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NEW PERSPECTIVES ON THE MATERIALS INTERFACE WITH THE THREE E'S — ENERGY, ENVIRONMENT, AND ECONOMICS

Donald S. Remer

ABSTRACT

New perspectives are presented on the materials interface with the three E's — Energy, Environment, and Economics. The past, present, and future energy picture is described from 1850 through the year 2030. The major energy sources such as oil, natural gas, coal, nuclear, and several new emerging energy options are compared and contrasted. The lead time, capital, and materials required for bringing on-stream new energy sources is described. Previous U. S. energy forecasts are reviewed and are found to be too optimistic. The U. S. materials situation is outlined with an emphasis on per capita materials use and the critical role that foreign sources play in our materials supply. The interrelationship between energy and materials production is considered for three areas: (1) industrial processing, (2) construction and buildings, and (3) the automobile.

1. INTRODUCTION

The Arab oil embargo in 1973 sent shivers throughout the entire world. Within a few months, the price of oil quadrupled and past forecasts of energy supply and demand were obsolete. A startling fact is that 67% of the world's oil reserves are in countries that consume only 4% of the world's oil production.

In addition to oil, for which the U.S. now imports almost half of its requirements, the U. S. is also strongly dependent on other countries for supplies of many other raw materials, especially metals. For example, the U. S. imports over 90% of our strontium, manganese, cobalt, tantalum, titanium, platinum, and aluminum and over 70% of our tin, nickel, gold, and chromium. The U. S. dependence on foreign energy and material imports is expanding rapidly. There is no question about it — we are in for a period of materials and energy shortages. This paper will look at several new perspectives on the interface between materials and the three E's — Energy, Environment, and Economics.

In Part 2, we will examine the energy picture starting with the past, and moving through the present, and then looking into the future. Each of the major energy sources will be discussed. The time period for developing and then depleting energy resources will be introduced. Then in Part 3, the materials situation will be outlined emphasizing per capita materials use and the critical role that foreign sources play in our materials supply. In Part 4, the interface between energy and materials will be considered in three areas: (1) industrial use, (2) construction and buildings, and (3) automobiles. One of the interesting insights we will see in this materials/energy interface is that the so-called "soft" energy options like solar energy and wind energy systems require more materials and land per BTU of energy produced than the traditional energy options like coal and oil.

As we consider these difficult topics we will see that there are no easy risk-free solutions to the materials-energy-environment options. If we continue to look for no-risk solutions, we will never find solutions, and this is the biggest risk of all.

2. ENERGY PERSPECTIVE

1850-1970

To get a proper energy perspective, we must take a quick excursion into our history and then move forward to today and finally take a peek at the future. In 1850, the United States used essentially one material for all of its energy — wood. About 60 years later, in 1910, the United States was still essentially using only one material for almost all of its energy. But in this sixty year period between 1850 and 1910, we had switched from a wood-based energy system to a coal-based energy system. In 1910, almost 90% of the U. S. energy requirements was supplied by coal.

In the next 60 years between 1910 and 1970, another energy revolution occurred. By 1970, coal was only providing 25% of our energy needs, and two other energy sources — **oil and natural gas** had become the primary energy suppliers. We have now completed two 60 year cycles; moving from wood first, to coal second, and now to oil and natural gas. Now the real question is what will happen during the next 60 year cycle, say by the year 2030.

In 1850, only one energy source was dominant. By 1970, three energy sources (natural gas, 38%; oil, 32%; and coal, 25%) provided 95% of our energy needs. I predict that by the year 2030, we will have from 6 to 9 important energy sources. The U. S. will depend on a broad mix of energy sources rather than just being dependent on one, two or three energy sources as we have been in the past.

Let's now turn our attention to the 1970's where quite a few very important developments occurred in the energy picture.

1970-1978

Starting around 1950, the United States began to import significant amounts of oil, and by 1970, we were importing 12% of our oil requirements. However, by 1977, imports had almost quadrupled to 46% of our oil requirements. In Table 1, we see the drop in U. S. crude oil production and the growth in oil imports from 1970 through 1977[1, 2]. During this period, our domestic crude oil production had dropped 18% while our total crude oil requirements as shown in Table 1 had increased by 33%. The gap was being filled by imports that were increasing by 26% per year.

TABLE 1
U. S. OIL SUPPLY

Year	Production, million barrels	Imports, million barrels	Total Crude Oil Supply, million barrels	Imports as a % of U.S. oil supply
1970	3,517	483	4,000	12
1971	3,454	613	4,067	15
1972	3,455	811	4,266	19
1973	3,361	1,184	4,545	26
1974	3,202	1,269	4,472	28
1975	3,060	1,490	4,550	33
1976	2,980	1,960	4,940	40
1977	2,897	2,422	5,319	46
	(3% per year)	26% per year	4% per year	} Annual % increase or (decrease) from 1970 through 1977

Keep in mind that at the same time that our oil imports quadrupled, the price per barrel also quadrupled. Therefore, the overall economic impact was more than a factor of 16. We are now in 1978 importing about half of our oil needs. And by 1980, our imports will be up to about 55-60% of our oil requirements.

