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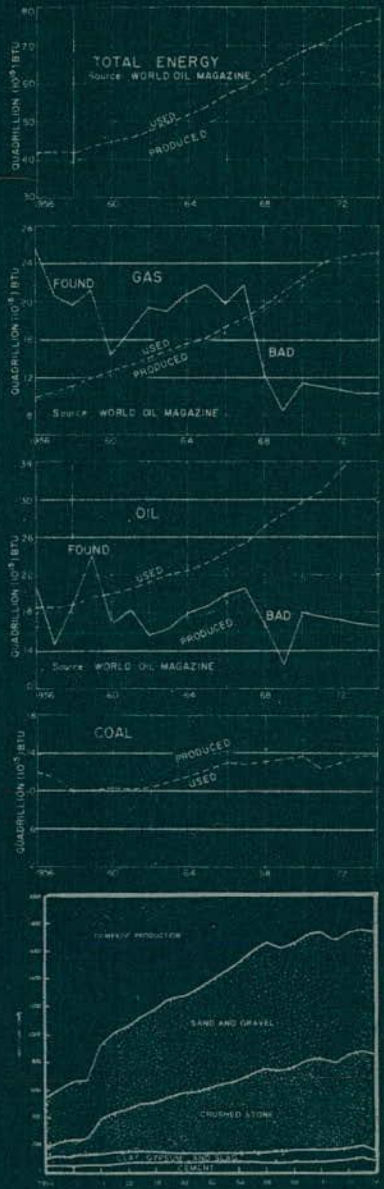

Optimizing the Use of Materials and Energy in Transportation Construction

1976 TRANSPORTATION RESEARCH BOARD

Optimizing the Use of Materials and Energy in Transportation Construction

Proceedings of a conference conducted by the Transportation Research Board November 12-14, 1975, and sponsored by the Federal Highway Administration of the U.S. Department of Transportation, the Federal Energy Administration, and the Energy Research and Development Administration.

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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W. B. Ledbetter, Texas A&M University

AN INTRODUCTION TO OPTIMIZING THE USE OF MATERIALS AND ENERGY IN TRANSPORTATION CONSTRUCTION

The construction of transportation facilities consumes vast quantities of materials. The annual figures are in billions of tons of aggregate and millions of tons of asphalt and portland cement and do not include the billions of tons of earth that is excavated, moved, shaped, compacted, and stabilized each year. These large quantities of materials cost money and energy to produce and place in a transportation facility.

In view of today's inflation, reduced material supplies, and curtailments of energy, an examination of the consumption of materials and energy and attempts to further optimize their use are needed. Therefore, the Federal Highway Administration, the Energy Research and Development Administration, and the Federal Energy Administration sponsored a 3-day workshop on Optimizing the Use of Materials and Energy in Transportation Construction, November 12-14, 1975, which was conducted by the Transportation Research Board. Fifty-four people from state transportation departments, federal governmental agencies, equipment manufacturers, material suppliers, trade associations, and universities attended. This Special Report contains the workshop proceedings.

The workshop participants heard from 4 keynote speakers, whose papers are given in this report. In the first paper, McKetta states that the energy crisis is real and serious. Furthermore, the energy situation will continue to get worse. Data given in Table 1, which are not in his paper but were received from him in a private communication, show the energy consumption in the United States in 1975. Transportation of people and goods consumes 25 percent of the total energy while all raw material processes consume only 6 percent. A natural question is, Why consider energy consumption in transportation construction when the greatest user is the transportation vehicle—the automobile? It is true that the automobile is the largest consumer of energy, but we cannot close our eyes to any energy consumer. Everything must be examined, scrutinized, questioned, evaluated, and ultimately optimized if we are to significantly reduce energy use. Transportation construction does consume significant quantities of energy, and energy must be conserved! It is necessary and timely that we examine our practices with the view to optimization.

Optimization is the key word! Optimizing means conserving scarce and expensive items by perhaps increasing the use of more plentiful items. Optimization means consuming 5 additional units of energy in a particular type of transportation construction to conserve 10 units of energy in automobile use, a net savings of 5 units of energy. The second keynote paper, by Chiogioji, indicates how energy implications can affect roadway decision making. The third keynote paper, by Marek and Jones, discusses the construction materials situation and points out where materials may be in short supply, and the fourth, by Cianchette, presents one contractor's view of how energy and materials can be optimized.

The subject of optimizing the use of materials and energy in transportation construc-

Table 1. Percentage of energy use in the United States in 1975.

Use	Industry	Commercial	Residential	Total
Transportation	9.1	1.0	15.0	25.1
Steam	16.7	–	–	16.7
Heating	11.5	6.9	11.0	29.4
Electrical drives	6.0	0.5	1.4	7.9
Raw materials (chemical)	5.5	–	–	5.5
Water heating	0.9	1.1	2.0	4.0
Air conditioning and refrigeration	0.1	2.9	2.3	5.3
Lighting	0.1	0.2	1.2	1.5
Electrolytic processing	1.2	–	–	1.2
Cooking	–	0.2	1.1	1.3
Other	0.1	0.2	1.8	2.1
Total	51.2	13.0	35.8	100.0

tion was examined by workshop participants in 7 sessions, each assigned a topic. In the sessions on each topic, participants were asked to identify current practices that conserve energy and materials in construction, suggest innovative practices that might be tried in construction and materials technology, and delineate research needs in these areas.

Participants recognized that, although "best" efforts toward optimization are always made, true optimization is seldom reached. Furthermore, as emphasized in the keynote papers, the bases for judgments are continually changing, and this new factor—energy—is having and will have an increasingly significant (if not overriding) influence on all future decisions concerning transportation construction. Optimization can only be achieved by full consideration of all factors—including energy—in their proper perspective.

Each topic chairman prepared a report summarizing the results of the discussions, and these 7 reports follow the 4 keynote papers in this Special Report. The following paragraphs introduce each of the 7 topics.

1: BINDING AGENTS

Binding agents in current use, or being considered for use, include asphalt products, hydraulic cement, lime, lime-fly ash, fly ash, sulfur, tar, wood lignin and resin, sulfate, and petroleum resin. In approximately 90 percent of present all-weather highways, asphalt is used as the binder in the main surface elements and in almost all the rest hydraulic cement is used. The main binders in the sublayers are water, lime, lime-fly ash, asphalt, and portland cement. The one promising new binder that will be available in sufficient quantity for large-scale use is sulfur, which has been used on an experimental basis in a sulfur-asphalt system and eventually may be able to be used without asphalt.

Considerable discussion concerned the fuel potential of asphalt. Because all asphalts used today contain significant quantities of chemically combined sulfur, they are unsuitable for use as a fuel without the development of technology for removing the sulfur. Therefore, many asphalts are now at least a by-product in the refining of petroleum that cannot be used for fuel. Consequently, the quantities of asphalt for transportation construction should be sufficient for the near future, provided asphalt use is optimized.

Portland cement, a most valuable binder, is also currently available in sufficient quantities for transportation construction, again provided its use is optimized. Cement is an energy-intensive product; approximately 7.5 million Btu (7912 MJ) are required to produce 1 ton (907 kg) of cement. Processes have been optimized and fuel efficiency increased by 1.6 percent in the last 2 years, despite a 2.6 percent increase in electric power consumption to meet air pollution standards (1).

2: QUALITY STANDARDS AND QUALITY CONTROL

From rather simple beginnings 5 or 6 decades ago, quality standards in transportation construction have evolved into sophisticated, complex, and time-consuming procedures. Consideration has been given solely to quality, and almost no thought has been given to energy. Today, transportation engineers are scrutinizing their quality standards and questioning whether a particular standard actually performs its intended function. Participants recognized that "first energy" like "first cost" is only the first step and that an arbitrary reduction in quality in initial design, materials selection, and construction standards could result in increased life-cycle costs of all types, including energy and service.

3: AGGREGATES AND OTHER MATERIALS

Aggregates constitute 70 to 100 percent of the solid volume of the pavement structure and thus play an important role in the optimization of materials and energy in transportation construction. According to Marek and Jones, almost 1.8 billion tons (1.5 billion metric tons) of nonmetallic construction materials (sand, gravel, crushed stone, clay, gypsum, slag, and cement) were consumed in 1974, 300 percent more than were consumed in 1950. Even with use of this magnitude, we will not run out of aggregate, for our proven reserves are all but inexhaustible. However, geographic distribution and quality often do not match requirements. The result is that hauling aggregate can consume large quantities of energy, and thus aggregate that is normally inexpensive can become quite costly.

4: EARTHWORK OR EXISTING ROADWAY PREPARATION

Since it often constitutes 30 percent or more of the construction cost, earthwork was considered to be a fruitful area for further optimization. Nature has provided a seemingly infinite variety of soils and soil problems, so the transportation engineer rightly considers each project to possess unique earthwork problems. The complexities of earthwork operations, however, should not deter their renewed examinations.

5: WASTE MATERIALS, BY-PRODUCTS, AND RECYCLED PRODUCTS

Many people believe that we are being inundated by our own waste products. Indeed, the quantities of waste materials and by-products are large, but they are relatively small when compared to the billions of tons of materials used in transportation construction each year. The disposal of waste materials costs money and energy. Materials such as aggregates cost money and energy. An optimum plan may be the use of waste products, by-products, and recycled products whenever possible in transportation facility construction.

6: PRODUCTION AND CONSTRUCTION TECHNIQUES

The energy consumed in producing materials and in constructing transportation facilities is significant. Participants agreed that there were potentials for energy savings and developed a number of recommendations.

7: NEW PRODUCTS AND PROCEDURES POST-1985

In one sense, this topic is the most important, for what is done now will largely influence activities after 1985. Changes are occurring extremely rapidly. We know our supply of fossil fuel is finite and dangerously small. Transportation, as the largest consumer of fossil fuel, is going to change drastically by 1985. How is it going to change? What effect will these changes have on transportation construction and reconstruction? What do we do now to prepare for the changes that will surely occur? Participants were in general agreement on 4 points:

1. By 1985 we will be expending most of our materials, energy, and money maintaining our transportation investment and least on new construction;
2. By 1985 we must have alternate binders to supplement asphalt and portland cement;
3. By 1985 we must have a fully integrated and cooperative transportation network in which all modes work optimally; and
4. Large research efforts are needed now if we are to be ready for 1985.

CONCLUDING REMARKS

The thoughtful ideas and suggestions emanating from the workshop will be effective only if they are implemented. That will require initiative by those individuals who are in responsible positions in transportation departments and who are willing to try them. We can learn from the turtle, who advances by sticking his neck out. To substantially reduce materials and energy used in transportation construction, we may have to adopt similar behavior.

REFERENCE

1. Cement Industry Reports Gains in Coal Conversion, Energy Efficiency. Portland Cement Association, news release, June 9, 1975.

John J. McKetta, University of Texas at Austin

THE ENERGY CRISIS: FACT OR FICTION

Our energy supply is in trouble. We cannot meet the enormous energy demands through the year 2000 without increasing the energy imported each year from overseas. We imported 30 percent more oil in 1974 than we did in 1972. This means that more than 40 percent of the oil used in the United States in 1974 was imported oil. We imported at the same rate in 1975.

We are in a massive energy crunch, and no one is doing anything about it. The causes for the crunch are senseless, inflexible governmental regulations and fanatical demands of extreme environmentalists. Although we will not solve our energy problems before the year 2000, we can alleviate the shortage slightly if

1. We become reasonable about the environmental demands and
2. We become sensible about encouraging U.S. businessmen to find new energy (especially oil and gas), conserving energy of all kinds, doing without certain luxuries, using coal on a much larger scale, using nuclear energy widely, encouraging research and development on broad fronts, and letting the marketplace establish the price of energy.

I, too, am an environmentalist. I want clean air and clean water. I am a member of the National Council for Environmental Balances and chairman of the National Air Quality Control Committee. We all want a clean environment, but we just cannot have no particulates in our air or distilled water in our streams. Yet, extreme environmentalists expect this purity even though it was never attained on this planet even before the advent of humans. Trade-offs are required for the best interests of society, and these trade-offs can be achieved only if the historical miscalculations of government and the overlay of new misjudgments are quickly countered.

The public believes that the energy crisis is over because there is much gasoline available at the pump. Unfortunately, the public is not told that approximately half of the liquid products we use comes from outside of our shores and that the actual liquid production in the United States was about 4 percent less in 1975 than it was in 1974. The imported liquid, however, has increased approximately 23 percent over 1973 (Table 1). Table 1 also shows that the cost of imported liquid was approximately $29 billion in 1975 compared with $7.5 billion in 1973. The public should be told that, even though the supply of gasoline is at the pump, the country will have great difficulty in paying for this imported liquid.

Figure 1 shows the total energy used by the United States from 1956 through 1974 and the total energy produced during those years. The area between these 2 lines indicates the amount of energy imported: more than 18 percent of total energy used in 1974 alone.

The dashed line in Figure 2 shows total gas used by the United States from 1956 through 1974, and the dotted line shows the gas produced, and the solid line indicates the total amount of gas found. Since 1967, we have consistently discovered less gas than

Table 1. Production and imports of liquid products.

Item	1973	1975	Percentage Difference
Production (crude and NGL), million barrels per day	9.372	8.978	-4
Imports (crude and products), million barrels per day	5.864	7.223	+23.2
Total, million barrels per day	15.236	16.201	+6.3
Percentage imported	38.2	44.5	
Cost per barrel of imports, dollars	3.5	11.0	
Cost per year of imports, billions of dollars	7.5	29.2	

Note: 1 barrel = 0.16 m³.

Figure 1. Energy used and produced by United States.

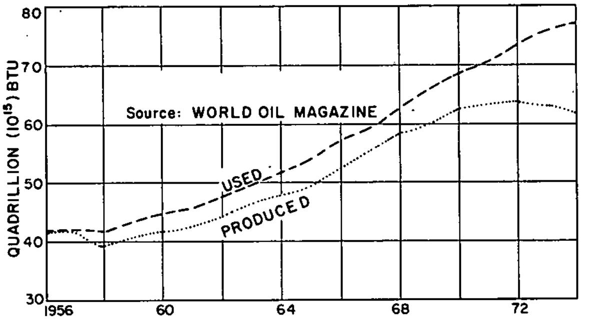


Figure 2. Gas used, produced, and found by United States.

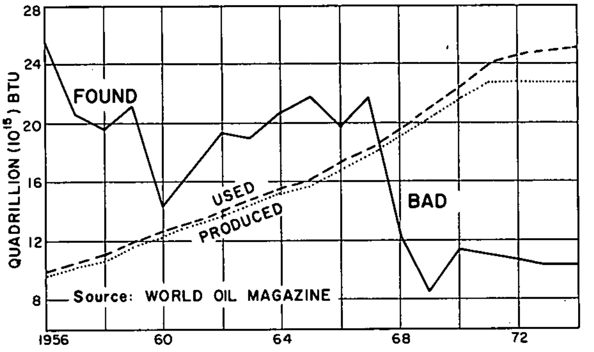


Figure 3. Oil used, produced, and found by United States.

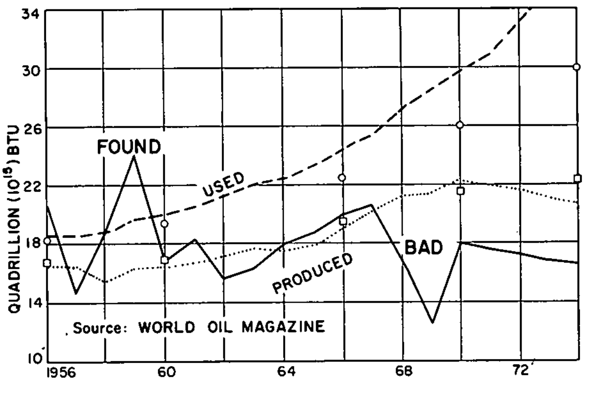
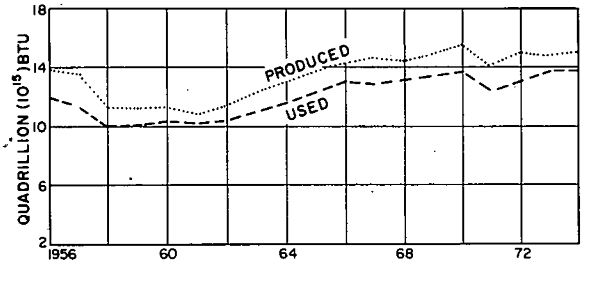


Figure 4. Coal used and produced by United States.



we have produced or used; the discovery line will not again cross the used or produced line in our lifetime. In 1974, we imported about 11 percent of the total gas that we used. The gas produced declined in 1973 for the first time.

