneous	$\sim 3.5 \times 10^3$/ton	$\approx 3.7 \times 10^6$ tons	$\sim 1.3 \times 10^{10}$	~ 0.008	

Table II Contd.

Item #	Finished Product	Energy per Unit Product kwht	Consumption (units) (1968)	Total Energy kwht	Per Capita Energy[2] kwht/hr.	Comments
30.	Commercial Misc. Heat	-	-	6.9×10^{11}	0.4	
31.	Misc. Space Heat	-	-	1.2×10^{11}	0.07	
32.	AEC			$\simeq 3 \times 10^{11}$	0.174	Operation of nuclear reprocessing plants, gaseous diffusion plants and weapons R & D. See reference [3] Ch. 10.
33.	Petroleum Processing	65 per barrel of crude	3.216×10^{9} barrels	2.12×10^{11}	0.123	
34.	Coal Processing	42/ton	556.7×10^{6} tons	3.3×10^{10}	.018	
35.	Misc. Industry	-	-	1.62×10^{12}	.94	Electronic industry, rubber, paints, miscellaneous mining fertilizers, toys, instruments, ceramics, stone & clay products, etc.
36.	Agricultural Kerosene Consumption	-	-	6.25×10^{9}	.004	
37.	Public Elec. Consumption	-	-	8.3×10^{10}	.048	Use by federal, state & local govt. excluding defense, AEC and street lighting
38.	Natural Gas Processing					
	(a) Pipeline Losses	-	-	1.59×10^{11}	.092	3% of ng production (average)
	(b) Gases vented & wasted	-	-	2.12×10^{11}	.123	4% " " "
	(c) Pipeline power	-	-	1.85×10^{11}	.107	3.5% " " "
	SUBTOTALS			17.2×10^{12}	9.98	
	Unaccounted for			1.1×10^{12}	0.62	See ref. [8]
	Total Consumption (1968)			18.3×10^{12}	10.6	

Notes for Table II

1. Figures are calculated by adding energy for manufacture and energy for processing the materials used. General accuracy limits ± 20%.
2. On the basis of U.S. population of 200 million.
3. On the basis of a 1% per year increase since 1950 during which year the consumption per capita (total for textile industry divided by the population in 1950) was 0.294 kwht/hr.
4. Total consumption elec. power in construction $\approx 0.7 \times 10^{12}$ kwht. This has been distributed to residential and non-residential according to the percentage of total construction money spent in the three sectors (43% residential, 47% industrial, commercial and public, 10% highways). All construction aluminium, steel, cement, sand and gravel was assumed to be in items 4 (b) and 5 according to Table III. Construction plastics are divided equally between residential and non-residential construction.
5. Too miscellaneous to compute one figure.
6. On the basis of a 10,000 lb. truck with material processing, energy approximately equal to that for steel which constitutes about 80% of the weight of the truck.
7. On the basis of a 3,300 lb. automobile (average including imports) calculated as in note 6 except that 0.2×10^6 tons of Al (40 lbs./car) has been added.
8. 1/6 ton of dead weight per gross ton. Assumed steel.
9. Roughly the same tonnage carried as trucks at approximately .18 kwht/ ton mile.

Notes for Table II (contd.)

10. About 10^6 tons of steel were used for ship construction. Of this about 0.08×10^6 tons was for civilian ships (gross weight divided by 6 - note 8). The rest of this steel (0.92×10^6 tons) is assumed to be military construction and the gross weight is obtained by multiplying this number by 6. Probably an underestimate since the weight of other materials is neglected.
11. Assuming the same energy/ton of steel as for car manufacture.
12. Assumes that 50% of the aluminium used for transportation was used for aircraft. See Table III. Also see reference [3] Table A 9-4.
13. Including all containering and packaging. About 50% in cans.
14. References: [3], [6] through [12].