Several key dates are important in the early 1970's. In 1972, U. S. natural gas production peaked at 22 trillion cubic feet per year and has been continuously dropping. By 1977, U. S. natural gas production was down to only 19 trillion cubic feet. This is 14% below our peak production in 1972. Our natural gas production will continue to decline even if new production materializes from offshore leases and Alaska's North Slope. Natural gas production from the Alaskan North Slope will start about 1984 and will only provide 6% of the U. S. gas production in the last half of the 1980's. About half of the U. S. gas production needed in 1990 must come from as yet undiscovered reserves. The U. S. is now importing about 5% of our natural gas requirements. This will increase to about 15-20% within ten years.

Not only did our natural gas production peak in the early 1970's, but also our oil production peaked in 1970 at 3.5 billion barrels as shown in Table 1. The drop in U. S. oil and gas production in the early 1970's set the stage for the OPEC (Organization of Petroleum Exporting Countries) oil embargo and price hike in 1973. This turned the world upside-down and we were in a new energy ballgame.

Up to 1974, the United States had been the number one oil producer in the world. Then, in 1974, we moved to number two producer behind the U.S.S.R. And recently, the U. S. has slipped to third place behind Saudi Arabia.

1978-1990

With our oil and gas production peaking and on the way down, we are now looking at energy sources such as nuclear, shale oil, wind, biomass, geothermal, tidal power, solar, etc. In addition to these new energy sources we are turning back to an old friend — **coal**. There are only two energy sources, coal and nuclear, that will provide significant amounts of additional energy by 1990. The pros and cons of these two energy sources will now be described.

(1) **Coal.** Fortunately, the U. S. has abundant coal reserves that account for 90% of our known domestic fossil fuel resources. By 1990, I predict coal use will double from 1977 levels in the U. S. and in the non-Communist world. Essentially all of the domestic growth in coal use will be consumed by the electric utility industry.

The U. S. currently supplies about half of the free world's coal supply and this will continue and even increase slightly through 1990 as shown in Table 2.[3]

At the present time most of the U. S. coal supply comes from the Eastern part of the U. S.; however, most of the growth in U. S. coal supply will come from Western production as shown in Table 3.[4, 5] The growth of Western coal from only 12% of total U. S. production to 45% by 1990 will have a lot of technical, geographical, and political implications. The logistics impact especially on the railroads will be very significant because Western coal is 700 - 1000 miles from the major midwestern coal markets. U. S. coal supply from the Eastern part of the U. S. will grow slowly from 1976 through 1990 at about 2.5% per year whereas Western coal will grow very rapidly at a rate of about 16.5% per year as shown in Table 3.

TABLE 2
REGIONAL COAL SUPPLY

Millions of Short Tons Per Year

	1976	1980	1985	1990
United States	670	830	1090	1500
Europe	360	360	370	380
Far East, Oceania	220	250	310	430
Other	145	170	310	430
Total	1395	1610	2080	2740

There are three major differences between most Western and Eastern coal.

1. Western coal has about 20% less energy per ton than Eastern coal.
2. Western coal tends to be located near the surface and Eastern coal is underground.
3. Western coal has less sulfur than Eastern coal.

Each of these differences has a very significant impact. For example, Western coal is primarily located near the surface, and this means strip mining will be used. On the other hand, most Eastern coal is underground, and this is a very labor intensive type of operation. Coal miners' wages have risen sharply since the last few strikes. Also, productivity, tons mined per worker, is far below what it used to be. Part of this productivity drop is a result of new government regulations aimed at improving the working environment for the miner. The two major agencies enforcing these regulations are OSHA (Office of Safety and Health Administration) and MSHA (Mining Safety and Health Administration).

TABLE 3
U.S. COAL SUPPLY

Millions of Short Tons Per Year

	1960	1976	1990
Eastern Production	420	580	825
Western Production	14	80	675
Total	434	670	1500

Sulfur is also a key variable. Western coal has much less sulfur which means less air pollution and reduced processing costs to remove sulfur. Looking at these three differences between Eastern and Western coal, I think the two most important ones, especially from a political and environmental viewpoint, are strip mining of Western coal versus high sulfur air pollution from Eastern coal. I feel that in this environmental energy tradeoff, strip mining with proper reclamation will win out over increased air pollution from Eastern coal. Unfortunately, some of the earlier strip mining in the U. S. did not have proper reclamation.

One of the great energy challenges we face in the U. S. over the next 15 years is the development of Western coal. This Western coal is located primarily in low population density areas, far from energy-consuming area, and hampered by environmental restrictions. We are very fortunate in the lower 48 states to have about one-third of the world's known economically recoverable coal reserves. Coal, our old friend, will provide almost 30% of U. S. energy needs in 1990 as compared to 20% in 1976.