Figure 3 shows similar information for oil. We imported more than 40 percent of the liquid hydrocarbon used in this country in 1974, and the quantity imported has continually risen. In 1973, imports averaged 6.0 million barrels (0.95 million m^3) per day. On January 11, 1973, President Nixon increased the import allowable by another 1 million barrels per day (0.16 million m^3). We now import more than 44 percent of all the liquid hydrocarbons we use. To import such large quantities is not desirable because the imports add to a negative balance of payments and dependence on imports constitutes a threat to our national security. The solid line in Figure 3 indicates the amount of new oil found from 1956 through 1974. We are now finding less oil each year than we produce or use, and in addition the production of oil continues to decline.

Figure 4 shows that the information for coal is the reverse of that for oil and gas. We have consistently produced more coal than we use. We have exported coal to Germany and Japan since 1946 as part of our reparations agreement. In 1974 the total income from the coal was $1 billion compared with $29 billion expended for hydrocarbon liquid. In 1970 the effect of the mine safety act and regulations of the Environmental Protection Agency on the production and use of coal can be seen. Twenty-two percent of the coal mines were closed, and production decreased during 1970 and 1971. During that same time, the use of high sulfur coal was restricted. The coal supply should be tripled by 1985 if we are to approach self sufficiency.

The left bar in Figure 5 shows the proved recoverable gas reserves as of December 31, 1972. At the end of 1974 we had 228 trillion ft^3 (6.45 trillion m^3) and approximately 10 years of proven recoverable gas reserves. We used 26.0 trillion ft^3 (0.74 trillion m^3) in 1974. The right bar shows the undiscovered potential of gas in the United States. Most of it is expected to be off the continental shelf. Even the most optimistic figures of 750 trillion ft^3 (21.23 trillion m^3) will last only 35 years. I believe it is extremely significant that, even though 70 percent of the proven recoverable reserves of gas are in the southwestern states, including Texas and Louisiana, these states are planning to depend on nuclear reactors for their electrical energy beginning in 1980.

Figure 6 shows that the proven recovered reserves for oil were 35.6 billion barrels (5.66 billion m^3) at the end of 1972 and 32.2 billion barrels (5.12 billion m^3) at the end of 1974. The 1974 usage rate of 6.4 billion barrels (1.02 billion m^3) gives us a 5-year reserve. The bar on the right side indicates the undiscovered oil potential, which may be as high as 100 billion barrels (15.89 billion m^3), slightly more than a 17-year supply.

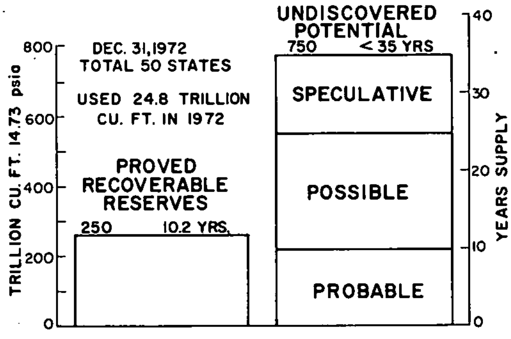
Figure 7 shows the dramatic decrease in the total wells drilled in the United States from 1956 through 1974: 58,000 in 1956 to 26,400 in 1973. The number of independent drillers decreased from more than 39,000 in 1956 to fewer than 3,800 in 1972 because the returns on their investments were not so high as those in other fields. The lower line shows that, of the exploratory wells drilled in 1974, only 13.3 percent showed any significant amount of hydrocarbon.

The top curve in Figure 8 shows the total demand of all types of energy in the United States during the 30-year span. The next curve shows the total energy the United States can supply during this period and is made up of nuclear and hydro, coal, oil from coal and shale, crude oil, natural gas liquid, gas from coal and shale, and natural gas. The total energy produced by the United States during this period is based on several assumptions.

1. The maximum population will not exceed 271 million by the year 2000,
2. Inflexible governmental regulations will be decreased between now and 2000,
3. Less resistance will be offered by the environmentalists, and
4. No major energy usage, such as general weather control and defogging of the cities, will take place between now and 2000.

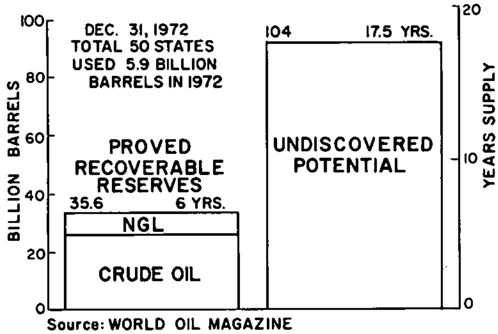
The area shown between the upper 2 curves represents the increasing amount of imports each year. By the year 2000 we will need to import more than 35 percent of our

Figure 5. Proven recoverable reserves and undiscovered potential of gas in United States.



Source: WORLD OIL MAGAZINE

Figure 6. Proven recoverable reserves and undiscovered potential of oil in United States.



Source: WORLD OIL MAGAZINE

Figure 7. Wells drilled in United States.

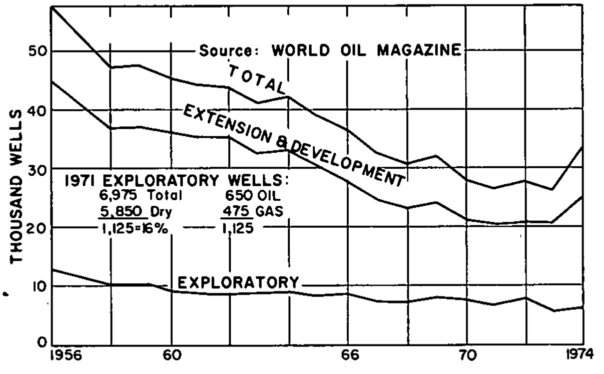


Figure 8. Energy supply and demand in United States and projection based on 1969 data.

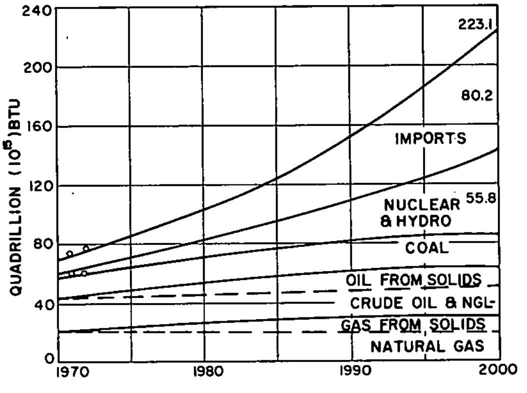


Figure 9. Energy supply and demand in United States and projection based on 1974 data.

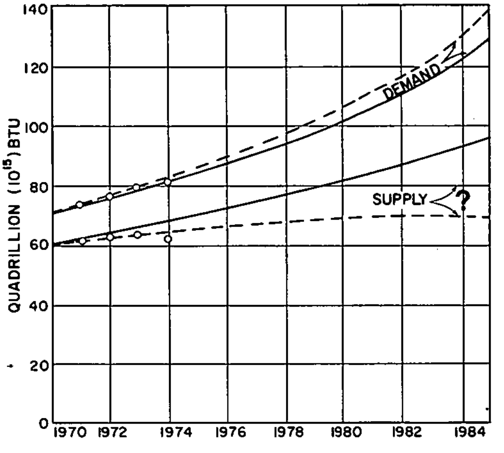


Table 2. Actual and predicted energy demand and supply.

Item	1972	1974	1985 Prediction 1969 Data	1985 Prediction 1974 Data
Demand, 10^{15} Btu	74	76.5	130	138.5
Supply, 10^{15} Btu	63	62	95	66.4
Imports, 10^{15} Btu	11	14.5	35	72.5
Imports, percent	14.9	19.0	26.8	52.0
Import, billions of barrels	1.9	2.6	5.9	12.3

Note: 1 Btu = 1055 J, and 1 barrel = 0.16 m^3.

Table 3. Energy sources in 1985.

Source	Predicted (10^{15} Btu) In 1970	In 1975
Oil and liquid	18.7	18.2
Gas	16.6	15.5
Coal	20.5	18.0
Nuclear and hydro	18.5	10.9[a]
Oil from solids	8.4	1.7
Gas from solids	12.3	2.0
Geothermal	0.15	0.09
Solar	0.10	0.01
Fusion	0.00	0.00
Hydrogen	0.005	0.005
Winds, tides	0.0005	0.0005
Total	95.25	66.405

Note: 1 Btu = 1055 J.

[a]If all planned nuclear plants are built.

total energy, provided there are enough tankers to haul this much energy and there is still a source of that energy. During the year 2000, 12 billion barrels (1.91 billion m^3) of oil will be imported. This would require more than 1,000 tankers of 1 million barrels (0.16 million m^3) net capacity (we have none yet of this size) continually on the high seas to make this delivery. The 12 billion barrels (1.91 billion m^3) of imports would make a negative balance of payments of more than $120 billion, or the equivalent of 120 million new jobs at $10,000 per person.

Figure 8 was prepared in January 1970 and is based on data through 1969. Figure 9, which shows demand and supply (the top 2 lines in Figure 8) for total U.S. energy between 1970 and 1985, is based on 1974 data. With the history of 1970 to 1974, the demand and supply curves (dashed lines in Figure 9) show that the U.S. energy picture is much more critical than we had thought. These data are given in Table 2, which also gives the prediction for 1985 based on both 1969 and 1974 data. The supply predicted for 1985 is now two-thirds of that we predicted in 1970.

The predicted energy sources are given in Table 3. We were optimistic early in 1970 that we would have a great supply of nuclear sources as well as a huge conversion of solids (coal, lignite, shale) into oil and gas. If all of the nuclear plants that are now in the planning or construction stage are completed by 1985 (many of these are now being held up in the courts for environmental, siting, and other reasons), only about half of that predicted in 1970 would be expected to be available in 1985. All of the predictors were overly optimistic on conversion of solids into oil and gas so that only about a seventh of this source will be available by 1985 as compared to that predicted in 1970.

Therefore, unless there is a severe rationing program, the United States can in no way meet the tremendous energy requirements between now and 1985 without annually increasing the amount of energy imported. By 1985 the amount of imports required will be more than 50 percent of the total energy demand. This will be an equivalent of 12.3 billion barrels (1.97 billion m^3) each year (Table 2), a total cost of more than $120 billion, providing the oil is available for us to import.

Melvin H. Chiogioji, Division of Buildings and Industry, Energy Research and Development Administration

ROADWAY DECISION MAKING AND IMPLICATIONS FOR ENERGY USE: SOME ECONOMIC CONSIDERATIONS

Ultimately, almost all decisions concerning location, basic design, and materials used in constructing a roadway have implications for energy consumption. Decisions made today in which one alternative is chosen over another influence energy consumption now and, perhaps more important, have ramifications that will affect energy consumption for years to come.

This paper does not present new data or a detailed methodology with which an engineer or planner can make a specific decision that is optimal in its energy consequences. The great diversity of design problems clearly makes this impossible. Instead, energy costs are discussed in relation to the many other factor costs that are considered as a part of the complex resource allocation problem that is at the center of every roadway design problem. The goal of this paper is to help those concerned with transportation planning to make decisions that are justified on economic grounds. To make such a decision requires knowledge of all the costs and benefits (defined in the broadest terms) associated with the project. Given uncertainty regarding the future, such decisions are always difficult. An intelligent consideration of the place of energy as a variable in the decision-making process requires knowledge of some of its unique characteristics.

ENERGY AS A FACTOR COST

Similarities to Costs of Other Inputs

Building a road requires combining a vast number of inputs, each of which has a price attached to it. Land, materials, equipment, labor, and energy may be used in an almost infinite number of different proportions. The quantity of a particular factor of production that is used is largely dependent on the price of that factor. Achieving a goal of minimization of total costs requires substituting less expensive inputs for those that are more expensive. This elementary concept of economizing on the use of high-cost resources is one of the most basic principles of economics, and it needs to be kept firmly in mind when energy is considered. Energy, like all other inputs, may be used sparingly or lavishly. Some energy must be used, of course, but energy that becomes expensive will be used in small quantities compared to present levels. In this regard, energy is like any other input.

Special Considerations

Several considerations are particularly applicable to energy as a factor of production. The present price of energy does not reflect its true value to society. Prices for both oil and natural gas are in part determined by the government rather than through a free market that uses prices to balance supply and demand. Put quite simply, energy has been too cheap. Through the first step toward complete deregulation, energy is beginning to assume a price closer to its true market value. Today, however, regulation of prices must still be considered. Predicting future prices of energy must involve predictions concerning the political process and the speed with which deregulation either does or does not occur. It must also try to deal with the vagaries of resource exploration and extraction.

The price of energy is also highly dependent on the actions of foreign countries. The unpredictable actions of foreign oil producing and exporting countries have a profound influence on the energy prices that American consumers face. Energy is in many ways a "special case" because of this element of uncertainty concerning future prices. The inherent unpredictability of foreign domestic politics means that those who are making decisions involving the use of energy at some future date are faced with a dilemma. That dilemma involves a choice between making a pessimistic or an optimistic assumption concerning the future price of energy. Although no prediction is made here concerning the future price of energy (other than a prediction that it will go up), a framework is established for examining energy and its importance in a broad sense. Dealing with energy intelligently requires a knowledge of the many areas of use and all of the direct and indirect costs related to energy consumption.

Broad View of Costs

A narrow view of the energy costs associated with a roadway looks only at the first costs of various alternatives. This approach involves, for example, choosing one type of surface over another because its energy content, perhaps measured in Btu/yd^2 (J/m^2), is less. First costs are an important consideration, and the various paving materials, base materials, and construction methods that can be used for a given project can vary greatly in terms of energy used. First costs are discussed later, but at this point it is important to note that an economic analysis of energy must go beyond mere consideration of first costs.

Those familiar with economic analysis of alternative investments are certainly familiar with life-cycle costs. In the context of energy costs associated with roadways, life-cycle costing considers energy used in construction, raw materials, maintenance, resurfacing, and replacement. (New technologies for pavement "recycling" may make the line between resurfacing and replacement unclear.) A life-cycle approach to energy must incorporate estimates of quantities of energy used during the life of the road and the cost of the energy at the time of use. A discounting procedure is used to diminish the importance of dollars spent in the future relative to those spent today. With rising energy costs, a failure to account for future energy use associated with a project can result in a serious understatement of true total energy costs. Energy use by vehicles on roadways is a factor that necessitates an approach even broader than direct life-cycle costing of alternatives. If energy consumption were not dependent partially on the type of road, then this would be a constant among construction alternatives and would not have to be considered. However, the vertical profile, horizontal alignment, and roadway characteristics all influence the fuel consumption of vehicles using a particular road, and 2 roads can vary considerably in characteristics influencing operating costs. On a heavily traveled road with a 20-year life, the additional energy costs that can result from decisions made during the design stage can potentially be of a magnitude that dwarfs any energy costs associated with construction and maintenance.

Energy Consumption Associated With Roadways

In keeping with the broad approach to energy usage being advocated, a broad definition of a roadway is clearly needed. Energy will be used at every stage in the life of a roadway from the initial grading operations through construction, maintenance, resurfacing, reconstruction, or retirement. Energy is also used to produce and transport every material—from the base materials to the pavement surface. Choices involving the design of bridges, dividers, drainage systems, and even landscaping schemes will all have consequences for energy use at the initial stages as well as during the life of the roadway. Energy costs associated with all of these components of a roadway should be considered.

METHODS OF ECONOMIZING ON THE USE OF ENERGY

Industrial Energy Conservation

A brief consideration of efforts now under way to conserve energy in the industrial sector suggests that there are similarities between conservation opportunities in this area and those in the roadway area. Industrial energy conservation can be achieved through actions that fall into 3 broad categories.