TABLE III

MATERIALS USAGE BREAKDOWN Figures are % of production (1968)

Item #	Material	Construction	Automotive	Domestic Equip.	Industrial Equip.	Packaging & Containers	Defense	Misc.
1.	Steel	19	21 (Cars & trucks only)	4.8	9.15	8.5	2.24	4.7 rail & ships 1.5 agriculture 29% Misc.
2.	Aluminum	22	20 (includes all forms of transportation) Assumed 5% cars, 5% mobile homes, 10% aircraft.		13 Elec.Equip.	10	not available	25 including defense
3.	Plastics	≈20				≈18		62
4.	Glass[1]	~40				~50		10
5.	Paper	8	–	–	–	40 (Industrial paperboard)		5.6 newsprint 21 other print 6.8 tissues,etc.
6.	Sand & Gravel	50 paving 50 building	–	–	–	–	–	–
7.	Cement[2]	50 paving 50 building						
8.	Lumber	43.5 Residential 31.0 Ind. & Comm.				18.5%		8

[1] Very approximate

[2] Assumed same as sand and gravel

References: [3], [6], [8].

III. A Comparison of Energy Consumption and Standards of Living in New Zealand and the United Kingdom:

Table IV shows a comparison between New Zealand and the United Kingdom. These countries have been selected since their standards of living are comparable and their per capita energy consumptions differ by a factor of two.

The large differences in energy consumption between these two countries can be attributed to the basic differences in the structure of their economies - i.e. the components that go to make up their GNPs.* The U.K. concentrates on the production and fabrication of primary metals, metals products and other manufactured goods. The economy of the U.K., can be called "energy intensive" [10] since the energy content of its products is high relative to their total value. (See Table V). The economy of New Zealand relies primarily on agrarian products such as butter, meat, wool etc. These products have a high value relative to the amount of energy spent in manufacturing them even though the food processing industry is highly automated. (In the U.S. where the food industry is automated it takes 7 1/2 times as much energy to make a ton of rolled steel than it does to produce a ton of food - see Tables I and II).

*The climate of both countries is approximately the same and though the population densities are very different this does not appear to be a factor - see item (2), col. (5) in Table IV.

TABLE IV

A Comparison of New Zeland & U. K.
(Quantities are for 1961)

Item #	Item	New Zealand	U. K.	Comments
1.	Population	2.4×10^6	52.7×10^6	
2.	Population density	$9/km^2$	$217/km^2$	Apparently not a major factor in energy consumption since Denmark has a population density of $107/km^2$ and an energy consumption about 1.3 times that of New Zealand. Population density of Aùstralia is lower than both Denmark & N.Z. but the energy consumption is higher. See Fig.4.
3.	Per capita GNP	U.S. \$1550	U.S.\$1400	
4.	Energy consumption per capita (a) Industrial Comm. & trans. (b) All other	 18,000 kwht 2,400 kwht	 32,000 kwht 6,000 kwht	The percapita energy for New Zealand includes energy for steel imports assuming all such imports were in the manufactured form. Difference is probably due to the colder climate of U.K. and the relatively inefficient space heating systems operative there.
5.	Steel consumption per capita	0.256 tons	0.4 tons	The difference is a good indication of the plowback of metals into industry in manufacturing industries oriented economy.
6.	Tin per capita	0.3 lbs.	1 lb.	See comments for item 5 above.
7.	Fertilizers per capita	210 lbs.	37 1bS,	
8.	Cement per capita	600 lbs.	600 lbs.	
9.	Net food supply per capita	3500 cal/day	3150 cal/day	
10,	Wheat productions per capita	187 lbs.	160 lbs.	Both countries import approx. the same quantity of wheat per capita.

TABLE IV (Contd.)