(2) **Nuclear.** In addition to fossil fuel energy sources, nuclear is the only other energy source that can provide a large amount of additional energy by 1990. The nuclear picture is not as bright as it was several years ago. The number of new nuclear power reactor orders[6] dropped from 35 in 1973 to 3 in 1976, as shown in Figure 1. Today,

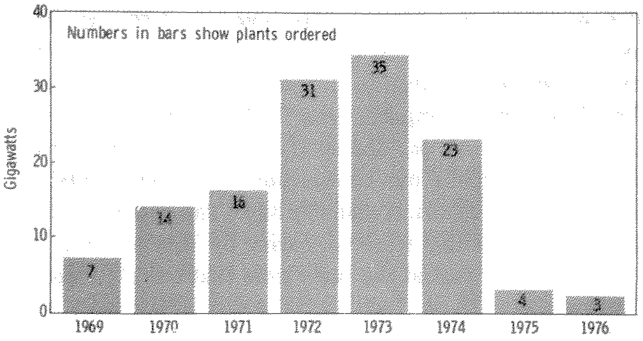

Figure 1. New Nuclear Power Reactor Orders.

out of 75 nuclear projects, 45 are deferred and 6 are cancelled. Compared with pre-embargo projections made in 1973 by many leading authorities, estimated 1985 nuclear output has been cut almost in half. There is one word that describes new nuclear power construction — **uncertainty**. The regulatory process is a nightmare and public acceptance is low, especially for a nuclear plant located nearby.

For example, construction of a conventional cooling tower, recently required 14 permits and 11 public hearings in Massachusetts.[7] For a nuclear plant, the number of permits and public hearings can easily expand to over a hundred.

A typical example is Long Island Lighting who proposed in 1969 to build two comparable nuclear plants, a Millstone Unit No. 2 and one in Shoreham. The Millstone Unit had smooth regulatory sailing and was in commercial operation in 1975 at a cost of $430 million dollars. The Shoreham reactor project ran into regulatory delays and the expected start-up date is now 1980 at an estimated cost of $1,200 million dollars. This extra 770 million dollars was caused by regulatory delays and must be paid for by the public in higher utility rates.[7]

I feel we need to have a temporary moratorium on local (city, state, county, etc.) permits by Federal mandate; otherwise, we may not see very many more new nuclear projects or new energy projects of any kind. An all encompassing Federal permit should be developed for new large scale energy projects.

Public acceptance of nuclear energy is centered around three subjects: (1) safety, (2) proliferation to make a bomb, and (3) waste disposal. In 1970, safety was the public's main concern; however, today the key issue is waste disposal.

I feel that waste disposal is a tractable problem. However, the U. S. has not been moving ahead in this area due to the low levels of government research funding for radioactive waste disposal. By law, the U. S. government is responsible for getting rid of nuclear wastes. We need a high priority well-funded program in this area. Unfortunately, the U. S. government has decided to defer facilities for reprocessing spent uranium to plutonium. This increases the urgency and scale of the spent fuel problem.

Let's go back about 90 years to get another perspective on the nuclear situation. Many of you may have heard about the article written by Thomas Edison for the *Scientific American* in 1889. This article warned the public about what he perceived as a major public danger. "My personal desire would be to prohibit entirely the use of alternating currents". He further said, "They are unnecessary as they are dangerous. I can therefore see no justification for the introduction of a system which has no element of permanency and every element of danger to life and property". In perspective, 88 years later, we certainly solved the alternating current hazard, and we can solve the potential problems associated with nuclear energy.

1990-2030

Now that we have discussed oil, natural gas, coal, and nuclear energy, what about all the other energy sources we hear so much about such as solar electricity, tidal power, bioconversion, wind power, oil shale, geothermal, etc. Although these are very important future energy sources, I do not see very much large scale commercialization by 1990. My estimate is that all of these new energy sources will supply less than 7% of U. S. requirements by 1990. However, several of these new energy sources can make an important local contribution by 1990, such as geothermal energy in several California locations.

It is interesting to go back to 1850 to see how long it took us to develop past energy resources. Wood was replaced with coal, and coal was then replaced by oil and natural gas. If we look at coal, oil, and natural gas, we see that each of these energy sources took about 30 years to increase from 10% of its ultimate use to 50% of its ultimate use. Coal reached its maximum production rate in 1920 (this was the maximum production until the last few years). The time for coal to move from 10% of ultimate in 1873 to 50% in 1902 was 29 years. Oil took 32 years and gas took 27 years. Three decades seems to be the period required to bring on a significant new energy resource. Of course, a crash program might shorten this period, but I doubt it.

Another consideration is the long lead time required to construct new plants. For example, a nuclear power plant is now taking about 10 years from the time the decision is made to allocate capital for the plant until the plant is producing power. And even a conventional, almost off-the-shelf, coal fired power plant takes from 5 to 8 years. Some typical lead times for several energy sources are summarized in Table 4.