Housekeeping Measures

Considerable conservation potential exists in the industrial sector through adoption of what are often called housekeeping measures. This housekeeping category involves changes in procedures and closer control of industrial processes. Reducing lighting and space heating levels in industrial plants, closer monitoring of processes, repair of steam leaks, and proper maintenance of equipment are examples of changes in procedure that have proved useful in reducing energy use.

Non-Output-Related Investments

A second category of industrial energy conservation potential involves capital expenditures for equipment specifically designed to reduce that portion of energy that is needlessly wasted. These are often called non-output-related investments because they do not have an effect on the quantity or quality of output produced. The revenues that are produced by such investments come in the form of dollars not spent on energy. Examples of such investments include insulation applied to various areas of process heat loss, recuperators and regenerators designed to return waste heat to the process, and boilers that use waste heat to supply steam.

Capital Turnover

The third general area of industrial conservation potential is usually called capital turnover. Energy use is reduced by installation of new equipment and construction of new plants that are inherently more efficient in their use of energy. The reduction in energy may come about either through a better designed piece of equipment installed as a part of an existing process or through adoption of an entirely new process. The new Alcoa process for producing aluminum is an example of an entirely new way of producing a product with a considerable savings in energy. Although capital turnover may be accelerated by government programs that stimulate investment, this area of conservation potential is usually considered to be effective in the long run because of market forces and technological progress.

Potential Areas for Saving Roadway Energy

Analogous to the housekeeping and non-output-related investment categories in the industrial sector are 2 areas in which energy savings can be achieved in roadways. The basic distribution is between actions involving capital use and factor substitution and measures aimed at stopping waste through little or no use of capital. In both cases, however, energy conservation measures must be assessed in terms of their returns relative to costs. If the full costs associated with a project exceed the resulting benefits, then the project is not economically justifiable and should not be pursued. Experience with energy conservation measures in the industrial, residential, and commercial sectors suggests that there are certain to be numerous economically justifiable opportunities for reducing energy use associated with roadways that are not being pursued.

Noncapital Areas

Numerous changes in procedure are possible that involve little or no expenditure of capital and yield potentially large benefits in the energy costs associated with the construction, maintenance, resurfacing, or reconstruction of roadways. A list of possible ways to change procedures and thereby reduce energy use includes the following:

1. Use maintenance vehicles more judiciously,
2. Use vehicles with better fuel economy,
3. Minimize double handling of materials during construction,
4. Reduce frequency of maintenance operations if adverse long-run effects are not likely to result,
5. Maintain vehicles and equipment better, and
6. Minimize waste of materials.

The thing that these various procedural changes have in common is a savings in energy with minimum trade-offs involving greater use of other factors. Additional labor is required with many types of procedural changes, but the benefits in the form of reduced energy expenditures are often large in relation to the minimal costs involved. Procedural changes aimed at reducing energy waste have this characteristic in common with other waste elimination measures.

Factor Substitution

A second major area of potential for saving energy involves factor substitutions of varying degrees of complexity. Within this category are direct substitutions of capital for energy as well as more subtle forms of substitution of one material for another that have life-cycle energy savings consequences. The substitution of one material for another to save energy involves some complex considerations concerning the true costs and benefits associated with such a substitution. A life-cycle approach to costs and benefits is essential to a proper evaluation of the trade-offs associated with choosing one construction alternative over another. First costs, maintenance costs, and user operating costs must all be considered.

A direct form of substituting capital for energy can involve greater use of capital in initial construction and maintenance in order to save fuel costs of vehicles using a roadway. For example, the choice of a lesser grade on a road will certainly tend toward minimization of user costs, but usually at the expense of greater construction costs. Minimization of user fuel costs requires a perfectly flat road with an even and smooth surface that is constantly maintained. Even extremely heavy traffic composed of vehicles that use high-priced fuel and have low fuel economy will not justify the huge capital costs that are sometimes required to minimize user fuel costs. The trade-offs are obvious, and roads designed today should incorporate a consideration of both probable fuel costs and traffic levels likely to be associated with a particular road during its lifetime. Greater first cost in order to reduce life-cycle costs may be justifiable.

Substitution of construction materials is often considered on the basis of cost minimization. The issues involved are certainly as complex as those in the case of minimization of user fuel cost through greater initial construction costs. The considerations relevant to comparing the energy implications of an asphalt and a cement pavement will serve to illustrate a number of points that apply equally to many different areas of construction and maintenance decision making.

Under an assumption of perfect knowledge, it is possible to determine the exact cost of an asphalt concrete or a portland cement concrete pavement adequate to meet the requirements of a particular situation. Energy contents as well as prices are associated with each surface, and these can be calculated in a rough way on the basis of the energy content of asphalt, cement, steel, aggregate, and the transportation and construction costs associated with each. For a comparison of the first costs associated with each pavement, it is the direct dollar costs and not the energy contents of the 2 materials that are the relevant factor. The price charged for the 2 materials will reflect, in part, the energy used in the manufacture and the price paid for the energy. (This relation between product prices and energy is considered in greater detail in the next section.) It is not normally within the realm of an engineer or planner to be concerned with the energy contents of pavement when first costs are examined.

The maintenance program required for a particular type of pavement in a specific application has serious implications for the total energy consumption associated with a particular roadway. For example, first-cost minimization may be achieved through use of an asphalt pavement in a particular situation. However, once the pavement is in place, a certain maintenance program will be required to keep the road in good condition. The high cost of maintaining the surface chosen relative to an alternative surface can mean that the first-cost advantage can be offset by greater life-cycle costs. A greater deterioration of the surface can be deemed acceptable, of course, and, although this may make total costs of one surface appear favorable, increased user fuel costs may be associated with such a decision.

This first-cost and life-cycle cost distinction is a common one and is certainly applicable to costs other than energy. It is particularly important in the case of energy costs because of the previously mentioned volatile nature of energy prices. The long-term commitment to a certain maintenance program means that future energy prices of alternative pavement and maintenance combinations must be considered. Materials required for future maintenance programs may be energy intensive and may increase in price because of increases in energy price. Both increases in prices of maintenance materials and the direct effects of fuel price increases on maintenance vehicle operating expenses must be considered as a part of a life-cycle determination of costs and benefits. Energy costs saved in the future are a benefit that must be weighed relative to first costs. Examples of possible material substitution decisions with consequences for first and life-cycle energy costs are numerous. A list of these may include

1. Use of blended cements that are less energy intensive;
2. Use of less energy-intensive base materials;
3. Different coatings on pipe and other metal roadway elements;
4. Different materials for guardrails, railroad crossings, bridges, and other features;
5. Changes in specifications for aggregates;
6. Reducing unnecessarily stringent specifications for materials (where life-cycle trade-offs are not adverse); and
7. Use of asphalt emulsions instead of hot mix.

Energy and Future Costs of Roadway Materials

As stated earlier, future energy prices are dependent on both foreign and domestic politics, as well as on the vagaries of resource discovery, to a degree that makes predictions hazardous. Future energy prices will be important in estimating direct fuel costs associated with maintenance programs that are likely to be required to maintain a particular roadway. They will also be important as one determinant of future prices of materials likely to be needed for future maintenance. In cases where a considerable time lag exists between project planning and actual construction, future energy prices may be relevant to evaluating probable first costs of alternative roadway designs. This section briefly outlines a framework for evaluating the relation between energy prices and product prices.

The extent to which increases in energy prices will result in increased product prices in a particular industry is dependent upon

1. Mix of fuel types used in the industry,
2. Price increases for various fuel types,
3. Amount of energy used to produce a unit of output,
4. Degree to which industry can (or chooses to) pass through energy price increases, and
5. In the long run, degree to which the efficiency energy use increases in the industry (through conservation measures and/or more modern equipment or both).

Table 1 (1) gives energy consumption profiles for a number of large energy-consuming industries. The steel, chemical, cement, and aluminum industries all produce products that are used in roadway construction. The large variations among industries in dependence on the various fuel types are apparent. There is also considerable regional variation in fuel consumption in the patterns. Figure 1 (2) shows historical data on the efficiency increases that have occurred in the industrial sector. Interindustry comparisons of these energy/output (E/O) ratios also show the differences in the energy required to produce a unit of output.

A set of calculations is provided for energy price increases associated with President Ford's 1974 proposed deregulation and tax program [price deregulation of domestic oil and new natural gas supplies and excise taxes on crude oil, imported oil, natural gas liquids, and natural gas of $2.00, $2.00, and $1.45/barrel ($12.50, $12.50, and $9.06/m^3) and $0.37/1000 ft^3 ($0.01/1000 m^3) respectively]. The energy price increases translate into product price increases (with an assumption of 100 percent pass-through). The nature of future variation among industries in product price increases will depend on the relative price increases in oil, gas, and coal. The size of future product price increases will depend, of course, on the size of future energy price increases. These can obviously be considerably larger than those in the deregulation and tax program, which is used here as an example. Two cases are calculated (Tables 2, 3, and 4): one in which coal prices rise in response to increases in gas and oil prices and one in which coal prices remain constant.

The calculation of the impact of energy price increases on product prices is a 3-step process. The first step (Table 2) involves estimating increases in the price of the various fuel types. The second step (Table 3) involves calculating the base energy price and energy price increases in each industry based on the industry's mix of fuel types. That is, industries that are large users of a fuel (such as coal in case 1) that is not increasing in price will not face large energy price increases. The final step involves use of energy/output coefficients as a measure of the importance of energy as a factor of production. The increase in product prices implied by increasing energy prices (assuming 100 percent pass-through) is calculated and given in Table 4. Increases in prices are substantially higher in the steel and cement industries if coal prices are assumed to rise in response to rising gas and oil prices.

These calculations show the way in which energy price increases are translated into product price increases. Since life-cycle costing involves a determination of future prices, this framework can be potentially useful to those making decisions that have consequences for future use of energy-intensive materials. Greater capital costs incurred as first costs may be economically justified based on the benefits associated with saving future maintenance that requires greater direct and indirect energy costs. One must carefully evaluate any design decision that implies a commitment to large use of materials for maintenance that will increase in price because of energy cost increases. The extent to which energy cost increases can translate into product price increases has just been shown. The regional variation among the various industries in their dependence on coal, oil, gas, and electricity has important implications for the

Table 1. Energy consumption distribution by industry and fuel.

Industry	Total Consumption[a] (10^{12} Btu)	Fuel (percent of total energy) Oil[b]	Gas[c]	Coal	Electric[d]	Other[e]
Steel	3,031.0	8.0	20.0	62.3	4.4	5.4
Chemical	4,888.0	22.7	59.0	10.3	8.0	—
Petrochemical	3,854.0	26.6	60.1	7.1	6.2	—
Paper	2,130.0	22.0	21.0	12.0	5.0	41.0
Aluminum	586.0	11.0	37.0	1.0	51.0	—
Cement	514.0	15.0	43.0	35.0	7.0	—
Total	11,149.0	17.6	39.2	25.4	8.7	9.3

Note: 1 Btu = 1055 J.

[a]Data for steel, paper, aluminum, and cement correspond to 1973 consumption. Chemical and petrochemical estimates correspond to 1974.
[b]Includes fuel oil and oil-derived feed stocks.
[c]Includes natural gas and natural gas liquids.
[d]Electricity valued at its thermal equivalence of 3,412 Btu/kw·h.
[e]Nonmarketable fuels such as wood chips and pulping liquors.

Figure 1. Historical trends in energy/output coefficients.

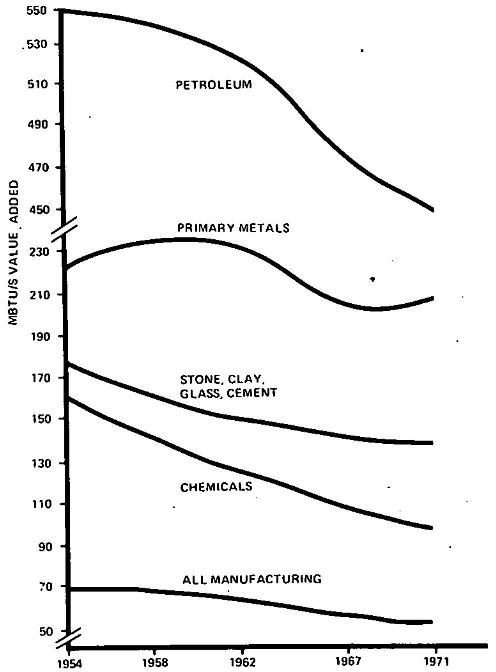


Table 2. Potential impact on nationwide fuel prices.

Fuel	Base Line	Case 1 Amount	Case 1 Percent	Case 2 Amount	Case 2 Percent
Coal	79.1	79.1	—	108.9	37.7
Oil[a]	195.4	258.1	32.1	258.1	32.1
Gas	52.4	95.4	82.1	96.4	82.1
Electricity	644.8	701.1	8.7	740.5	14.8

Note: Amounts are in cents/10^{12} Btu, where 1 Btu = 1055 J.
[a]Prices given correspond to residual oil.

Table 3. Estimated increase in average fuel costs.

Industry	Estimated Base-Line Prices[a] (dollars/10^{12} Btu)	Case 1: Tax and Deregulation Program (percent increase)	Case 2: Coal Price Rise (percent increase)
Steel	1.39	12.3	26.8
Chemical	1.37	42.7	44.2
Petrochemical	1.40	41.7	43.9
Paper	1.40	19.0	23.0
Aluminum	1.88	21.1	33.4
Cement	1.20	25.0	36.0
All	1.40	27.7	34.4

[a]Based on a mix of fuels given in Table 1 and price increases given in Table 2.

Table 4. Potential impact of fuel price increases on average output prices.

Industry	Absolute Fuel Price Increase (cents/10^{12} Btu) Case 1	Case 2	Energy/Output Coefficient[a] (10^{12} Btu/dollars output)	Implied Increase in Product Prices (percent increase) Case 1	Case 2
Steel	17.0	37.2	0.140	2.4	5.2
Chemical	58.5	60.6	0.072	4.2	4.4
Petrochemical	58.4	61.5	0.144	8.4	8.9
Paper	26.6	32.2	0.139	3.8	4.4
Aluminum	39.7	62.8	0.140	5.6	8.8
Cement	30.0	43.2	0.267	8.0	11.5

[a]Energy consumption relative to 1974 product prices.

product price increases likely to be facing roadway construction throughout the country. The declines in energy/output ratios shown in Figure 1 are expected to continue. Perhaps analogous to the "capital turnover" category of industrial energy conservation, this decline of E/O coefficients means that roadway construction and maintenance will be able to take advantage of the efficiency gains of industries that supply their materials and equipment. With energy prices increasing, these supplying industries can certainly be expected to economize on the use of more expensive energy inputs.

CONCLUSIONS

There are a number of reasons why optimal decisions concerning energy use are not made. Consideration of the true costs and benefits associated with each planning and design decision is not an easy task. Some of the reasons why energy costs are not always properly considered as a part of a life-cycle view of allocation of resources include

1. Incomplete knowledge of all costs and benefits associated with a certain project;
2. Uncertainty concerning future energy prices;
3. Desire to avoid the risk of trying new technologies and materials;
4. Institutional constraints in the form of specifications, materials, or construction methods (or all of these) that are unnecessarily stringent; and
5. Methods of funding roads that may emphasize minimization of first costs at expense of life-cycle and especially user costs.

Dealing with energy use requires a broad look at all of its implications. Narrow and traditional approaches are not appropriate when one deals with a resource whose price is increasing so rapidly and unpredictably. To even speak of the energy problems of the transportation sector or of the industrial sector as if they were separate is to adopt too narrow a view. An example may be helpful to illustrate this point. As noted earlier, roadways will be able to take advantage of the industrial sector's trend toward economizing on the use of energy per unit of output. One sector should not view the actions of the other sector as a "given." For example, in the case of specifications concerning blended cement, builders of roadways can help cement producers achieve reductions in energy use per unit of output. Use of blended cements should be evaluated carefully to see where they are and are not appropriate. A large market for this product can spur advances in the cement industry in the use of a proven energy-saving technology. There are undoubtedly many other areas where a better use of energy resources can be achieved through a broader view of energy use that does not compartmentalize a complicated problem.

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WILL THERE BE A MATERIALS CRISIS?