Item #	Item	New Zealand	U.K.	Comments
11.	Meat Production per capita	685 lbs.	78 lbs.	
12.	Butter Production	216.6 tons	49.1 tons	N.Z. butter is 99.9 factory manufactured as compared with 90% for U.K.
13.	Rail freight per capita	910 ton km.	600 ton km.	
14.	Unemployment	0.4 %	1.5 %	
15.	# of people/ telephone	2.87	6.17	
16.	# of people/ car	4.4	8.2	
17.	# of people/ commercial vehicle	18.4	36	
18.	# of passenger -Km by aircraft per capita	114	132	
19.	Education, # of school students per teacher	26 (1960)	29 (1959)	
20.	# people/doctor	830	810	Dentists excluded. Data are for 1967.
21.	Housing (a)#people/house	4.26	3.84	Includes only those housing units that are occupied.
	(b) # of rooms/house	4.8	4.6	

SOURCE: U.N. Statistical Handbook (1962, 1969) Reference [12].

TABLE V

Item #	Industry	% of the price of the final product spent on energy
1.	Tobacco	0.9
2.	Textile	3.1
3.	Paper	6.9
4.	Glass	11.2
5.	Primary metals	22.8
6.	Average for all industries	4.5

DATA ARE FOR THE U.S.A., 1950.

Reference: [8].

IV. The Reduction of Energy and Raw Materials Consumption.

The methods by which energy and raw materials consumption can be reduced are discussed in this section. A proposed model of energy consumption for the year 2000 is presented in Table VII.

The discussion here is predicated on the basic assumption that the people of this country consider their current "standard of living" in terms of material facilities to be "good" and do not desire it changed in any basic way. Consequent to this is the retention of the industrial (rather than agrarian) structure of the economy.

(i) Five methods of reducing energy and/or raw materials consumption are outlined below. They are:

1. The use of solar energy
2. The use of the "total energy" concept in industry.
3. Materials reuse and recycling.
4. The improvement of fuel usage efficiency in transportation.
5. Improvement in the thermal efficiency of electric power plants.

1. The use of solar energy. The ecological advantages of the use of solar energy are manifold. The scientific feasibility of solar energy use has been established and it currently has technological applications in the space program and to a small extent in miscellaneous low energy applications such as highway telephones. It is believed that the economic application of solar energy for household heating and for the partial substitution of household and commercial electrical energy requirements by the use of heat pumps could be developed within a few years, if the necessary funding for the R & D were to become available. Many houses using

solar energy for heating are currently in existence. These must be considered as pilot projects and development is certainly required for large scale application.

2. <u>The "Total Energy" Concept</u> (see references [13], [14], [15]). This concept is built around the utilization of waste heat from the generation of electricity. It is applicable primarily to industries (or a group of contiguously located industries) and other establishments with large demands of heat, electricity and/or motive power. Electricity is generated locally. The waste heat (in the form of the combustion produced gases) is then utilized to run large turbines (generally larger than 1000 hp., although smaller ones have been installed), or in such operations as preheating, drying, space heating or even desalination. The overall thermal efficiency of such establishments is claimed to be 75-85% (as compared with 40% or less for fossil fuel or nuclear power plants). This concept has been applied to industry on a limited scale and can be applied to hospitals and commercial establishments with nearly continuous power demands.

3. <u>Materials Reuse and Recycling</u>: The energy requirements for the recycling of metals are generally much smaller than those for their production from ore (See Table VII). Therefore, even if the energy for the fabrication of end products were to remain constant, the total energy requirements for a given end product are generally lower (See Table VII).

As regards cans and containers it is found that the differences in the energy of manufacture of new containers does not vary much between steel and aluminum containers (steel being lower per can than aluminum).

The weight of bottles is too variable for a direct comparison and the energy of manufacture for a bottle may vary between half and double that for a comparable steel container. While recycling of metal containers effects economies in both energy and materials consumption compared to the production of new ones, the most economical from the point of view of both energy and materials is the reuse of bottles as the energy requirements for cleaning are negligible compared to those for the manufacture of new containers. In Table VI, it has been assumed that containers will be of glass and will be reused. (Note: generally a 10% allowance for breakage and loss has been made in Table VII for items reused or recycled.)