These long lead times shown in Table 4 are for conventional energy sources. When we look at commercializing new energy sources, the development process takes about 25 years to go from a research idea to commercial protoype

TABLE 4
TIMES TO BRING ON NEW ENERGY PROJECTS

	YEARS
Coal-fired power plant	5-8
Surface coal mine	2-4
Underground coal mine	3-5
Uranium exploration and mine	7-10
Nuclear power plant	8-12
Hydroelectric dam	5-8
Oil and gas production from new fields	3-10

as shown in Figure 2. We must move through four distinct development steps: (1) laboratory scale, (2) pilot plant, (3) demonstration plant, and (4) commercial prototype[8].

Let's look at an example. Fission was first demonstrated in 1942-43 at the University of Chicago. In 1972, thirty years later, nuclear power was only supplying 1% of our energy requirements in the U. S. Therefore, you can now see how far away a new technology like fusion is today.

A significant impact to these long development periods is the advances required in materials technology. This materials/energy interaction will be discussed later in this paper.

The status of new energy sources are at three technology levels: (1) theoretical, (2) experimental, or (3) practical. For example, thermonuclear fusion is at the theoretical stage whereas breeder reactors are at the experimental stage. Summarized in Table 5 is the current 1978 technology level for three energy sources: (1) synthetic fuels, (2) advanced nuclear, and (3) renewable energy resources.[3]

Previous Energy Forecasts

Previous energy supply/demand forecasts have been too optimistic. For example, in Table 6, there are three former world energy supply/demand forecasts made by Exxon.[3] The first forecast in 1973 projected that the world-wide energy growth rate would be 6.8 million barrels/day oil equivalent in the 1980-85 period. However, Exxon's most recent forecast in 1977 is for 4.0 million barrels/day oil equivalent, which is only 60% of their 1973 forecast.

Earlier forecasters have also been overly optimistic on U. S. total energy production. For example,in 1970, three well known forecasts (USDI-USGS, 1970; Love-Simon, 1972-3; NPC, 1970) projected total U. S. energy production in 1985 at between 98 and 118 Q's (Quadrillion BTU's per year).[9] However, current estimates are about ⅔ of those levels. These earlier forecasts overestimated the growth in nuclear energy and the conversion of solids (coal, lignite, shale, etc.) into oil and gas. The oil embargo with the quadrupling of world wide oil prices also put a crimp in these forecasts. However, notice in Table 6 that even the Exxon forecast in 1975 (post oil embargo) has been reduced by 13% in their most recent 1977 forecast. I wanted to present these caveats so you can appreciate the great difficulties associated with energy forecasts.

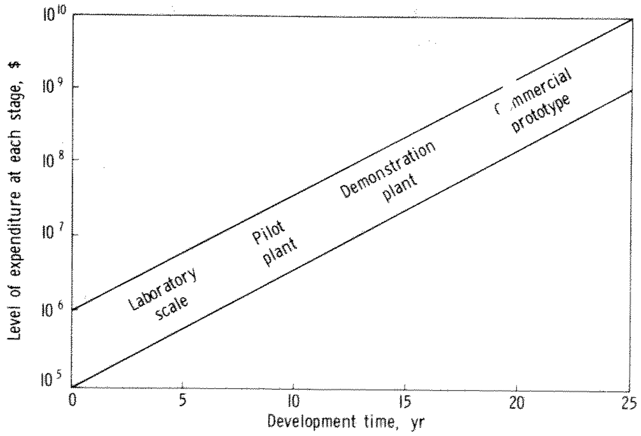

Figure 2. Development Cost And Time For New Technology.

3. MATERIALS AVAILABILITY and CONSUMPTION

Now that we have looked at the energy picture, let's turn our attention to the U. S. materials situation. In the United States we use a tremendous amount of raw materials. Our per capita use of raw materials is about 42,000 pounds per year. About 60% of this materials consumption is for a material end-use such as iron and steel for construction and about 40% as an energy end-use such as petroleum to make gasoline. Summarized in Table 7 is the material consumption intensity for nonmetallic minerals, metals, polymers, wood, fibers, leather, and fossil fuels.[10]

TABLE 5
NEW ENERGY SOURCES

SOURCE		STATUS OF TECHNOLOGY	1978
	THEORETICAL	EXPERIMENTAL	PRACTICAL
Synthetic Fuels		Coal liquids (New technology)	Coal gas Heavy oil from sands Oil shale Heavy oil production Coal liquids (Fischer-Tropsch)
Advanced nuclear	Thermonuclear fusion	Breeder reactors	
Renewable energy sources	Widespread solar electricity Wave power Ocean thermal gradient	Widespread wind power Geothermal (Other than dry steam)	Solar electricity (Remote locations) Solar heating Solar cooling Local wind power Tidal power Bioconversion Geothermal (Dry steam)