An abundant supply of minerals is essential to the vitality, security, and survival of an industrial nation. This paper discusses the supply of 6 major construction materials: stone, sand and gravel, cement, lime, iron and steel, and asphalt. Annual requirements per U.S. citizen, production and consumption data, estimates of resources, and factors affecting resource availability are presented. Conclusions relating adequacy of supply and the ability to meet future demands are drawn. The question of whether there is to be a materials crisis is addressed.

For many years our nation has assumed that the sources of domestic materials and energy are infinite. Unfortunately, the Earth's crust is not an infinite storehouse that can be readily tapped for new supplies of all kinds of mineral raw materials. All minerals are in finite quantities; they cannot be regenerated or replaced at rates comparable with their extraction. However, some minerals are more abundant than are others.

The law of conservation of matter dictates that matter can be neither created nor destroyed; only the form can be altered. Alteration through use reduces the availability of certain forms of matter and thereby creates "shortages" of matter in the form desired at a given time.

The life cycle of materials is shown in Figure 1 (1), which indicates that materials extracted can be refined and processed into bulk materials that, in turn, can be processed into engineering materials. Engineering materials are used for a given period of time and then can be either (a) recycled into new materials for reuse or (b) temporarily disposed of on Earth. (In the latter instance natural forces work to alter the form of the material.)

Vigorous industrial and economic growth in the United States during the past century, although resulting in the highest standard of living in the world, has created "shortages" of materials and energy. In most instances, the shortages are a direct result of a failure to develop new material sources as fast as required by the economy. To continue the current standard of living, while at the same time helping to raise the standard of living of underdeveloped areas of the world, will require a large increase in raw material supplies in the years ahead. Use of currently subeconomic resources or newly discovered resources or both will be necessary to meet the demand. Such use will be possible only through a concerted, well-planned, time-consuming effort by industry, government, and academe.

RESERVES VERSUS RESOURCES

Many terms have been used to describe and classify mineral reserves and resources. The definitions (9) used in this paper were developed by the U.S. Bureau of Mines and the U.S. Geological Survey and are somewhat different from those in Webster's Dictionary.

Figure 1. Life cycle of materials.

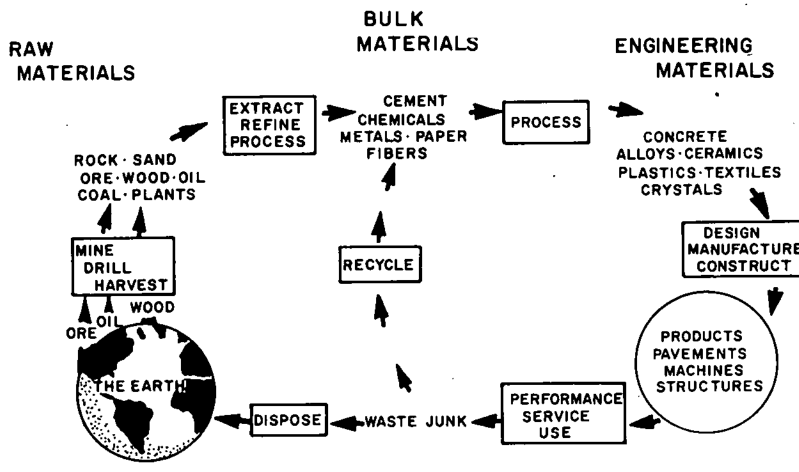


Figure 2. Classification of mineral resources.

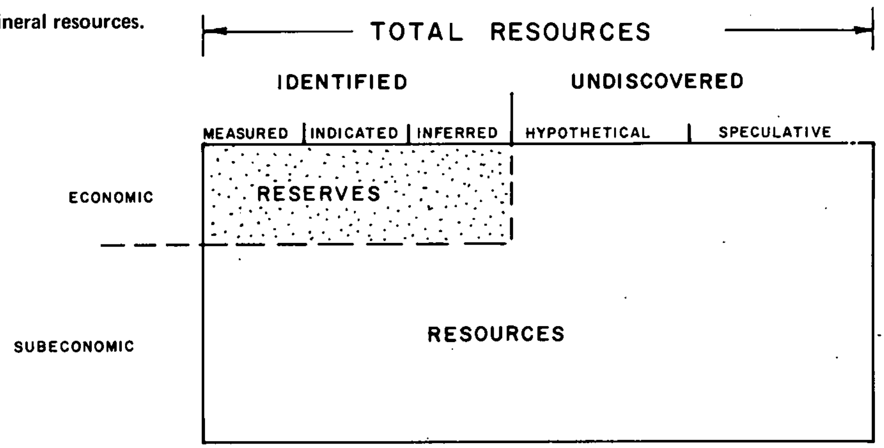
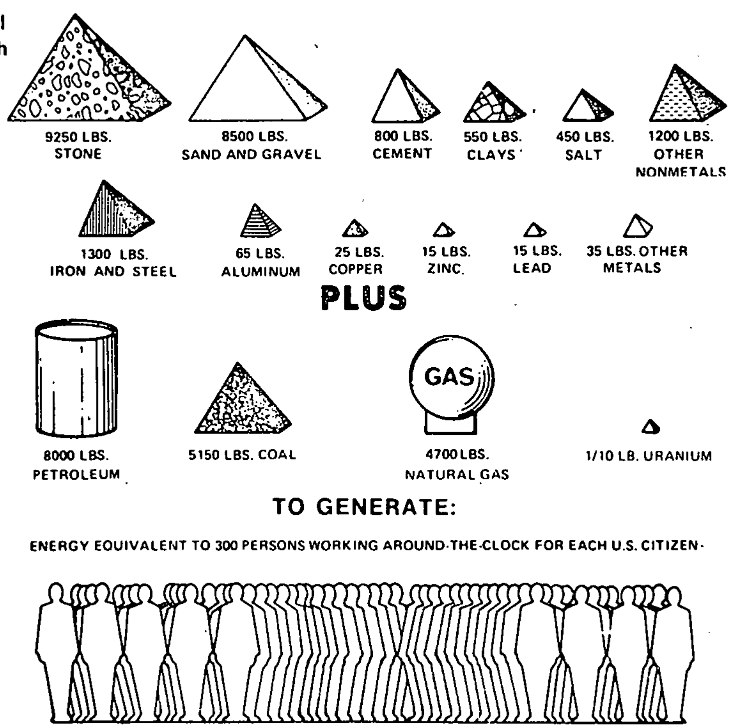


Figure 3. Annual new mineral material requirements for each U.S. citizen.



1. A resource is a concentration of naturally occurring solid, liquid, or gaseous materials in or on Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.
2. A reserve is that portion of the identified resource from which a usable mineral or energy commodity can be economically and legally extracted at the time of determination.

Resources include reserves and other mineral deposits that may eventually become available, including (a) known deposits that cannot be profitably mined at the present time because of economics, technology, or legal restraints; or (b) unknown deposits that may be inferred to exist on the basis of geological evaluations. Total resources may be divided and subdivided as shown in Figure 2 (9). Mineral reserves and resources are dynamic quantities. As such, they must be constantly reappraised to permit evaluation of the status of the mineral in question. Known reserves of many minerals represent a supply of only a few years, but reserves of other minerals are adequate for hundreds of years. In many instances known reserves constitute only a small fraction of potentially available resources. Resources of specific materials with limited reserves exist, but to make them available reserves may require enormous and costly efforts of exploration and research (9).

MINERAL REQUIREMENTS

New mineral materials required annually for each U.S. citizen are shown in Figure 3. Approximately 40,000 lb (18 144 kg) per person is needed. U.S. total use of new mineral supplies exceeds 4 billion tons (3.63 Gg). Minerals for use in construction and for energy constitute the major fraction of this requirement (8, 11). These new mineral material requirements are based on a one-time use and then disposal of the material. Recycling of materials can significantly reduce these requirements per capita for a new mineral material.

PRODUCTION AND CONSUMPTION

Production and consumption data for each of 6 construction materials from 1970 through 1974 are given in Table 1. Estimated years of resources remaining at current levels of consumption are given in Table 2.

In 1974, an estimated 981 million short tons (890 Pg) of crushed stone were produced and consumed in the United States. Fifteen percent of crushed stone is used for cement and lime manufacture. World production and consumption during 1974 exceeded 7.6 billion tons (6893 Pg) (7). Demand is expected to increase at an annual rate of 5 percent through 1980. Resources of crushed stone have never been systematically estimated and are probably so vast as to be incalculable (3). However, geographic distribution and quality often do not match requirements. U.S. resources of crushed stone (a composite of crushed carbonate, crushed granitic-metamorphic complex, and crushed igneous stone) are shown in Figure 4 (10).

An estimated 904 million short tons (820 Pg) of sand and gravel were produced in the United States in 1974. Of this amount, 902 million tons (818 Pg) were consumed. World production exceeded 6.8 billion tons (6168 Pg) in 1974 (7). Demand is expected to increase at an annual rate of 4 percent through 1980. Sand and gravel resources of the United States are shown in Figure 5 (10). The sand and gravel resources of the United States and the world are literally inexhaustible. However, geographic distribution and quality often do not match market requirements.

Cement production in 1974 in the United States was 84 million tons (76 Pg). Consumption was virtually the same as production. World total production was 771 million tons (699 Pg). Production in the United States and in the world was approximately 84 percent of existing plant capacity (6, 7). Crushed carbonate stone is a primary raw material required for the manufacture of cement. Other required raw materials in-

Table 1. Production and consumption of 6 construction materials.

Material	Item	1970	1971	1972	1973	1974[a]
Stone, million short tons	U.S. production	869	876	920	1,060	981
	U.S. consumption	Virtually same as production				
	World total production	–	–	–	6,932	7,614
Sand and gravel, million short tons	U.S. production	944	919	914	984	904
	U.S. consumption	964	918	913	982	902
	World total production	–	–	–	6,996	6,804
Cement, million short tons	U.S. production	74.3	78.3	82.6	85.4	84.0
	U.S. consumption	75.9	81.5	84.9	90.5	84.6
	World total production	–	–	–	780.3	771.0
Lime, million short tons	U.S. production	19.7	19.6	20.3	21.1	21.9
	U.S. consumption	19.9	19.8	20.5	21.4	22.3
	World total production	–	–	–	118.8	122.9
Iron ore, million long tons	U.S. production	89.8	80.8	75.4	87.7	83.0
	U.S. consumption	131.6	116.2	126.9	146.9	140.5
	World total production	–	–	–	850.5	877.0
	U.S. reserves	–	–	–	–	9,000
	World reserves	–	–	–	–	249,000
Petroleum, millions of barrels	U.S. production, crude	3,517	3,454	3,455	3,361	3,230
	U.S. demand, crude	3,984	4,082	4,280	4,548	4,459
	U.S. demand, products	5,364	5,553	5,990	6,298	6,182
	World total production	–	–	–	21,511	21,570
	Asphalt and road oil demand[b]	119.5	122.5	128.4	136.4	133.8

Note: 1 short ton = 907.2 kg, 1 long ton = 1016 kg, and 1 barrel = 0.16 m^3.

[a]Estimated. [b]Calculated at 3 percent of total consumption.

Table 2. Potential availability of construction materials at current level of consumption.

Material	Remaining Years of Availability	Material	Remaining Years of Availability
Stone	∞[a]	Lime	∞[a]
Sand and gravel	∞[a]	Iron ore	866
Cement	∞[a]	Asphalt and road oil	93 to 200[b]

Note: Calculations involved dividing total resources divided into 1974 world production, which is assumed to be equal to consumption without restriction.

[a]Although resources are not infinite, they are so vast as to be inexhaustible.

[b]Calculated by dividing estimate of potentially recoverable crude petroleum resources by world total production in 1974. Asphalt and road oil is assumed to be 3 percent of total consumption of refined petroleum products.

Figure 4. Distribution of crushed stone resources, including crushed carbonate, crushed granitic-metamorphic complex, and crushed igneous stone.

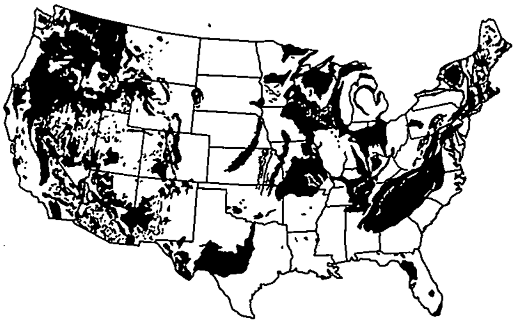
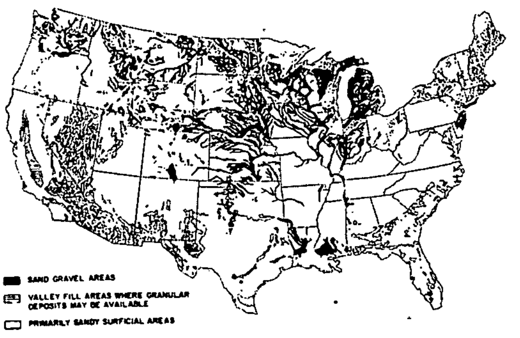


Figure 5. Distribution of sand and gravel resources.



clude natural argillaceous materials such as clay, shale, or slate. Considerable energy is also required to chemically transform the raw materials to the desired end product. Raw materials for use in cement manufacture are abundant in most countries, but are not always located near market areas. U.S. supply and use of major nonmetallic construction materials, including cement, stone, sand, and gravel, are shown in Figure 6 (8).

In 1974, U.S. production of lime was 21.9 million tons (20 Pg). Consumption was essentially the same as production. World total production was 122.9 million tons (112 Pg) in 1974 (7). Demand is expected to increase at an annual rate of 2.6 percent through 1980. Raw material resources for lime manufacture, which consist essentially of crushed carbonate stone, in the United States and the world, are abundant.

U.S. production of iron ore in 1974 was estimated at 83 million long tons (84 Pg). U.S. consumption exceeded 140 million long tons (142 Pg). Domestic ore supplied about 60 percent of the demand. Imports, largely from Canada and Venezuela, supplied the remainder. U.S. demand is expected to increase at an annual rate of 2 percent through 1980, and production capacity is expected to increase by 20 percent by 1978. Domestic reserves of iron ore have been estimated at 2 billion short tons (1814 Pg) of contained iron and an additional 16 billion tons (15 Eg) of higher cost potential reserves. World reserves of iron ore exceed 760 billion tons (689 Eg) (7). The U.S. demand and supply for iron in the United States from 1950 to 1974, with projections to the year 2000, are shown in Figure 7 (5).

U.S. reserves of petroleum exceed 35 billion barrels. Estimates of world resources of recoverable crude petroleum vary from 2.0 to 4.5 trillion barrels (320 to 720 billion m^3) (7). An estimate of asphalt and road oil production and consumption can be made by assuming that 3 percent of the petroleum, after being refined into various products, goes to this use. In 1974, an estimated 97 million barrels (16 million m^3) as asphalt and road oil were produced from U.S. crude oil.

Table 2 gives a summary of the potential availability of each product at the current level of consumption. For 5 of the 6 construction materials, the estimated years of potentially available resources at current levels of consumption exceed 800. Only petroleum crude oil, with its components of asphalt and road oil, is in relatively short supply. Resources of this product will be exhausted within 200 years.

RESOURCES OF SELECTED MINERAL COMMODITIES

Although the scope of this paper is limited to a discussion of 6 major construction materials, much of the discussion is equally applicable to other minerals. Unfortunately, the resources of some minerals are small. Table 3, which was compiled by the U.S. Geological Survey and the U.S. Bureau of Mines, gives the domestic resource status of 63 selected mineral commodities (8). The data indicate that the domestic resources of approximately 60 percent of the minerals listed are sufficient to provide materials for at least 500 years at the present levels of consumption. Domestic resources of approximately 15 percent of the minerals listed will be exhausted within the next 20 years.

Identified resources include reserves and materials other than reserves that are reasonably well known with regard to location, extent, and grade and that may be exploited in the future under more favorable economic conditions or with improvements in technology. Hypothetical resources are undiscovered, but are predicted geologically. The resource appraisal terms in Table 3 indicate the percentage the domestic resources are of the minimum anticipated cumulative demand between 1968 and 2000. These percentages are as follows:

Term	Percentage	Term	Percentage
Huge	1,000	Moderate	35 to 75
Very large	200 to 1,000	Small	10 to 35
Large	75 to 200	Insignificant	10

Figure 6. U.S. supply and use of major nonmetallic construction materials.