4. Transportation fuel economy: On adding all the civilian usage of transportation energy in Table II, one finds that about one fourth of the total energy consumption is directly attributable to this sector.* This energy consumption can be reduced by increasing the fuel economy of automobiles, by partial replacement of commuter traffic by rapid transit and partial replacement of truck freight. The example of the automobile is illustrated below.

The average weight of an American car (including imports) is about 3000 lbs; the average gasoline utilization is 13.9 miles/gallon; and the average life is about 5 years. On changing these numbers to 2000 lbs., 25 miles/gallon, and 10 years, diverting 30% of the mileage to mass transit (see Para. (ii) 1 below), maintaining production at the replacement rate

*This does not include energy demands for gas stations, sales stores, petroleum processing, maintenance and repair shops and spare parts manufacture except at the factory of origin.

(on the basis of 2 persons/car compared to 2.6 persons/car at present) and utilizing recycled materials (paragraph 2) below one has the following:

Energy for production	12,500 kwht/car (Note 3, Table VII)
No. of cars produced	11.25×10^6/yr. (Population 225×10^6)
Energy for operation	0.6 kwht/hr per capita
Total per capita =	0.67 kwht/hr. per capita
	(Compared with 1.75 kwht/hr. in 1968)

5. <u>The improvement of thermal efficiencies of electric power plants</u>. This can be achieved by the use of MHD topping cycles and/or an increase in maximum operating temperatures. Both of these fare serious materials problems.

Item 36 in Table VI illustrates the saving in energy that can be accomplished by increasing the thermal efficiency to 50%. While these savings are not very large, their consequences on the environment in terms of the reduction of thermal pollution are important.

6. <u>Miscellaneous Methods</u>. The development of superconductor applications for the transmission of electrical energy and for electric motors will probably effect large savings in materials usage in the electric industry. For example it is estimated that a 3000 hp. superconductor motor would be about 1/10th the size of the present one [16]. The technical feasibility of these processes has not been established and they will not make any major impact on the energy picture in the near future.

(ii) A model for energy consumption in the year 2000.

Basic assumptions:

(1) The asumption as regards standards of living mentioned above applies. It is often argued that increased energy consumption is necessary to raise the standard of living of those who do not now fully partake of the material well being in the U.S. In a limited study on apartment houses in New York City (17), it was found that household electrical energy consumption was higher in the poor section studied than in the ones occupied by the more affluent. (A definitive study of energy consumption and income levels has not yet been conducted.) The indications are that

TABLE VI

COMPARISON OF PASSENGER TRANSPORTATION METHODS

Items	Transport Mode	Energy[1] kwht/pass. mile.
1.	Car (2 passengers/car)	1.47
2.	Bus (U.S. Average)	.37
3.	(a) train (possible) (b) U. S. average	0.22[2] 0.58
4.	Air (U.S. average 50% load factor)	2.0
5.	Ship	4.4

[1] 44 kwht/gallon of fuel oil

[2] Mix of commuter & pullman trains.

Reference: [6].

direct energy consumption by households is fairly independent of income, although this must necessarily be regarded at this time as a qualitative judgment. The indirect consumption of electricity in the consumption of goods is undoubtedly lower for people with low income levels. Allowances for this have been made in Table VII. A 10% per capita increase in housing, increases in public transportation energy and a decrease in the ratio of number of people per car from 2.6 to 2 have been incorporated.

(2) Population growth rate of approximately 1/4% per year. The columns on per capita energy are not affected by this assumption.

(3) Development of solar energy heat pumps for partial household and commercial applications. It is assumed that this will take effect starting 1980 and that the construction of households will incorporate the use of sound insulation techniques.