TABLE 6
EXXON'S FORECASTS FOR WORLD ENERGY GROWTH IN 1980 TO 1985 PERIOD

	Average annual increase in million barrels/day oil equivalence in free world.
1973 Forecast	6.8
1975 Forecast	4.5
1977 Forecast	4.0

This large materials requirement can be put in a different light when we consider that a significant percent of these materials are imported. For example, we import over 90% of our columbium, mica (sheet), strontium, cobalt, manganese, tantalum, titanium (rutile), platinum group metals, and bauxite and alumina. The U. S. imports over 50% of our requirements for 23 important metals and minerals[11] as shown in Table 8. These imports also show up in our balance of payments deficit. In 1976, our total U. S. imports of raw and processed minerals was $51 billion dollars and our exports only $32 billion dollars. While a little more than half of these imports are for energy end uses, the remainder is composed of many metals and minerals essential to the U. S. economy as shown in Table 8. The major foreign sources for these minerals are also shown in Table 8. Many of these sources are in politically and economically unstable regions.

TABLE 7
MATERIALS CONSUMED PER CAPITA IN THE UNITED STATES

MATERIAL END USES	POUNDS PER CAPITA
Nonrenewable Resources	
Nonmetallic minerals	
Sand and gravel	9,000
Stone	8,500
Cement	800
Clays	600
	18,900
Metals	
Iron and steel	1,200
Aluminum	50
Copper	25
Lead	15
Zinc	15
Other metals	35
	1,340
Polymers (synthetics, mostly from oil and natural gas)	
Plastics and resins	100
Synthetic rubber	26
Noncellulosic fibers	22
	148
Minerals for chemical and agricultural industries (fertilizers)	1,650
Renewable Resources	
Wood and wood products	
Lumber	1,140
Plywood and veneer	220
Pulp product	780
Other	80
	2,220
Natural rubber	8
Fibers	
Cotton	19
Other plant	1
Animal (wool, silk)	1
Synthetic (cellulosic)	8
Leather	14
	51
Energy End Uses	
Nonrenewable Resources	
Petroleum	7,800
Natural Gas	5,000
Coal	5,000
	17,800
Grand Total	42,110

On the other hand, if we look at four major metals such as copper, iron ore, lead, and zinc as shown in Table 9, we see that the U. S. has a larger ratio of proven reserves to annual production than we do for crude oil.[12] For example, the ratio of proven domestic iron ore deposits to annual domestic production is 24 versus 11 for oil, (see Table 9).

TABLE 8
IMPORTANT MINERALS AND METALS WHERE IMPORTS ARE OVER 50% OF U.S. CONSUMPTION IN 1976

Minerals and Metals	Percentage Imported	Some Major Foreign Sources
Columbium	100	Brazil, Thailand, Nigeria
Mica (sheet)	100	India, Brazil, Malagasy Republic
Strontium	100	Mexico, U. K., Spain
Cobalt	98	Zaire, Belgium, Luxembourg
Manganese	98	Brazil, Gabon, Australia
Tantalum	94	Thailand, Canada, Australia
Titanium (rutile)	93	Australia, India
Platinum Group Metals	92	U. K., U.S.S.R., South Africa
Bauxite & Alumina	90	Jamaica, Surinam, Guinea
Chromium	89	U.S.S.R., South Africa, Philippines
Tin	85	Malaysia, Thailand, Bolivia
Asbestos	83	Canada, South Africa
Fluorine	79	Mexico, Spain, Italy
Nickel	71	Canada, Norway, New Caledonia
Gold	70	Canada, Switzerland, U.S.S.R.
Mercury	65	Canada, Algeria, Mexico
Cadmium	64	Canada, Mexico, Australia
Potassium	62	Canada
Antimony	61	South Africa, P.R. China, Bolivia
Selenium	59	Canada, Japan, Mexico
Tungsten	59	Canada, Bolivia, Peru
Zinc	59	Canada, Mexico, Australia
Tellurium	57	Peru, Canada

A major source of metals in the United States is from scrap metals recycling and this will be more important in the future. For example, in Table 10, we see that 50 percent of U. S. antimony consumption is supplied by scrap metals recycling.[13] From a comparison of Table 8 with Table 10, you can see how significant recycling is to reducing our metal import requirements.

TABLE 9
RATIO OF DOMESTIC RESERVES TO ANNUAL DOMESTIC NEEDS OF FIVE MAJOR EARTH RESOURCES

Resource	Ratio of Proven Domestic Reserves to Annual Domestic Production	Ratio of Proven Domestic Reserves to Annual Domestic Needs (i.e., Domestic Production & Imports)
Copper	57	50
Iron Ore	24	14
Lead	87	67
Zinc	61	24
Crude Oil	11	7

One added comment on conserving materials and energy, the U. S. should consider following European practice and change pressure vessel codes to allow the use of more high-strength low alloy steels. This would conserve alloying elements and reduce facilities and energy needed for heat treatment of current steels.