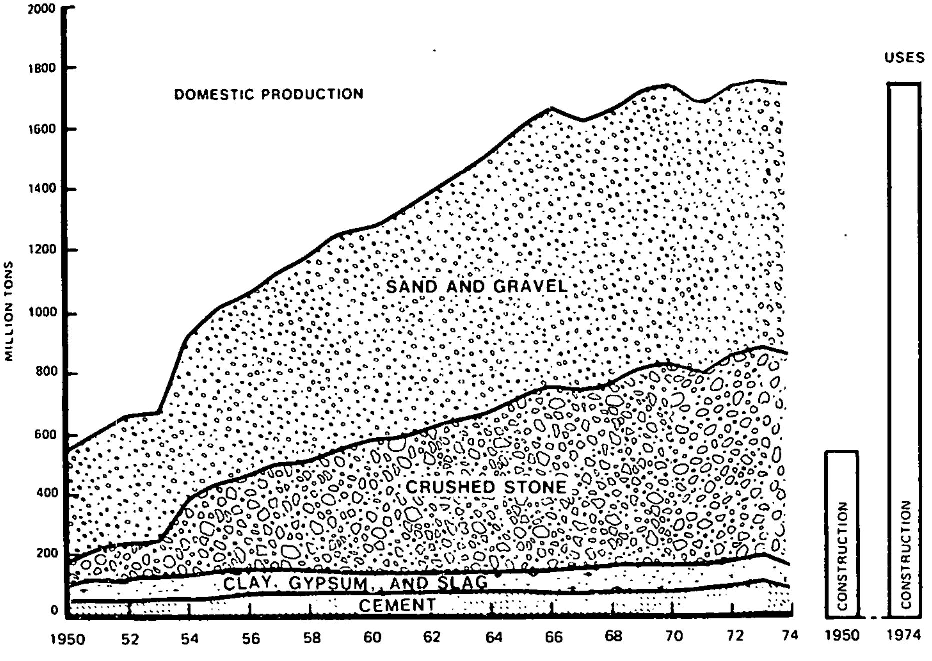
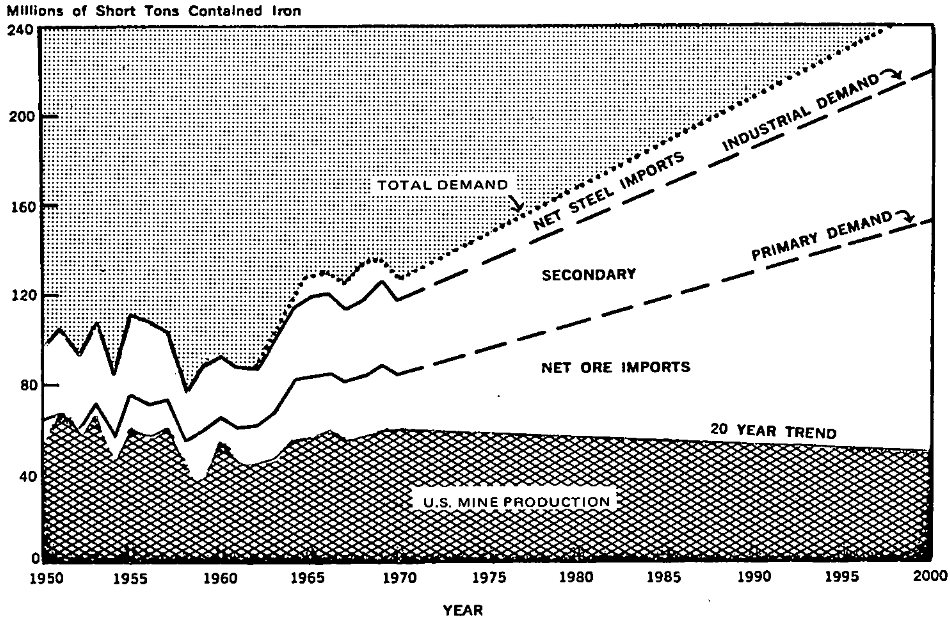


Figure 7. U.S. demand and supply of iron.



The term, known data insufficient, means that the resources were not estimated because of insufficient geologic knowledge of surface or subsurface areas.

SHORTAGES: REAL OR ARTIFICIAL

Shortages of materials can be real or artificial. Real shortages are created by depletion or exhaustion of resources in the world. These shortages cannot be overcome by raising the price or developing new technology. They are a result of geologic unavailability, which dictates mineral supply. If a mineral is not geologically available, favorable economics and technology are not pertinent.

Artificial shortages are created by constraints placed on the use of available resources. Some artificial shortages are frequently a matter of the material being in the wrong location or in the wrong form to permit economic exploitation at a given time. Other shortages are created by man-made obstacles, occasionally arrived at without justification by narrow viewpoints or by short-range planning. (These include shortages created by overly restrictive specifications on quality for specific applications, unstable specifications that retard producer incentive for producing temporarily desired products, and limited industry capacity.) Still other shortages are created by unplanned land use (surface), actions taken because of concern for the environment, or nonavailability of energy necessary for mineral extraction or processing. Artificial shortages can be lessened by changes in national goals and policies, changes in attitudes and opinions, and proper long-range planning of resource use.

FACTORS AFFECTING POTENTIAL AVAILABILITY OF RESOURCES

A wide range of forces influence the availability of resources. These social, cultural, political, technological, and economic forces are functions of rate of population and economic growth, national goals and priorities, and concern for the environment (5). This paper discusses 5 primary factors that affect resource availability: geology, energy, technology, economics, and law.

Geology

The population of the United States and of the world is concentrated in relatively small tracts for reasons that are related to geography and seldom related to the supply of products required to build for that population. The occurrence, form, and distribution of resources affect resource availability, particularly in areas where resources are nonexistent.

In the United States as a whole, source material for use in the production of quality construction materials (with the exception of asphalt) is in abundant supply for the foreseeable future. Some areas of the country are lacking quality materials because of geographic distribution of the materials. "Shortages" exist because local deposits never existed or have been exhausted, are approaching depletion, or are unexploitable because of one or more factors that are discussed later in this paper. Such shortages result not from the exhaustion of total resources but from economic considerations that create artificial shortages in a local area.

Based on data shown in Figures 4 and 5 and responses to a questionnaire sent to highway departments throughout the United States, Witczak (10) defined areas that are lacking in quality aggregates for use in construction and for use in the manufacture of cement and lime. These areas (with some modification by the authors) are shown in Figure 8, which indicates that artificial shortages of aggregates exist in only limited areas of the United States.

Generally, the eastern and the western sections of the United States have an equivalent potential for stone sources (Figure 4). However, the type of stone that exists is

Table 3. Selected mineral resources.

Mineral	Resources Identified	Resources Hypothetical	Mineral	Resources Identified	Resources Hypothetical
Aluminum	Very large	Known data insufficient	Magnesium	Huge	Huge
Antimony	Small	Small	Manganese	Large	Known data insufficient
Asbestos	Small	Insignificant	Mercury	Small	Known data insufficient
Barite	Very large	Very large	Mica		
Beryllium	Very large	Huge	Sheet	Insignificant	Very large
Bismuth	Small	Known data insufficient	Scrap and flake	Huge	Huge
Boron	Very large	Huge	Molybdenum	Huge	Huge
Bromine	Huge	Huge	Natural gas	Moderate	Large
Calcium chloride			Nickel	Large	Known data insufficient
(Brine)	Very large	Huge	Nitrogen	Huge	Huge
Chlorine	Huge	Huge	Peat	Huge	Known data insufficient
Chromium	Insignificant	Insignificant	Petroleum liquids	Large	Large
Clay	Large	Very large	Phosphate	Very large	Huge
Coal	Huge	Huge	Platinum group	Moderate	Large
Cobalt	Huge	Large	Potash	Very large	Huge
Columbium	Very large	Known data insufficient	Rare earths	Huge	Known data insufficient
Construction stone:			Salt	Huge	Huge
Crushed	Large	Known data insufficient	Sand and gravel	Large	Known data insufficient
Dimension	Large	Known data insufficient	Silver	Moderate	Large
Copper	Large	Large	Sodium carbonate		
Diatomite	Huge	Known data insufficient	and sulfate	Huge	Huge
Feldspar	Huge	Huge	Strontium	Huge	Huge
Fluorine	Small	Small	Sulfur	Huge	Huge
Gold	Large	Known data insufficient	Talc	Very large	Huge
Graphite	Very large	Known data insufficient	Tantalum	Huge	Known data insufficient
Gypsum	Huge	Huge	Thorium	Very large	Known data insufficient
Iodine	Very large	Huge	Tin	Insignificant	Insignificant
Iron	Very large	Huge	Titanium	Very large	Very large
Kyanite	Huge	Huge	Tungsten	Moderate	Moderate
Lead	Large	Moderate	Uranium	Small	Small
Limestone and			Vanadium	Very large	Known data insufficient
dolomite	Large	Known data insufficient	Zeolites	Huge	Huge
Lithium	Huge	Huge	Zinc	Very large	Very large
			Zirconium	Large	Known data insufficient

Figure 8. Areas lacking quality aggregates.

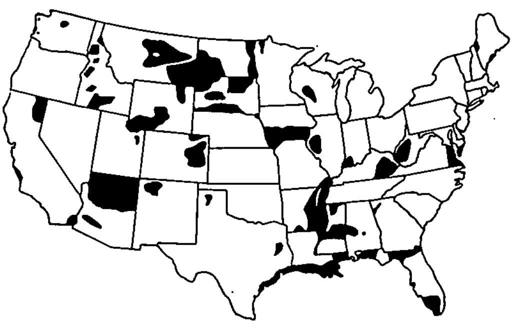


Table 4. Land use for mining major minerals in the United States.

Mineral	Approximate Acres Mined: Number	Approximate Acres Mined: Percent
Coal	1,600,000	40
Sand and gravel	1,000,000	25
Stone, gold, clay, phosphate, and iron	1,200,000	30
Other	200,000	5
Total	4,000,000	100

different. In the east, the greatest source of crushed stone exploited is crushed carbonate; less frequent sources are granitic-metamorphic complex and basaltic types. In the west, the granitic-metamorphic complex and basaltic types predominate, and carbonates decrease in occurrence (10).

Sand and gravel deposits occur in great abundance in the northern areas of the Midwest (Figure 5). Other large sand and gravel deposits are found in valley fills in the West. Deposits generally are nonexistent in the East (10).

Energy

Supply of conventional construction materials is directly related to energy availability (4).

Energy is required for extraction, refining, and processing of all bulk materials, and additional energy is required to process bulk materials into desired engineering materials. Some materials, such as cement, lime, and iron, are energy intensive. Many materials, including stone, sand, and gravel, are not energy intensive, but require, nevertheless, some energy output. Still others (asphalt and road oil) are a form of energy in themselves, and their use in construction reduces potential energy reserves.

Constraints placed on the availability and use of energy adversely affect the production of construction materials. Such constraints reduce the ability to produce (availability of) such materials and, in effect, create artificial shortages of the materials, even though adequate resources exist. Many energy-related shortages of materials could be overcome by increasing energy supplies.

Technology

Extraction of minerals and subsequent processing of the minerals to usable form require extensive technology. Technology establishes equipment and procedures for achieving a practical and useful product. Existing technology is sufficient to provide construction materials from economic reserves (by today's standards). New technologies and new developments may be required for production of materials from currently subeconomic resources. If the new technologies are not developed, artificial shortages of specific products could result. Such shortages will cease to exist as new technologies are developed. New technologies can lead to advantages such as identification of resources previously unknown, improved methods of exploration, improved productivity, substitute materials, safer working conditions, and lower costs (8).

Economics

Artificial shortages of a mineral commodity can be created when the commodity is not available at an acceptable price to perform a desired function. The price of a material affects the demand, and this in turn influences the supply of the material. The primary objective of a material producer (private company) in our society is to provide a marketable product at a profit (9). Any factors that can improve the profit structure of a material can increase material supply, provided adequate resources of the material exist.

The cost of a product is affected by extraction costs, processing costs, and transportation costs. Consequently, the price that society chooses to place on a material commodity directly affects the producer's ability to produce various commodities over time from available resources and distribute them for consumption, now and in the future.

Price increase can either transform currently subeconomic resources into a reserve category or increase the distance materials can be transported while providing the desired economic return to the producer or do both. Resources are economical or not only as they meet competitive costs and prices (5). Resources that are now economically unfeasible for exploitation may become economically feasible in the future through technologic advances or increased demand or both.

Land Use and Law

Competition for land in the United States, coupled with public concern over the environment, is having a profound effect on the availability of material resources (5). Land use determines, in large measure, the extent to which the nation is able to meet its mineral needs.

Mining of minerals has disturbed less than 0.3 percent of the total land area of the United States. Approximately 4 million acres (16 billion m^2) of land area have been affected [Table 4 (5)]. These data indicate that approximately 50 percent of the land used for mining major commodities provides minerals for use in construction. Considering the dependence of our industrial nation on such commodities, this land use percentage is quite small.

Several construction material industries, because urban areas are their main market and because transportation costs of the products sold are high in proportion to their value, need to locate within economical hauling distance of the city to avoid prohibitively high costs to the user (5). Residential and commercial developments have, on occasion, engulfed mining operations that at one time were miles from the closest development. Resulting community pressures and complaints have forced the closing of some operations before available deposits were mined out (5). In some instances, urban sprawl covered choice mineral reserves before they were developed and exploited.

Extraction of mineral reserves is not permitted or is permitted to only a limited extent on certain public lands, including lands in the National Park System and National Wildlife Refuge System and administered by Department of Defense. More than 100 million acres (405 billion m^2) of federal land are used hardly at all for mineral production (2, 5).

Political actions have also diminished the availability of land for production of industrial materials. Wilderness preservation, wild and scenic rivers, national trails, national recreation areas, enlargement of the National Park System, protection of watersheds, preservation of aesthetic values, and administrative withdrawals have restricted access to existing mineral reserves and potential resources. Land that contains stone, sand, gravel, and other mineral deposits must be reserved for mining. The United States must preserve opportunities for extraction of common and essential minerals to obtain the most efficacious use of its resources. Careful consideration must be given to decisions that restrict resource exploitation and concomitant availability. Land use decisions must be made by officials who are not influenced by uninformed emotional people and local politics.

A comprehensive land use plan and a national materials policy are needed to minimize artificial shortages of materials in the future. A national policy will encourage investors to lease and pay interest for many years on properties that can eventually be exploited for materials while the risk of nonrecovery of the investment due to human frivolities or new technology is minimized.

SUMMARY AND CONCLUSIONS

The United States and other nations of the world are not going to run out of mineral resources (5). Artificial shortages of certain minerals, however, are being created through exhaustion of accessible supplies and known reserves. In addition, factors such as zoning, artificial ecological fears, technical ignorance, poor administration and management, overly restrictive specifications and poor engineering, lack of continuity or dependability of construction programs, lack of long-range planning, and lack of investment protection are continually interacting to create artificial shortages of minerals with identified reserves. Such shortages have on occasion provided new incentives for development and adoption of new technologies and new approaches for exploitation of remaining resources. Resources of minerals with limited subeconomic reserves exist. To make them available reserves may require enormous, costly, and time-consuming efforts. Good resource and environmental management is a prerequisite to an adequate supply of minerals for construction applications, and all other applications, for the foreseeable future.

The United States needs to develop a national materials policy that can properly and adequately define the problems affecting resource availability and define a plan and objectives for resolving the problems. Irresponsible action today will create a materials crisis tomorrow. A crisis will be averted if misused, overly restrictive, or short-sighted actions are minimized through proper and total planning for the future.