(4) Technological innovations other than the use of solar energy and heat pumps have not been incorporated. A major omission is the application of the "total energy" principle (See above). This has been omitted in the interest of accuracy as the application of this principle must be considered separately for each industry and the net savings (or lack thereof) will vary largely with the type of industry and size of the plant.

TABLE VII

A PROPOSED MODEL FOR ENERGY CONSUMPTION FOR THE YEAR 2000

Item #	Finished Product	Energy for Production kwht	Consumption units	Total Energy kwht	Per Capita Energy kwht/hr.	Per Capita Reduction Compared to 1968 kwht/hr.	Comments (Note 2)
1.	Food	1600/ton	2.25×10^8 tons	3.6×10^{11}	0.185	0	
2.	Beverages						
(a)	Carbonated	~ 3/gallon	5.6×10^9 gal.	1.7×10^{10}	.009	0	
(b)	Distilled	~ 15/gallon	2.25×10^8 gal.	3.38×10^9	.002	0	
3.	Textiles	(Note 5 Table II)		6.9×10^{10}	.035	0	
4.	Construction (All types)	(Note 5 Table II)		1.35×10^{12}	.687	-.017	10% per capita increase in housing assumed. Could be reduced if construction metals are recycled. All new materials assumed.
5.	Roads	(Note 5 Table II)		2.11×10^{11}	.107	0	It's assumed that energy reduction in road building will be counterbalanced by better street lighting.
6.	Trucks						
(a)	Manufacture	58,000	1×10^6 (Note 5)	5.8×10^{10}	.029	.069	
(b)	Operation	-	-	5.65×10^{11}	.285 (Note 5)	.285	Excluding basic materials transport energy. See Tables I & II.
7.	Passenger Cars						
(a)	Manufacture	12,000	11.25×10^6/yr.	1.35×10^{11}	.068	0.121	As outlined in the text. See also Note 3.
(b)	Operation	-	-	1.19×10^{12}	0.602	0.943	

TABLE VII Contd.

Item #	Finished Product	Energy for Production kwht	Consumption units	Total Energy kwht	Per Capita Energy kwht/hr.	Per Capita Reduction Compared to 1968 kwht/hr	Comments
(b)	Aluminium	27,800/ton (Note 9)	4.5×10^6 tons	1.2×10^{10}	.006	.011	
13.	Defense Related Steel	13,250/ton (Note 9)	1.16×10^6 tons	1.55×10^{10}	.008	.016	50% per capita reduction in consumption.
14.	Misc. Steel	13,250/ton (Note 9)	22×10^6 tons (Note 11)	2.92×10^{11}	.148	.162	
15.	Agricultural Implements	13,250/ton (Note 9)	1.55×10^6 tons	2.05×10^{10}	.011	.005	
16.	Steel Packaging	13,250/ton (Note 9)	4×10^6 tons	5.3×10^{10}	.026	.064	Note 12.
17.	Aluminium Packaging	27,800/ton	0.225×10^6 tons	6.5×10^9	.003	.016	Note 12.
18.	Miscellaneous Aluminium	27,800/ton	1.125×10^6 tons	3.12×10^{10}	.016	.025	
19.	Glass						
(a)	Containers (Note 13)						
(i)	New	8000/ton	0.526×10^6 tons	4.3×10^9	.002	.021	
(ii)	Reused	800/ton	4.734×10^6 tons	3.78×10^9	.002	-.002	
(b)	Miscellaneous	8000/ton	1.125×10^6 tons	9×10^9	.005	0	
20.	Wooden Crates	1.51/bd. ft.	1.285×10^{10} bd. ft.	1.94×10^{10}	.010	0	