TABLE 10
DOMESTIC METALS CONSUMPTION FROM RECYCLED SCRAP METALS

Metal	Approximate percent of U. S. metals consumption obtained from recycling scrap metals
Antimony	50
Lead	35
Copper, Iron, Silver	25
Nickel, Tin, Mercury, Gold, Platinum	20
Tantalum	10-15
Zinc, Chromium	5-10
Magnesium, Tungsten, Cobalt, Selenium	1-5

4. ENERGY/MATERIALS INTERFACE

In this paper, we first considered the energy situation and then the materials picture. Now it is time to tie these two together and look at the energy/materials interface. Energy and materials are closely interconnected in many ways. For example, materials production, requiring both recovery and processing, consumes almost one fifth of all the energy used in the United States. In this section, we will consider three areas where energy and materials interface. These areas are: (1) industrial processing, (2) construction and buildings, and (3) automobiles.

Industrial Processing

The materials industry as previously mentioned uses 20% of the nation's energy. Metals processing requires 8%, chemicals — 6%, petroleum refining — 4%, and non-metallics — 2%. Five basic materials, steel, aluminum, plastics, cement, and gasoline, account for half of this 20%.

Energy is a major cost of producing materials. For example, the energy cost as a percent of total annual operating costs for producing five primary metals and iron ore pellets is shown in Table 11. We see in Table 11 that 37-41% of the total annual operating costs for producing nickel, iron ore pellets, and aluminum are a result of electric power and fuel requirements.[14] These annual operating costs exclude depreciation, interest charges, and amortization.

TABLE 11
ENERGY COSTS AS A PERCENT OF TOTAL ANNUAL OPERATING COSTS FOR PRODUCING FIVE PRIMARY METALS AND IRON ORE PELLETS

	Electric Power %	Fuel %	Total Energy %
Nickel	12	35	47
Iron Ore Pellets	13	25	38
Aluminum	30	7	37
Zinc	18	3	21
Lead	3	14	17
Copper	9	6	15

These energy costs for metals production are a little misleading because domestic energy costs are artificially low relative to the world energy price as a result of U. S. government price controls. Probably, a better way to compare material requirements for energy is on a net energy unit basis as shown in Table 12 for ten metal industries.[15] These industries consume about 8% of this country's total energy. From Table 12 we see that certain metals such as uranium, titanium, magnesium, and aluminum stand out as requiring very large amounts of energy per ton. Metals require significantly more energy per ton for processing than other common materials.

There are many ways the primary metals industry can greatly reduce energy consumption. For example, hot coke is usually quenched with water in the U.S. steel industry. This dissipates the heat and also produces significant air and water pollution. On the other hand, in Europe and the USSR, coke is cooled with an inert gas that is recycled to recapture the heat.

A second example is continuous casting of steel that saves a million BTU's per ton of steel compared to ingot pouring. These two examples plus several others can reduce the fuel needs of the steel industry by almost 50% by the year 2000.

Earlier in this paper, we discussed several fossil fuel

TABLE 12
ENERGY REQUIREMENTS FOR TEN METAL INDUSTRIES IN U. S.

Metal	Products	Energy required per net ton, 10^6 BTU's
Iron and Steel	Steel slabs	24
	Gray iron castings	34
	Carbon steel castings	42
Aluminum	Ingot	244
Zinc	Ingot	65
Lead	Ingot	27
Copper	Cement copper	87
	Refined copper	112
Chromium	High-carbon ferroalloy	61
	Low-carbon ferroalloy	129
Magnesium	Metal	358
Manganese	Ferromanganese	49.5
	Blast furnace	46
	Electric furnace	52
Titanium	Metal	408
Uranium	Uranium oxide	
	Acid circuit	776
	Alkaline circuit	1123
	Resin-in-pulp	795

energy sources. The energy cost to bring these energy sources to market is shown in Table 13. From this table, we see that for every 100 BTU's obtained from petroleum refining, we use 11 BTU's in the refining process.

The six largest chemicals in terms of energy consumption are ethylene, ammonia, chlorine, styrene, methanol, and acetylene. Ethylene production alone consumes more energy than the other five chemicals together. For those of you who are interested in ethylene and its derivatives, a recent model has been developed for correlating and predicting ethylene production growth rates.[16, 17] It is a shame that we are burning up our valuable hydrocarbons in energy applications rather than saving these hydrocarbons for making petrochemicals such as ethylene, propylene, butadiene, benzene, etc.

Now that we have discussed the energy/materials interface in the industrial processing area, let's turn our attention to the energy/materials interface in the construction industry.

TABLE 13
ENERGY COSTS OF BRINGING FOSSIL FUELS TO MARKET

Fossil Fuel	Energy Used BTU's per 10^6 BTU's	%
Coal	30,000	3
Petroleum	60,000	6
Petroleum refining	110,000	11
Natural gas	70,000	7

Construction and Buildings

Buildings consume energy in four phases. First, as we discussed earlier, energy is used to manufacture materials for construction. Second, energy is used in the construction process. Third, lighting, heating, and air conditioning are used throughout the life cycle of the building. And finally, in the fourth step, energy is required for demolition. The energy consumption for the first three steps can be cut significantly in the future.