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CONTRACTOR'S VIEW OF OPTIMIZING MATERIALS AND ENERGY

The Associated General Contractors (AGC) of America, an organization in which I serve as chairman of the Highway Division, represents the people who actually use the energy and put in place the materials, the conservation of which was the subject of this workshop. It is an important and timely subject. The supply of materials and energy is a major concern throughout the country. We have not yet, however, received many indications from our members that they have had problems getting materials and fuel. This is not to say that contractors are not looking ahead. We do as much of this as do most businessmen, particularly those of us in highway construction who have so much invested in equipment. This is to say though that we have a great deal of confidence in our ability to get the job done under almost any circumstances. (As you know, we worry about getting the job in the first place.) Nevertheless, the shortages we faced a couple of years ago did teach most contractors a lesson, and some of the things we learned at that time are appropriate to this discussion.

Shortages and the necessity they create to conserve and make optimum use of what we have should be on every contractor's mind these days. There are some early warning signals that shortages of the past may be pale compared to shortages to come. The signals to which I refer are the normal business cycles that swing through the supply sector of the construction industry, the cycles in which suppliers and manufacturers keep ahead and then fall behind demand. The sharp slowdown in expansion plans in the asphalt, cement, and steel industries is of real concern as we look ahead to coming business opportunities. The extremely high cost of money to finance inventories affects stocks of materials of both manufacturers and suppliers.

The shortages of 2 years ago started a transformation in the long-established ways of doing business in highway contracting and other construction fields. Certain broad categories of change can be ascertained.

1. Older, established contracting firms have the most stable growth in difficult times. Established contractors have proved their business ability. They have built lines of credit and solid relations with suppliers and others with whom they do business. They are less likely to be caught in a situation from which they cannot recover.

2. Newer firms and firms out to make a quick turnover will find it tougher to get new business. Although construction will always—and should always—encourage new entrepreneurs, these firms are going to find it harder to operate profitably. In some cases, it may be difficult to obtain suppliers. Capital loans to them will be less attractive. The construction industry's reputation as an easy-to-enter business will likely change. The industry is getting more sophisticated each year.

3. Suppliers will find contractors taking a harder stand for firm prices. Contractors are adopting new methods of dealing with suppliers, particularly in the matter of receiving quotations. Quotations agreed to and accepted over the phone will be in-

creasingly recognized as a form of contract, and contractors will be more insistent that these prices be firm or a maximum escalator be included.

4. Creditors can be expected to give higher ratings to contractors who have remained solvent and profitable during the present economic crisis.

There are still other examples. Contractors who are operating successfully today have been doing a good deal of belt tightening. They have been reevaluating projects in terms of completion times. In highway construction, the prospect of so-called staged construction is becoming more acceptable to shorten the time between start and completion of a given project.

Actions of the government and other contract-awarding agencies and owners to permit payment for fabricated materials stored on or near the job site have encouraged contractors to purchase supplies well in advance of need in order to have them on time and at the price planned for the job. This is one of the major ways contractors are surviving today's cost crunch. At the same time, the necessity for doing this makes the contractor a possessor of inventory and therefore more dependable in terms of completion schedules.

Purchasing policy of many construction companies has long been a problem, not only to the industry but to suppliers as well. Contractors are not solely to blame for their past purchasing practices. Owners and awarding agencies must speed up the award of a contract. If contractors can place equipment and material orders within 30 days after bid openings, a number of problems would lessen. For one, the cost submitted in a bid would be more likely to hold up by the time of award. For another, it would help halt the need for escalation clauses by suppliers.

Another way to survive in these times is to urge owners to speed up payments. Slow payment policies and payments that are held up to enable the owner to take advantage of the high return on short-term investments do a serious injustice to the contractor. In the long run, the owner does not really gain from such practices, for contractors must include the cost of this money in their bids.

Delays cost money, especially the delay between bid opening, contract award, and notice to proceed. These delays can be prevented by cooperation between the parties to the contract.

These are a few things that can relieve some of the cost pressures that a general contractor faces in the normal course of doing business. There are, of course, a number of things that a contractor can do to get better job performance.

Some policies that were established by general contractors in times of shortage could be well followed at all times. Of necessity, these policies concern the use of equipment more than the use of materials, although I will comment on materials later. AGC compiled the following checklist during the oil embargo and furnished it to all members as a guideline during that crisis period. It should continue in force, however, as good business practice.

<u>Office</u>

1. Reduce night lighting to minimum necessary for proper security.
2. Maintain office temperature at no more than 68 F (20 C) during working hours.
3. Prohibit use of portable electric heaters in office.
4. Reduce energy consumption for interior lighting by turning off lights when not needed, using lights that require less energy, closer matching of amount of light used to amount of light needed, and using sunlight whenever possible.

<u>Company Vehicles</u>

1. Drive at slow speeds until engines warm up (cold engines consume more gasoline than warm engines).
2. Shut off engines when not in use.

3. Maintain proper tire pressure (low pressure can increase gas usage by as much as 10 percent).

4. Place company automobiles on a strict, periodic tune-up schedule [10,000 to 15,000 miles (16 000 to 24 000 km)] (an out-of-tune engine can lower gas mileage by 10 percent). Inspect hoses, nozzles, and tanks for leakage.

5. Keep records of gasoline mileage for company automobiles.

6. Monitor gasoline charge-out records to identify and control any excess use.

7. Restrict use of company vehicles to company business.

8. When vehicle replacement is necessary, replace with high-economy vehicle.

Equipment

1. Do a better job of matching equipment to the job (a bucket that is too wide or too narrow is energy inefficient).

2. Improve earth-moving techniques. Maintain short-haul distances and smooth haul roads. Do not move dirt twice, and try not to move any extra material. Keep air filters clean. Check the fuel injection system. Be on the lookout for burned intake and exhaust valves.

3. Make sure tires are properly inflated and that crawler tracks are properly adjusted.

4. See that operators are trained and motivated to look for machine efficiency and fuel conservation.

Field

1. Consolidate material deliveries and reduce job-site deliveries to one per day, if possible.

2. Reduce on-site lighting (60-W bulbs are suggested for hallways and other areas not requiring high-intensity lighting) but remain in compliance with requirements of Occupational Safety and Health Administration.

3. Shut off rather than idle equipment, particularly during shift changes and lunch.

4. Extend time for oil change, when possible, depending on conditions (some contractors feel more frequent filter changes will prolong time between oil changes).

5. Use proper equipment for long-distance material hauling (small vehicles or other improper equipment may consume large amount of fuel on long hauls).

6. Use maximum daylight hours for construction activity.

7. Plan the locale of strategic lighting equipment and the operation of pumps and motors required for certain air pollution control devices. Monitor these operations on a day-to-day basis.

8. Implement scheduled maintenance programs for both gasoline and diesel equipment (calibration of pumps and injectors is necessary to get proper combustion and reduce excessive fuel consumption). Wash air cleaners, turbos, and lines.

9. Use double covers for concrete heating. Heat only to bare minimum according to specifications, and shut down on warm days. Do not heat longer than necessary.

10. When temporary heat is required, check all areas to prevent heat loss.

11. Conduct periodic "energy audits" to determine further conservation measures.

12. Conserve job-site visits and inspections.

13. Do not fuel rental equipment unless authorized by main office.

14. Give project manager responsibility for all petroleum products deliveries, disbursement, and accounting.

15. Make only one morning and one afternoon parts delivery to main facility and job site.

Conservation Measures Requiring Federal, State, or Local Variances

1. Use higher sulfur fuels or blends for hot-mix plant operations (this would release a large amount of diesel fuel for vehicles rather than for use in drying aggregates).

2. Use solid fuel salamanders for cold weather building heating.

General Policies

1. Encourage better commuting habits by (a) providing prime reserved parking spaces for

car pools, (b) providing clearinghouse service for matching prospective car poolers, and (c) providing up-to-date information on all mass transit system schedules.

2. Adopt mandatory 55-mph (88-km/h) speed limit on all vehicles.
3. Use "buddy" system for lunch and remote job sites.
4. Consolidate supervision if possible to reduce vehicle use.

Two years ago, AGC participated with the American Association of State Highway and Transportation Officials and the American Road Builders' Association in the preparation and publication of a booklet, Cost Cutting Suggestions on Highway Construction. I feel that the suggestions fit perfectly with at least 2 objectives of this workshop: identification of current and innovative construction practices to use materials efficiently and to conserve energy. I might say, too, that I was a member of the subcommittee that developed these recommendations, so I take some pride in the authorship. The following are the 12 suggestions we made for cutting costs in highway construction.

1. To permit the placement, consolidation, and finishing of portland cement concrete without the aid of preerected side forms in the construction of pavements, median barriers, curbs, and gutters, it is recommended that restrictive specifications requiring fixed-form construction be replaced with provisions allowing the option of using slip-form techniques. It is also recommended that the requirements for reinforcing steel be simplified to the maximum extent possible, particularly with respect to median barriers.
2. To standardize bridge components, it is recommended that the use of prefabricated bridge components be increased.
3. To simplify the use of materials conventionally used in highway construction, it is proposed that precast inlet and manhole standard details be developed and included in contracts as acceptable alternatives and it is recommended that these standards be used as alternate construction bid items.
4. To meet rather stringent gradation requirements in specifications involving soil and aggregate materials, it is proposed that additional efforts be made to use naturally occurring material with a minimum of costly processing.
5. To permit alternative designs involving various pipe products, it is proposed that, wherever site conditions will permit, alternative designs be prepared for all types of pipe that can be expected to perform satisfactorily and are reasonably competitive in price and the least costly alternative be selected for use, the costs being determined by the competitive bidding process.
6. To provide for the elimination of transverse reinforcing steel in continuously reinforced concrete pavement in an effort to take advantage of modern developments in paving equipment technology and to reduce unit costs of pavement, it is recommended that standard contract provisions be adopted to permit the elimination of transverse steel wherever possible.
7. To implement the concept of a flare-end section on pipe in lieu of headwalls, it is recommended that a standard plan or plans for such flare inlets, including structural and hydraulic considerations, be developed.
8. To standardize the details of highway elements on a nationwide basis, it is recommended that each state highway department and the respective contractor associations review what immediate and further actions could be taken to increase standardization of details in their plans and specifications.
9. To substitute latex, acrylic, and polyester coatings, or no treatment, in lieu of rubbing concrete structure surfaces when such surfaces require some treatment, it is recommended that rubbing of exposed, formed surfaces of concrete structures be eliminated and that finishing consist merely of plugging tie holes and removing fins or other protrusions. In some cases a higher finish may be desired and in such cases it is recommended that a coating of latex, acrylic, or polyester material be used.
10. To minimize geometric complexities in bridges, it is recommended that a comprehensive and diligent analysis be made of the entire project at the preliminary design stage.

11. To establish that thick lift bituminous paving, commonly known as black base, should not be regarded in the same light as surface course paving, it is suggested that a reassessment and broadening of the specifications be made with the thought that this is base course material.

12. To encourage the use of the dryer drum concept to produce hot emulsion mixes, it is recommended that the film, The Dryer Drum Process, produced by the Federal Highway Administration, be shown at contractor and contractor-state meetings to familiarize them with the process and the suitability of the product.

Finally, I will say a word about what happens when shortages occur and pricing policies change radically. These 2 conditions have a significant bearing on how a contractor performs and consequently have a direct relation to this discussion. When these conditions occur, some contractors make a fast call for escalation clauses in their contracts. These clauses are considered to be protection against runaway prices. Interestingly, Associated General Contractors has not endorsed escalation clauses. In fact, AGC has steadfastly maintained its long-held opposition to escalation clauses, which would surely have harmful long-term effects. Nevertheless, contractors feel that, if any future price aberrations should suddenly occur, general contractors must insist on the following responsibilities of suppliers:

1. Quotations to general contractors must be firm and void of price-in-effect clauses or unlimited escalation clauses. If it is anticipated that prices will rise during the term of a contract, any escalation clause should specify an upper limit above which the price will not rise.
2. Quotations, whether written or verbal, must be adhered to by the subcontractor or supplier.
3. Contracts must be honored regardless of future factors affecting price.

In recommending this, general contractors recognize the dependency and trust we must place in our subcontractors and suppliers. We recognize further that they, through all tiers, should be more expert than we are in assessing the effects of all factors on their work and pricing structure. And we expect subcontractors and suppliers to exercise their responsibilities to the industry and to the contract system.

Woodrow J. Halstead, Charlottesville, Virginia, chairman

Workshop Topic 1
BINDERS

Consideration was first given to existing binder systems and to possible alternatives that might be developed. A list of these is as follows:

1. Asphalt products,
2. Hydraulic cements (portland, blended, slag),
3. Lime,
4. Pozzolanic materials (lime-fly ash and others based on atmospheric temperature reactions among calcium-silicon-water),
5. Sulfur,
6. Wood lignins and resins,
7. Tars (derived from coal),
8. Petroleum resins (epoxy-polyester), and
9. Sulfates (primarily calcium sulfate wastes from scrubbers to remove sulfur oxides from stock gases).

An examination of each of these types of materials resulted in the conclusion that little possibility existed for the development of completely new binder systems. The first 4 in the list generally represent the major materials now available. Asphalt products are now used in about 90 percent of all U.S. highway pavement structures and are also the mainstay in maintenance efforts. The hydraulic cements, principally portland cement, provide the binder for most highway structures and a substantial portion of high types of pavements. They also have a significant role in soil stabilization. Lime and lime-fly ash or other pozzolanic systems have significant roles in base course construction and stabilization.

The most likely probability of a new binder that can be substantially used appears to be sulfur. This may be used either as the total binder or in combination with asphalt. In the present state of development, the sulfur-asphalt combinations appear to have more promise.

The interest in wood lignin and wood resins is derived primarily from the fact that wood is a renewable resource. Lignin wastes have been used in some "stabilization" and dust palliative projects, but because of their water solubility have not provided permanence. Some studies now under way show possibilities of developing a useful product from wood wastes, but such efforts are still in the feasibility stage.

Tars derived from various coal processing activities can be used as highway binders, and a body of technology is available. However, the overall better performance of asphalt as a highway binder and the greater value of tar as a fuel, usually at the site of its manufacture, make it highly unlikely that appreciable amounts of tar will become available in the near future for highway construction in the United States. However, in the long run, should coal be developed as the principal source of liquid fuel, it is possible that usable binders could be manufactured from residual products or even directly from coal.

Petroleum resins are extremely expensive, require large amounts of energy in their manufacture, and therefore cannot be considered for highway construction except for special applications in limited quantities. The waste sulfates may have application in embankments or base courses. However, this product was not discussed. The technology for its use relates more closely to the problems of solid waste utilization.

In the final analysis, the binder problem becomes one of establishing the optimum use of the available systems. It is necessary to consider cost and energy effectiveness of trade-offs among possible alternatives. The availability of specific binders for each construction project is an important factor in such considerations since the cost of transporting materials quickly changes both cost and energy consumption. Consequently, a national policy that one type of construction should be used in preference to another cannot be established; decisions must be reached on a project-by-project basis. This leads to a recognition of the need for better knowledge of energy-use factors for all activities relating to highway construction. A number of agencies have conducted preliminary studies and some values are becoming available, but differences exist in the factors published for the same operation. A priority effort to establish universally acceptable energy use factors is needed, and it is recommended that the Transportation Research Board, through one of its established committees or by a special task force, undertake this task.

One of the major differences of opinion that exists is the question of whether the Btus in asphalt should be considered in calculating the energy used in asphalt construction. Although it is true that the asphaltic portion of the original crude oil represents a potential energy source, once the petroleum is refined in such a manner that asphalt is a product and reaches the market for highway use, that product becomes a construction material and the Btus in the asphalt are no longer available as energy.

It so happens that when the Btus in asphalt are included as "energy," computations indicate that the requirements for asphalt construction exceed those for equal areas of portland cement concrete construction. The picture is reversed if the asphalt Btus are not included as energy. In this case the computations indicate that portland cement concrete requires more energy. The asphalt industry and the portland cement industry are both quite concerned over the "image" created by publication of such comparisons, and each defends its own interpretation. However, to the highway engineer these figures have little meaning. The energy of transporting needed ingredients to a job site significantly changes both the costs and energy-use factors and could be the determining factor for many projects.