Item #	Finished Product	Energy for Production kwht	Consumption units	Total Energy kwht	Per Capita Energy kwht/hr.	Per Capita Reduction Compared to 1968 kwht/hr.	Comments
8.	Ships	-	-	5.15×10^{10}	.026 (Note 6)	0	
9.	Aircraft						
(a)	Civilian	-	-	3.50×10^{11}	.179	.016	See Note 7.
(b)	Military	-	-	9.05×10^{10}	.046	.047	50% per capita decrease - assuming the war is over.
10.	Trains						
(a)	Passenger			1.90×10^{11}	.096	-.096	Note 8.
(b)	Freight			3.72×10^{11}	.188	-.046	Note 10.
11.	Industrial Machinery						
(a)	Steel, Pb, Zn	13,250/ton (Note 9)	9.7×10^{6} tons	1.3×10^{11}	.066	.033	All machinery including basic materials processing machinery.
(b)	Aluminium	27,800/ton (note 9)	0.28×10^{6} tons	7.8×10^{9}	.004	.018	50% per capita reduction in electrical at and on demand due to per capita reduction in energy consumption.
(c)	Copper	20,000/ton (Note 9)	1×10^{6} tons	2×10^{10}	.010	.024	
(d)	Steel alloys	62,000/ton	4.5×10^{6} tons	2.84×10^{11}	.144	0	Assumed new.
12.	Household & Commercial Durables:						
(a)	Steel	13,250/ton (Note 9)	5×10^{6} tons	6.6×10^{10}	.034	.017	

TABLE VII Contd.

Item #	Finished Product	Energy for Production kwht	Consumption units	Total Energy kwht	Per Capita Energy kwht/ hr.	Per Capita Reduction Compared to 1968 kwht/hr	Comments
32.	Public elec. Consumption	-	-	1.04×10^{11}	.053	-.005	10% increase per capita for running of sewage treatment facilities (fertilizer production).
33.	Natural gas processing						
(a)	Pipeline losses	-	-	4.26×10^{10}	.023	.069	Production at 50% of 1968 per capita level. Loss rate at 50% of 1968 loss rate.
(b)	gases vented & wasted	-	-	6×10^{10}	.031	.092	
(c)	Pipeline power	-	-	1.05×10^{11}	.054	.053	50% of 1968 level (per capita)
34.	Unaccounted for in 1968			9.2×10^{11}	.465	.155	25% per capita reduction assumed.
35.	Improvement in Elec. generation efficiency	-	-	-	-0.33	.33	Note 18.
	Totals			13.2×10^{12}	6.7	4.0	

TABLE VII Contd.

Item #	Finished Product	Energy for Production kwht	Consumption units	Total Energy kwht	Per Capita Energy kwht/hr.	Per Capita Reduction Compared to 1968 kwht/hr	Comments
21.	Plastics	~3.5×10^3/ ton	8.94×10^6 tons	3.12×10^{10}	.016	-0.006	Including containers at the 1968 per capita level. Increase due to substitution for misc. steel.
22.	Paper & Paperboard	6400/ton	52×10^6 tons	3.40×10^{11}	.172	0	Note 14.
23.	Non-Energy Uses	-	-	6.9×10^{11}	0.35	0.35	Note 16.
24.	Inorganic Chemicals	2700/ton	67×10^6 tons	1.81×10^{11}	.093	0	
25.	Household heat and electricity	-	-	2.35×10^{12}	1.19	0.785	Note 17.
26.	Commercial & Misc. Space Heat and Commercial Misc. Heat			9.9×10^{11}	0.5	0.1	Reduction due to improved insulation techniques.
27.	Commercial Ltg. & Misc. Electricity			5.95×10^{11}	.3	0	
28.	AEC			3.0×10^{11}	.152	.022	Note 17
29.	Misc. Industry	-	-	1.39×10^{12}	.705	.245	A 25% reduction in per capita energy is assumed.
30.	Petroleum Processing	65 /barrel of crude	1.83×10^9 barrels	1.23×10^{11}	.063	.06	50% per capita of 1968 due to reduction in transportation requirements.
31.	Agricultural Kerosene	-	-	7.0×10^9	.004	0	

Notes for Table VII

1. Based on a population of 225 million i.e. a 1/4% growth rate. Per capita consumption of items is assumed the same as for 1968 except as specifically described.