The manufacturing of building materials has many opportunities to reduce energy requirements. For example, in the U. S. we use an average of 1.2 million BTU's to decompose limestone to make a barrel of cement. On the other hand, in Europe only 0.55 million BTU's are used per barrel of cement. This 50% saving in energy is a result of recapturing the waste heat from cement kilns and using the waste heat to preheat the limestone feedstock. This is a good example where cheap domestic energy prices caused by government price controls has made it economically attractive to waste energy. However, this situation is changing rapidly as energy prices rise and the return on investment for energy reduction is becoming attractive.

Not only is the capital investment/energy trade off changing, but also the labor/energy mix is changing in the direction of using more labor. For example, Richard Stein, Chairman of the New York Board for Architecture, has criticized the present "trend toward construction techniques which substitute masses of material for more careful design and construction." Stein calculated that the electricity required for producing unnecessary cement is about 20 billion kilowatt-hours per year.[18] This is equivalent to the electricity used by 3 million families. These energy savings could be obtained by using more labor to mix and place the concrete during construction. Since energy costs are going up faster than labor costs, new economic calculations are driving the optimum towards using more labor. This will have significant political and social ramifications.

Energy is usually not a criterion in selecting building materials. However, stainless steel, for example, can often be an excellent substitute for aluminum. Even though more steel is required than aluminum, the energy cost for refining a pound of steel is only about 20% of the energy required to refine a pound of aluminum. Refer to Table 12.

Heating fuel could be reduced by about 25% if older buildings were upgraded to the 1971 FHA insulation standards. Another 25% reduction in heating fuel is possible if the older buildings were upgraded to the 1974 FHA insulation standards.[18]

Switching from filament to fluorescent bulbs is also a significant way to save energy in buildings. Most people do not realize it, but fluorescent bulbs produce 3 to 4 times as much light per kilowatt as incandescent bulbs. New materials breakthroughs in coatings is further increasing the energy efficiency of light bulbs.

One last item and maybe the most important for the energy/materials interface is the amount of materials required to **construct** different energy systems. The amount of construction materials used per unit energy output is highest for the nonconventional systems and lowest for the four conventional technologies — natural gas, oil, coal, and nuclear. Windpower systems, which use large amounts of steel have the highest requirement for construction materials and use two times the weight of construction materials than any other nonconventional energy technology. Figure 3 shows that nonconventional

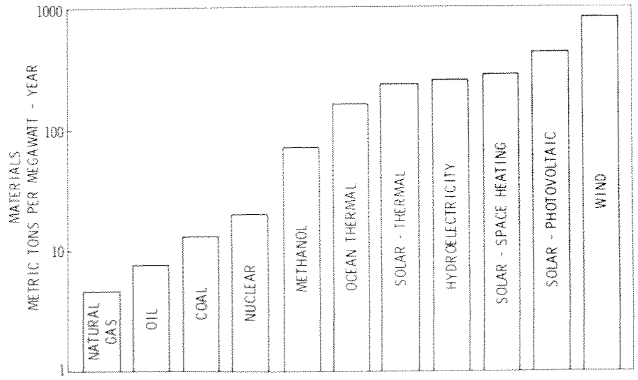

Figure 3. Material Acquisition for Energy Options.

energy sources use from 10 to 100 times more weight of construction materials per unit of energy output than conventional energy sources.[19] This study also shows the same trends for construction labor. Nonconventional energy sources require more construction manpower per unit energy output than conventional energy sources.

In addition to using more materials and more labor, the nonconventional energy sources also use more land. Shown in Table 14 is the land area required for a power plant to generate one gigawatt (1,000 megawatts or 1 billion watts) of electricity. Geothermal power requires 320 times as much land as nuclear or coal generation and windmill energy systems require 9,000 times more land than coal or nuclear power.[20]

The last energy/materials interface I will consider is the automotive industry.

Automobiles

A discussion of the energy/materials interface would not be complete without considering the automobile. The automobile both directly and indirectly consumes almost 22% of our total energy budget in the United States as shown in Table 15.

The auto industry in the U. S. uses 20% of our annual requirements for steel, 65% of our rubber, 35% of our zinc, and 10% of our aluminum and copper. All of these metals as discussed earlier, require a lot of energy to extract and refine.

Automobiles are junked too early. The life expectancy of the average vehicle can be tripled by replacing worn car parts. The energy cost for these replacements is only about 15% of the energy to produce a new car.

The energy/materials interface has been increased dramatically since the U. S. Government mandated fuel consumption standards for 1985. Automobile fuel consumption is reduced about 3% for each 100 lb. of weight reduction. For example, Ford Motor Company is required to reduce the average weight of a car from 4,200 lb. to 2,750 lb. by 1985. This will require a massive substitution of heavy materials by light materials. By 1985, the use of aluminum, plastics, and high strength steel are expected to increase by a factor of two.