Although the question of whether the Btus in asphalt count as energy may be academic to the highway engineer faced with a decision on a given project, it is of importance to those concerned with overall national energy policies. Eventually a decision may be needed as to how best to use the total potential energy available to the United States. A complete discussion of the pros and cons of various decisions or policies regarding energy use was beyond the scope of this conference. I will note only that the decision as to what process will be used in refining a given crude is not made by the highway engineer. Technology is available to refine petroleums by "cracking" so that no asphalt is attained. Also, the same "heavy ends" can be used to make either heavy grades of commercial fuel oil or asphalt, and the balance between these two uses is controlled somewhat by the relative demands as well as other economic considerations. It is somewhat fortunate for the highway industry that certain restraints now exist that make infeasible the complete cracking of the heavy ends to increase production of gasoline or lighter fuel oils. Similarly, restraints exist that make it undesirable in view of antipollution requirements to burn all asphalt as a fuel. The chief factor in this regard is the sulfur content. Most asphalts contain combined sulfur that is extremely difficult to remove or cannot be removed by existing technology. Accordingly, existing regulations for maximum sulfur dioxide in exhausts cannot be complied with if such products are burned with present equipment.

In view of these restraints and with the knowledge that a substantial lead time is required to change refining processes, it appears that, barring political decisions to withhold imports of crudes, the supply of asphalt for highway construction will be adequate for the near future. However, the long-range possibilities are that greater energy demands will produce shifts in refining and combustion technology that will ultimately reduce the supply of asphalt available to the highway industry. At the present time it is not possible to predict how soon this will occur or what will be the total impact, but preparations should be made for this eventuality. We cannot sit back and wait for asphalt supplies to disappear before taking action. We must establish alternatives and conduct research or develop needed technology for making needed shifts in materials. In particular, the increasing cost of energy and the shrinking highway dollar make it imperative that all possible measures be taken to optimize use of energy and materials. Considerations must be given to both cost effectiveness and energy effectiveness. Under present circumstances the most cost effective may not be the most energy effective; but provided artificial restraints on the cost of energy are removed, eventually differences would likely disappear. It was also recognized that cost effectiveness would probably control highway decisions, unless regulations or political restraints are introduced.

The discussion brought out the following findings and recommendations.

CHANGES WITHIN EXISTING TECHNOLOGY

1. Optimize design. It was the consensus of all groups that design and specification requirements have not kept pace with the development of knowledge. Although much of the improvements that can be made in this area will relate to construction practices, important savings can be made in amounts of binder used and the energy required for their efficient use. For example, the principle of retaining large amounts of untreated material within an envelope of stable material such as portland cement concrete or asphalt concrete was discussed. The support provided by such "retaining walls" provides adequate saving in binder and, of course, money.
2. Eliminate artificial restraints. A factor relating to design changes is the need to review specification and procedures with the purpose of eliminating artificial restraints and of permitting alternatives based on cost or energy effectiveness. Contractors should be permitted to adjust their procedures to minimize consumption of energy as long as the product furnished complies with contractual requirements.
3. Use emulsions in lieu of cutbacks for tack coats. In this instance some regulatory pressures may be required. It was reported to the conference that in many areas the attitude of highway construction or maintenance engineers is that, as long as cutbacks are available, they will use them. On the other hand, asphalt manufacturers have taken the attitude that, as long as there is a demand, they will continue to furnish cutbacks. Continued use of cutbacks for tack coats as well as other purposes continues to waste the energy in petroleum distillate used (gasoline or kerosene) and to create air pollutants when evaporated.
4. Evaluate practices for crack sealing. Current sealing practices often result in a waste of materials and effort. Even though sealing may be desired and needed, present practices usually result only in temporary bridging of a crack with little or no beneficial effect.
5. Design asphalt mixtures to use less asphalt per volume unit of construction. Several possibilities exist. For example, larger aggregates that have less surface area to be covered with asphalt may be used. In other design variations, more filler may be added. In this case, asphalt plus filler would provide the "mortar" and less asphalt would be used for equal amounts of "binder" (considering the mortar as the effective binder).
6. Design portland cement concrete to meet the needs. Do not use greater thickness or higher cement content than is needed for the job.
7. Use fly ash or other available pozzolans in portland cement concrete. These products can be used to replace part of the cement. Such mixes should be designed and proportions properly selected. A one-for-one substitution, all other things being equal, may not provide the best product.

INNOVATIVE TECHNIQUES

1. Use recycling procedures that provide for making use of the asphalt in old pavements as a significant portion of the binding agent in the new pavement. Usually a special softening or rejuvenating agent is required. However, use of these techniques not only saves binder but considerable energy if accomplished with a minimum of hauling.

The energy of breaking up the old pavement and processing must, of course, be considered on the negative side when the overall effectiveness of such measures is evaluated.

2. Use special water reducing agents in portland cement concrete to provide equal strengths and performance with less cement. Recent results with these "super" water reducers indicate that full-scale trials are warranted.

3. Use combinations of stabilizing materials to provide improved performance with less material. For example, studies have shown that, with some heavy clays, an initial treatment with a small amount of lime followed by additional treatment with portland cement may be a more effective means of stabilizing such materials than treatment with equivalent amounts of either lime or portland cement used separately.

RESEARCH NEEDS

Discussions revealed that a number of things relating to binders are being tried and in the opinion of some were ready for implementation; but others believed more study was needed. Some of the major items are listed below.

1. Use of emulsion mixtures in lieu of hot mix. This suggestion has received widespread attention because of the apparent significant saving in energy by the elimination of aggregate and asphalt heating. However, most of the conferees agreed that we need to know more before this idea can be universally endorsed. We need to know more about the properties of the individual emulsions and the residual properties of the cured mixture. We need to have better knowledge of fatigue properties and other performance characteristics. We also need a better understanding of the energy trade-offs involved. Although savings of energy during actual mixing and laying may be evident, the loss to the driving public by longer traffic delays and possible adverse effects on durability must be assessed. In this regard NCHRP Synthesis 30, Bituminous Emulsions for Highway Pavements, brings together a wealth of knowledge that should be used as a guideline to develop further research and experimental construction that will provide needed answers.

2. Sulfur and sulfur-asphalt systems. Laboratory research and results of field studies in Canada and France show considerable promise for the use of sulfur as a significant extender for asphalt as well as a means of using otherwise unsuitable sands for aggregate. Field trials have begun in the United States, but a more widespread effort under different environmental conditions is needed. Handling techniques and equipment are also required. We also need to measure the possibility of long-term leaching or other environmental effects.

3. Special reinforcing additives for asphalts. The addition of rubber and other polymers to improve the performance of asphalts has been the subject of considerable research with uncertain results. However, the possibility still exists that useful additives can be found to significantly upgrade asphalt performance. One possibility now under study by a private company is the incorporation into the mix of pelletized carbon black that disperses into the asphalt during the mixing cycle. The resulting mixture is claimed to have superior "toughness" and abrasive resistance.

4. Better prime coats. Many who are willing to eliminate cutbacks as tack coats believe that the present available emulsions do not provide adequate primes. Consequently studies should be conducted both to determine more precisely the conditions under which prime coats are needed and to develop a better priming material, preferably an emulsion.

5. Performance of 2-layered portland cement concrete pavements. These consist of a lower portion made of local materials and less cement and an upper portion of high-grade concrete. One state is now planning to build such an experimental pavement.

GENERAL COMMENT

Throughout the discussions, one thought was repeatedly expressed: In any comparison of cost effectiveness or energy-use effectiveness, the total life of the pavement and the total effects on energy consumption must be considered. We must avoid changes that look good in the short run but result in loss of durability or traffic slowdown and tie-ups that ultimately waste both energy and money.

To assist in this type of evaluation, a careful systems analysis or decision analysis should be made to pinpoint those areas of promising payoff. The energy used in transportation construction in the United States is a relatively small portion of the total energy. Consequently, our efforts will have a minimal effect on the total energy picture. However, as a means of stretching the highway dollar, the energy and materials conservation measures will have a significant impact.

With regard to the future, demands for energy derived from petroleum (gasoline, fuel oil) will likely remain high or increase while existing supplies of petroleum are being depleted. The trend will likely be toward more complete refining by cracking suitable crudes and a consequent decrease of available asphalt. We will then be faced with the need to establish priorities to conserve the available supplies of asphalt for use in the more critical applications, such as use of asphalt in surfaces or for maintenance only.

In contrast to the probable ultimate reduction of asphalt supply because of petroleum depletions, the raw materials for cement manufacture appear plentiful. Exhaustion of specific deposits and quarries will, of course, occur but the basic minerals will always be available somewhere. The problem here will be one of production capacity which, one hopes, will increase as needed.

Accordingly it appears that the highway industry will be faced with the need to make use of hydraulic cements or pozzolanic materials in applications for which asphalts are now used. The needed changes should be controlled by the laws of supply and demand without arbitrary bans or regulations that could unnecessarily create economic and business hardships without accompanying benefits.

J. F. McLaughlin, Purdue University, chairman

Workshop Topic 2
QUALITY STANDARDS

The quality standards that have evolved for highway design, materials, and construction have reached their present state via a path that has been almost completely independent of energy considerations. The introduction of this new factor has an extremely disquieting effect. It is forcing us to examine those standards in minute detail, to develop better quantitative justification for the quality levels that are imposed, and to show relations to functional requirements during the life cycle of the system or subsystem. This is at best a difficult task and frequently an impossible task with currently available data as the only resource.

In the past we have sought excellence in highway design and construction and have not been overly concerned with the question, How good is good enough? except as prescribed by general design and by specification considerations dictated by level of service. The industry has done an excellent job according to the rules that have been in effect; but we now have new rules, not all of which are yet written. This is a dilemma but also an opportunity. We should focus on the opportunity because it gives us a chance to write the rules—and all who discussed this topic think that we should.

No one who participated in the discussions, and certainly not I, would suggest that realistic quality standards be abandoned or compromised. It was evident, however, that the introduction of the energy factor has catalyzed, and is bringing to an end point, a reaction that has been in process for several years. We recognize that "first energy" like "first cost" is, indeed, only the first step and that reduction of quality in initial design, materials selection, and construction standards may well result in life-cycle costs of all sorts—energy, money, and service—that are below optimum. However, phrases like "sacred cows in the specification book" and "gold-plated but meaningless requirements" repeatedly emerged in the discussion. A pervasive theme relating to research needs on quality standards could be identified:

> All states should be urged to review critically all of their geometric and structural design, materials, and construction standards and specifications to see whether there can be revision or elimination of those provisions that are unnecessary but consumptive of materials and energy.

This is research and not bookkeeping because we are asking ourselves to relate quantitative requirements with quality, life-cycle cost, performance, and energy and to justify the level demanded of the first in terms of what should be expected of the rest.

The details elaborating this theme consumed more than 9 hours of discussion and are not unimportant, but they are impossible to relate in a brief presentation. The following is a noninclusive list of some of these that may serve to illustrate the main point.

1. Materials specifications are too often applied on a statewide basis without recognition of real differences in availability. More flexible specifications coupled with design alternatives could be more economical in terms of monetary and energy expenditures.

2. The experience and initiative of the contractor must play a larger role in highway construction. Many examples of outstanding current practice in this area can be cited. End-result specifications head in this direction and need further development.

3. Several specific quality standards (design, materials, and construction) should be examined (or have been examined) because of the promise shown in reducing energy requirements. These include

a. Reduction in mixing temperature for asphalt mixtures;

b. Use of the drum drier;

c. Requirement of an aggregate blend that calls for the least volume of asphalt per unit of mixture;

d. Modification of thickness design requirement for full-depth asphalt pavement based on lower expected moisture content of the subgrade;

e. Use of plain concrete instead of reinforced concrete; and

f. Critical examination of energy spent on the cosmetic aspects of the roadside.

Safety and environmental quality are no doubt more sacred and have been subject to less quantitative justification than, for example, the minimum compressive strength of concrete. Since we are in a new ball game, let us examine all of the players in terms of the new rules. It is not beyond belief that some requirements that are relative to these aspects of highway design, construction, and operation and were developed in a system unconstrained by financial and energy consumption considerations are not consonant with current reality and need modification. If we are going to look at sacred cows, let us round up the whole herd.

The area of quality standards appears to have great if not the greatest potential for energy savings. Examination of standards might also have side effects that equal or exceed the energy conservation benefits.

Grant J. Allen, Arizona Department of Transportation, chairman

Workshop Topic 3
AGGREGATES AND OTHER MATERIALS

The 3 sessions concerning the use and purpose of aggregates and other materials consumed or exceeded the allotted time in each case without completely covering the field of aggregate design, production, and use. From the beginning, a need was felt for defining the use and purpose of aggregates to provide a guideline for the discussion. The definition accepted for the purpose of this workshop is as follows:

> Aggregate is a processed and graded material providing bulk and strength in transportation structures.

Although the title of this discussion refers to aggregates and other materials, because of time limitations, the other materials considered during the discussion were restricted to mineral fillers and materials closely related to aggregates. It was also agreed that the full life cycle of the system would be considered and the discussion should not be allowed to become locked into initial costs only.

An attempt was made to follow step by step the design, production, and use of aggregate materials and to evaluate the energy inputs involved along the way. It was decided at the beginning that any reasonable assessment of those inputs could be made only by considering an energy and cost analysis of each item to see what trade-offs might be possible.

The first consideration—and as it turned out, one of the most important—was the optimization of design for aggregates to make the best use of local materials. It was felt that, with regard to aggregates, the most effective way to reduce construction costs and in effect to conserve energy is to use local aggregates wherever possible. This use may well be limited to the lower levels of subbase, base, or surfacing where substandard materials are involved. Or it may be some measure of upgrading such aggregates by blending with other aggregates or perhaps the use of some type of additive for beneficiation. Standard quality aggregates locally available may also be upgraded reasonably and economically as a trade-off for the additional quantity that would otherwise be required. Because transporting materials plays such an enormous role in energy consumption, the location of a material source in proximity to the project is of prime importance. The cost incurred, whether by the contractor or by the contracting agency, in investigating all possible sources of material within reasonable limits of the project will usually yield big dividends. In many cases this will mean assessing the operational costs involved in opening up a new source and those involved in hauling longer distances from an established source.

Another important consideration is the effort necessary to produce a specified material from a particular source. Here the acceptance of a gradation allowing a somewhat larger size aggregate will in many cases reduce crushing costs and yield additional benefits such as lower binder requirements. Many contracting agencies are inclined to establish a grading requirement for a particular source and hold firm to the specification even though it might impose unduly high production costs. In most instances a slight modification of the gradation to more nearly fit a realistic production of the pit material can be effected without adversely affecting the quality of the product.

There are many situations in which "staged construction" or larger aggregate production contracts may well fit into the scheme of costs and energy conservation. For example, if a single source of supply must necessarily serve 2 or more projects, a single crushing operation in the pit should be considered. Planning and scheduling large movements of aggregates possibly by rail or waterway may also be considered.

Recycling aggregates to make use of existing materials that have often been entirely wasted is another consideration that will continue to demand more attention. Although these materials should be considered under the original design requirement to make use of local material, specific mention is made here since the use of these sources are rather new and innovative.

Other measures that may be of benefit in conserving materials and energy include, but are not limited to, the following:

1. Have uniform specifications for an area, i.e., do not require a material supplier operating from a single source to produce to meet the varying specifications of the several agencies who may be in the area (a more general use of existing AASHTO and ASTM specifications would be one means of accomplishing this);
2. Use lightweight aggregate, particularly those from natural extractions;
3. Place base and surfacing courses in lifts greater than conventionally used;
4. Have density requirements for base and surfacing courses rather than a prescribed rolling sequence; and
5. Provide for payment by plans quantity (volume basis) for base materials to reduce aggregate waste, which often is due to the inattention of the inspector.

In view of the foregoing possibilities, the following are some of the innovations that might be considered.

1. If recycling of existing asphalt pavement is possible, to what extent and how effectively can this be achieved in place? Is there equipment now available that can scarify, pick up this material, sufficiently reduce it to approximately its original particle size by means of traveling mixers or pulverizers or both, and remix it with an additional quantity of binder and perhaps flux oils to provide a recompacted base or surfacing course that will satisfy traffic needs for a reasonable period?
2. Can existing portland cement concrete be salvaged, crushed, and reused as aggregates for either flexible or rigid pavement construction? Recent reports point to the judicious use of materials that are usually considered substandard in certain elements of a composite pavement structure where less strength can be tolerated.
3. Will end-product specifications including statistical acceptance provide benefits? This type of specification has had some use, but have the benefits in measures of savings really been defined?