2. Negative number denotes an increase over the 1968 levels.

3. Energy for production is calculated as follows:

a) Materials processing energy (fully recycled metals)

1. All metals except aluminium	= 4,200 kwht/ton	= 4,200 kwht/ton	
2. Aluminium	= 25,000/ton	= 375	"/40 lbs
b) Manufacture energy/ton	7,400 kwht	= 7,400	
		11,975	

4. 10,000 lb. trucks calculated as in note 3.

5. Assume that 50% of the present truck freight will be diverted to railroads. The production of 10^6 trucks is equal to 50% of the per capita production of 1968. Similarly for fuel consumption.

6. Includes manufacture of civilian and military ships and operation of civilian ships. Operation of military ships is included in item 9. No change in per capita energy consumption compared to 1968 i.e. materials assumed to be new.

7. 50% new and 50% recycled aluminium. Per capita production and fuel consumption at 1968 levels. It is assumed that increases in per capita travel can be accomodated by improving the load factor which is only 50% at present - See Table IV.

8. Includes operation + 10% for manufacture. Replaces 30% of the 1968 per capita car milege.

Notes for Table VII contd.

9. In general machinery energy figures are calculated assuming 90% recycled and 10% new materials with the same energy/ton for fabrication as in 1968. Thus for steel 1 ton of end product requires 13,250 kwht. of energy.

10. Increase is due to take over of 50% of truck ton milege.

11. Assumed that 25% of the per capita demand for miscellaneous steel will be replaced by non-metals. These non-metals are assumed to have ½ the density of steel so that the corresponding per capita consumption by weight of these items is reduced by half.

12. All metal cans are assumed to have been replaced by reusable glass containers.

13. All metal containers have been replaced by reusable glass containers. Therefore with a 10% breakage rate, 10% of the containers are new and 90% are reused. It is assumed that the average weight of the glass container will be reduced by 50% (see "Resources in America's Future" [3]) and that the energy required for reuse as represented by cleaning is 10% of the energy for the manufacture of a new container. Transportation has been accounted for in item numbers 6 to 10. The per capita requirements for containers is assumed by be at the 1960 level.

14. It is assumed that paper and paperboard will be recycled, but that this will not result in energy savings.

15. Since most of the non-energy use is accounted for by lubricants, carbon black and petroleum pipeline losses, it is assumed that improvements in materials and reduction in pipeline losses and improvments in lubrication techniques will have the 1968 level of per capita

Notes for Table VII contd.

energy use for this item.

16. It is projected that in the year 2000, 53% of the dwelling units will have been built in the period 1980-2000. See reference [3]. Allowing 10 years for research and development of solar energy usage, it is assumed that dwelling units constructed after 1980 will get 75% of their heat and electricity requirements from a combination of solar energy, heat pumps and improved insulation techniques.
17. It's assumed that no new nuclear power plants will be built.
18. Assumes that 50% of the generating plants in operation in the year 2000 will have a thermal efficiency of 50% compared to about 35% at present, by the use of higher operating temperatures and cycles.
19. References: [3], [10], [11], [18].

V. Conclusions

Table VII demonstrates that substantial decreases in fuel consumption and mineral ores can be effected whilst maintaining the availability of the goods to which this society has become accustomed and improving the availability of housing, mass transportation, street lighting and public services. Consequent to this is the reduction in the amounts of pollutants that are caused by fuel consumption. The recycling of metals substantially mitigates the problems of solid waste disposal and decreases the vast amount of metals discharged into the water systems of the earth by man.

Serious efforts need to be made in the implementation of programs that reduce pollution before it is made, since these efforts will yield a more livable environment and a conservation of our non-renewable resources and at the same time provide us with the paraphernalia of the modern civilized existence.

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