TABLE 14
LAND AREA NEEDED FOR A POWER PLANT TO GENERATE 1 GIGAWATT OF ELECTRICITY

	Square Miles
Nuclear	0.05
Coal	0.05
Geothermal	16
Solar	47
Biomass	260
Windmills	484

TABLE 15
TOTAL ENERGY USED BY AUTOMOBILES IN U. S.

	% of U. S. Energy Consumption
Gasoline Consumption	13.3
Gasoline Refining and Retail Sales	3.1
Highway Construction	1.5
Automobile Manufacturing	1.2
Parking and Garaging	0.7
Repairs, Maintenance, Parts	0.5
Insurance	0.5
Tire Manufacturing & Retail Sales	0.3
Automobile Retail Sales	0.3
Oil Consumption, Refining, and Retail Sales	0.2
Total	21.6

Mr. W. Dale Compton, Vice-President of Research and Development for Ford, was asked if Ford had studied the U. S. energy impact of these material substitutions. His reply was — no, only the requirement to meet the mandatory fuel economy standard was considered. Mr. Compton also said that weight reduction had replaced cost as the main criterion in material selection at Ford.[21]

It is possible that this view of weight reduction may not actually reduce net energy consumption. What is needed now, is a life cycle cost analysis for the entire energy/materials interface. The concept of looking at the total cost or the total energy balance over the life cycle of a product is becoming very important. Several recent articles have treated life cycle cost economic models.[22, 23]

A good example of the Energy/Materials/Economics interface is in the potential introduction of graphite reinforced plastic composites for lightweight passenger automobiles by the early to mid 1980's. A normal four-leaf spring weighs 28 lb.; however, using composite materials, the spring will only weigh about 4.5 lb. This type of spring has been tested on both cars and trucks. The weight saving on a heavy-duty truck could be up to 400 lb. Composite driveshafts and gears have also been tested. The composite driveshaft will save 75 lb. over conventional driveshafts.

Today, graphite composites cost about $20 per lb. At $10 per lb. car builders could justify some applications, and at $6 - $8 per lb. graphite composites would be very attractive. This pressure to increase gasoline mileage in passenger cars has led Detroit to use more high strength low alloy steels and also to accept aluminum for bumpers, hoods, and decks.

5. SUMMARY

The U. S. has gone through three 60 year energy phases. In 1850, we used wood. By 1910, coal provided almost 90% of our energy; and by 1970, coal had slipped to third place behind natural gas and oil. In phase 4, which we are now entering, we will see a resurgence of coal and maybe a sharp growth in nuclear energy. Phase 5 will start in the year 2030. At that time, new energy sources, being developed today, will start to play a significant role in the energy picture, and we will then depend on about 6-9 energy sources.

U. S. oil and natural gas production peaked in the early 1970's, setting the stage for the OPEC oil embargo in 1973. We now import almost half of our oil. Since 1970, the price of oil has more than quadrupled and the amount of oil imports has also more than quadrupled. This cash flow factor of 16 is playing havoc with our balance of payments and the American dollar.

U. S. growth in domestic coal production will come primarily from strip mining Western coal that has about 20% less energy per ton than Eastern coal, and also less sulfur than Eastern coal. Nuclear energy growth is facing uncertainty and the outlook is less optimistic than several years ago.

It takes about 30 years to bring on stream significant quantities of a new energy source. Lead times for constructing energy plants has also been increasing primarily because of regulatory permits. Previous U. S. energy forecasts have almost all proven to be overly optimistic.

Per capita raw materials use in the U. S. is about 42,000 lb. per year. We depend on imports for many critical materials. For example, we import over 90% of our columbium, mica (sheet), strontium, cobalt, manganese, tantalum, titanium (rutile), platinum group metals, bauxite and alumina.

Recovery and processing of materials consumes 20% of the total energy use in the U. S. Five basic materials, steel, aluminum, plastics, cement and gasoline, account for half of this 20%. Energy costs are going up faster than labor costs. As a result, economics are shifting the optimum mix towards using more labor. This will have significant social and political ramifications.

The amount of construction materials, construction labor, and land use required is higher per unit energy produced for the nonconventional energy options such as solar, geothermal, windmills and ocean thermal, than for the four conventional energy options — coal, oil, nuclear, and natural gas.

The automobile both directly and indirectly consumes over 22% of our total energy budget in the U. S. The average weight of new U. S. built cars must be reduced by 1500 lb. by 1985 in order to meet the government mileage requirements. This will require a massive substitution of heavy materials by light materials. Weight reduction is replacing cost as the major criterion in materials selection for the automotive industry.

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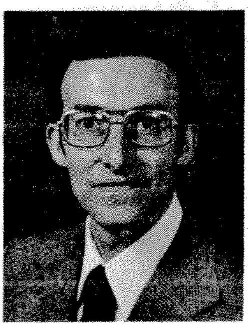

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