Research needs in the area of aggregate production and control include the following:

1. Improvements in methods of upgrading and using local aggregates ("sprinkle treatment" or blending of polish-resistant aggregates with local materials offers an alternative approach to maximizing the use of local materials); and
2. Examination of all quality test procedures and requirements currently being used for aggregates to determine whether the measured properties really relate to performance (new or modified testing procedures may be in order to prevent rejection of usable materials).

Lyndon H. Moore, New York State Department of Transportation, chairman

Workshop Topic 4 EARTHWORK OR EXISTING ROADWAY PREPARATION

Workshop participants concluded that earthwork is a promising area for achieving improvements in the use of materials and energy. Since 30 percent or more of the highway construction dollar is invested in earthwork, significant savings can be achieved by more efficient use of materials and energy and more effective design and construction procedures. These savings can contribute to increasing the miles of highway construction in an era of shrinking transportation budgets and continuing inflation.

A rational assessment of earthwork considerations on a nationwide basis must proceed from initial recognition of the wide range of physical characteristics of the native soil and rock materials involved. These properties also can undergo extreme changes when the material is subjected to environmental changes of moisture and temperature. The range of physical properties is far greater than that of processed and manufactured materials used in the remainder of the highway facility.

Workshop discussions included all phases of design and construction beneath the pavement section including earthwork, appurtenances such as walls and drainage, use of waste materials, and geometric design standards.

EARTHWORK DESIGN

Every transportation project ranging from new facilities to improving existing facilities should include sufficient subsurface explorations, testing, and analysis to determine the adequacy of the in-place foundation soils to support the proposed embankments, structures, pavement section, and cut slopes. For major projects on new location, the investigation should commence in the planning phase in order to identify areas requiring costly foundation treatment. Line shifts to areas of more favorable soil conditions may allow significant savings in foundation treatment costs. Summaries of best current practices are available in NCHRP publications (1, 2, 3).

An important factor in achieving economy in earthwork is use of on-site materials to minimize energy expenditure. Sufficient explorations and test data should be provided to the contractor during bid preparation to adequately define the soil properties for excavation and compaction considerations. Sufficient explorations should be made to accurately define soil and rock quantities where unclassified excavation items are used. Complete and well-organized subsurface data will reduce the "risk factor" that all contractors must consider when preparing bids on earthwork items and will provide the means for selecting the most efficient equipment for construction operations. Maximum use of on-site materials for embankment construction, granular backfill, subbase, aggregate, and stone filling for stream-bank protection will serve to reduce the energy used during construction. In some instances standard specifications may require modification to allow maximum use of on-site material.

A suggested area for research is improvement of procedures for investigation of cut-slope stability problems in earth and rock. Landslides in the United States annually cost an estimated $100 million to repair. Groundwater is a factor in 95 percent of these failures. Improved exploration methods are needed to define the location and movement of groundwater since effective groundwater control is in many cases the most economical and effective corrective solution. Also, research is needed to develop improved procedures for design of rock cut slopes and improved remedial measures for stabilizing existing unstable rock slopes.

EARTHWORK CONSTRUCTION

Workshop participants concluded that a nationwide improvement of earthwork construction specifications is probably the most significant measure that could contribute to optimum use of energy and materials in the earthwork area. In the last 25 years the construction equipment industry has provided earth-moving equipment with improved capacity and improved compaction equipment of various types. This equipment evolution has resulted in more efficient earth-moving operations requiring less energy per cubic yard of material excavated, placed, and compacted. However, there have been few changes in earthwork specifications allowing the contractor to place thicker lifts with fewer passes and use the increased capacity of the compaction equipment. Most states still limit loose lift thickness to 6 to 8 in. (15 to 20 cm). It is obvious that earthwork specifications have not responded to technical improvements.

In 1973, New York State adopted new earthwork specifications designed to accommodate the increased capacity of present compaction equipment and to allow a greater efficiency in construction operations. Maximum allowable lift thicknesses were established for each type and size of compaction equipment along with maximum speed and pass requirements. Acceptance of each lift is based on conformance with the above requirements, density test criteria, and the requirement that there be no rutting under the final pass on the lift surface. Under the new specification, the contractors have increased the loose lift thickness for plastic glacial tills to 12 to 15 in. (30 to 38 cm) and for sands and gravels to 15 to 24 in. (38 to 61 cm). In many cases this was less than the maximum allowed for the equipment. The contractor is also responsible for controlling the moisture content to achieve the compaction requirements. Both the transportation department and the contractors have been satisfied with this specification.

Another area in which traditional conservative practices were examined was preparation of the existing ground surface. A number of states have eliminated stripping of topsoil and removal of stumps where gradelines are higher than 6 ft (1.8 m). No adverse results were reported. Other suggested practices were elimination of compaction of ground surface under high fills and elimination of the practice of excavating shallow organic deposits until soil investigations are made. Many shallow organic deposits contain a small amount of organic material and will rapidly compress and be stable under the embankment weight.

Topsoil has been traditionally used on earth cut and embankment slopes to aid in establishing turf growth. In many states the topsoil operation has been eliminated, and adequate turf has been obtained by applying mulch and fertilizer during the seeding operation. The exception to this policy is along urban expressways where landscaping is an important consideration.

Disposal of logs and brush has become a problem in many areas that have no-burning regulations. Allowing the contractor to place and bury this material in the outer portion of embankment is a practical solution in several states.

Workshop discussions directed emphasis on the need for a number of research investigations to improve the efficiency of embankment construction.

1. Is there a more practical method of measuring soil densification than the moisture-density relation used for 50 years? A possible area that may be worthy of investigation is the modulus of elasticity. A rapid economical field test is needed to minimize delays to the contractor.

2. What degree of embankment densification is required to adequately support pavement and imposed loads? Can density requirements be varied with vertical elevation in the embankment section?

3. What cumulative changes occur in strength properties of in-place embankment soils that undergo annual cycles of environmental changes? What is the effect on pavement performance?

4. How feasible and efficient are earthmoving methods such as conveyor belt systems?

Participants emphasized the importance of providing a stable embankment surface at subgrade elevation. Sufficient strength must be provided to adequately support equipment for construction of the pavement. Adequate year-round subgrade support is a requirement for successful pavement performance as demonstrated by projects such as the AASHO Road Test.

When fine-grained soils are placed in the embankment at subgrade, they often have insufficient stability to support construction equipment. A number of states incorporate additives such as lime, cement, and fly ash or mixtures of lime and cement within the upper 6 to 12 in. (15 to 30 cm) of the embankment to increase the strength of the subgrade soil. It was concluded that the increased strength of stabilized subgrade soils could be considered in the total pavement design analysis in order to reduce the thickness cost of more expensive layers in the upper portion of the pavement.

Most pavement designers select subgrade support values prior to construction. Because of the variability of soils that could be found at final embankment or cut subgrade elevation, pavements could be overdesigned or underdesigned. In Colorado, strength tests are made on the soils from, or near, subgrade elevation during construction, and the pavement thickness is adjusted in the subbase layer to achieve a total pavement strength consistent with the pavement design procedure.

In some areas of the country, embankments are constructed with expansive clays. To reduce postconstruction swelling they are placed at moisture contents higher than optimum moisture. This causes difficulties in compaction and results in deep rutting. As a construction expedient, lime, fly ash, or cement is added in small quantities to increase stability and workability. Also, additives may be considered as a means to use on-site soils rather than haul borrow material from distant sources.

ROADWAY APPURTENANCES

Since nearly 10 percent of the highway construction dollar is invested in drainage, savings in materials and energy should be considered. Recently long-span corrugated plate structures have been introduced nationwide as a cost savings substitute for rigid structures. Since a portion of the strength of these structures is obtained from the pressure of the surrounding soil, there is a reduction in the amount of manufactured material needed.

Recent research findings in the area of pavement performance have emphasized the need for improved subdrainage in the pavement section. The use of plastic filter cloth and small-diameter pipe should be investigated from the standpoint of reducing trenching excavation quantities, underdrain filter quantities, and conduit material.

The introduction of reinforced earth wall construction in the United States has provided a positive method for reducing the materials and energy input for construction of earth-retaining structures. Horizontal metal strips incorporated into the backfill increase the internal strength of the earth mass and practically eliminate the horizontal pressure on the vertical wall component. Cost savings of this design compared with conventional wall designs have been in the order of 30 to 50 percent (6). Another recent innovation is the development of interlocking precast concrete units for wall construction.

In the last 5 years, temporary erosion controls have become an important consideration in highway construction. Plastic filter cloth can be efficiently used to replace stone for slope protection of temporary diversion channels. This material can also be used in temporary sediment retention structures to allow passage of water and retain soil particles as a replacement for graded filters composed of processed sand and stone materials.

The use of recharge basins in areas of permeable soils and low water table can provide a means of disposing of highway runoff with a savings in drainage pipe (4, 5).

USE OF WASTE MATERIALS

Municipal waste is the largest and most universal source of material that could be considered for use in highway earthwork. On a project in California, several hundred thousand cubic yards of sanitary landfill material has been successfully incorporated into earthwork grading by alternating layers of earth and refuse material. Sandy soil was blended with 6-in. (15-cm) layers of refuse and compacted by sheepsfoot compactors (7). Proposals have been developed in the New York City area to compress and bale municipal waste and haul the bales by rail to distant disposal sites. These wastes could be considered as a material source for embankment construction, based on a further investigation of the compressibility characteristics of the baled material. Fly ash has been successfully used as embankment material in Illinois. Consideration must be given to moisture control during placement. An earth protective layer is essential on the outer slopes to prevent water and wind erosion (8). Many other industrial waste materials that are hard and inert can be used for embankment material where they are economically available.

GEOMETRIC DESIGN STANDARDS

Workshop panels concurred that the volume of earthwork could be reduced significantly by modifying current geometric design standards. It is obvious that the major policy factor in this problem is safety; however, these considerations are included as a means of reducing materials and energy. Specific suggestions were (a) using steeper side slopes than those mandated by current safety standards and (b) altering grade and sight distance requirements to reduce earthwork volumes.

SUMMARY

The earthwork portion of the highway facility comprises probably 90 percent of the volume of material used in construction. More effective use of on-site materials, improved construction procedures, and use of new materials and methods for the construction of appurtenant structures will make a significant contribution to conservation of energy and materials in future highway construction.

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Workshop Topic 5
WASTE MATERIALS, BY-PRODUCTS, AND RECYCLED PRODUCTS

Expansion, rehabilitation, and maintenance of the transportation system are dependent on a supply of aggregate and binder. Projected aggregate requirements for 1985 are more than double the amounts for 1966, and binder requirements are also expected to increase significantly (1).

The demand for construction aggregates is increasing at a time when sources near urban and other high-use areas are being depleted, and the quality of available materials is either at a low level or becoming unavailable in certain locations because of mining restrictions, environmental protection regulations, and appreciating land values.

A restriction on aggregate and binder availability only recently recognized is that of energy. The primary binders used in paving materials are energy intensive and dependent to a large degree on the availability of natural gas and petroleum. Unfortunately natural gas and petroleum are now in short supply, and the forecast is for this supply to become more critical in the next 10 to 20 years. These critical supplies will almost certainly result in increased costs of primary energy sources, and thus the price of materials, such as binders, that are energy intensive will continue to increase. In addition, binders such as asphalt may eventually become a fuel source, provided the technology is developed to economically remove sulfur from the asphalt.

Although not so energy intensive as binders, aggregates require energy for removal from their source, crushing, sizing, transporting, placing, and compacting. Energy required by increased haul distances resulting from localized aggregate depletion may require that alternative aggregates be investigated.

Shortly before the widespread recognition of the short supply of energy, the concern for the environment became nationally important. A wide variety of environmental legislation was enacted with regard to air, water, and land pollution. One result of this legislation and subsequent regulation is finding suitable places for an abundant supply of waste products from industry, mineral processes, and domestic sources.

The purpose of the discussions conducted under topic 5 was to examine current and innovative practices and research needs concerning the use of wastes and by-products that result from industry, mineral processing, and domestic sources, some of which are now available because of air, water, and land pollution regulations. The reuse or recycling of road-building materials was considered within the scope of this topic. A summary of these discussions follows.

SUMMARY OF DISCUSSION

A recent NCHRP study conducted by Valley Forge Laboratories (2) delineated the types and amounts of waste materials that are potential replacements for highway aggregates. These materials have been classed in terms of industrial wastes, mineral wastes, and domestic wastes. Annually about 3.5 billion tons (3.2 Pg) of these solid wastes are being generated. The materials with the largest available tonnage include fly ash, blast furnace slag, steel slag, foundry wastes, coal refuse, copper tailings, dredge spoil, phosphate slimes, taconite tailings, and iron ore tailings. Another potentially large amount of waste solids may become available in the form of scrubber sludges as power generating facilities begin to use limestone scrubbers for SO_2 removal from stack gases. Many of these materials that exist in relatively large tonnages are located in areas away from urban areas. Thus, the available market is limited.

In addition to their use as aggregates and filler, many waste and by-products have potential use as a binder. Among the more important materials are sulfur and fly ash. Sulfur is expected to increase in supply because of the pollution-abatement programs and the necessity to burn the higher sulfur crudes and coals. Fly ash may be used as a partial replacement for portland cement and as a pozzolan in lime and portland concrete mixtures. Other potential binders may emerge from wood by-products in the form of resins or lignin or from pyrolysis of wood or other materials.

A list of 53 waste materials that have a potential for use as an aggregate, filler, partial binder replacement, or binder is given in Table 1. The probable use of each of the materials in terms of a binder or aggregate is shown together with annual quantity produced (if the information was available), extent of the material, assessment of additional energy required to use the material in the roadway, estimate of cost, potential use, and assessment of research requirements. A further notation indicates whether research has a likely long-term or short-term payoff. The assessment of energy requirements and costs to other materials is on a relative scale. Sufficient information for many of the materials was not available to complete the table.

The second major item discussed was that of pavement recycling operations. Two types of construction operations are in general use: in-place recycling and recycling through a central plant. Untreated and treated materials have been recycled by these construction operations. Treated materials are defined here as a chemically bound material. Table 2 gives the various types of pavement recycling operations and the present extent of their use. An estimate of whether the process can be implemented and the process and energy requirements costs are also given and are relative to other items within this table. Heater-planer, heater-scarifier, and heater-scarifier-remix operations have been used in many states and are included. Table 3 gives a list of typical examples of recycling operations in the United States.

CURRENT AND INNOVATIVE PRACTICES

Current regular practices in some portions of the United States are considered to be innovative in other locations. Historically new materials or a construction process is developed in one locale and refined in other localities before being widely accepted. For this reason those waste and by-product materials and the recycling operations that appear promising and are currently practiced in certain localities will be considered innovative, for the use of most of the materials and processes described above is not widespread in the engineering community.

The most promising binder systems from waste and by-product materials appear to be sulfur and fly ash. Relatively large quantities of these materials now exist or will exist in the future. Sulfur may be used as an asphalt extender or perhaps substitute or as a primary cementing agent. Fly ash as a pozzolan in portland cement and lime and cement stabilization appears promising and currently is in fairly widespread use. Promising aggregate substitutes appear to be blast furnace slag, steel slag, bottom ash, and mining wastes.

Recycling operations (Tables 2 and 3) are being used in certain locations. In-place recycling of untreated base courses has become popular on many maintenance and reconstruction projects. The use of heater-planers and heater-scarifiers is also being practiced on an increased scale in certain areas of the country. Recycling of pavement materials by techniques now practiced or that could be developed by short-term research projects must be considered as one of the more promising material and energy-

Table 1. Waste materials.

Material	Probable Use: Binder	Probable Use: Aggregate	Annual Quantity[a] (× 10^6 tons)	Extent of Material	Additional Energy Required	Cost	Potential Use	Research Required[b]
Sulfur-asphalt	X	X	NA	National	Low to moderate	Moderate	Probable	Yes, short
Sulfur-primary binder	X		NA	National	Moderate	High	No	Yes, long
Fly ash-lime-cement	X		32	Regional	Moderate	Moderate	Yes	Yes, short
Fly ash, sintered		X	32	Regional	High	High	Yes	Nominal
Fly ash, fill		X	32	Regional	Low	Low	Yes	Nominal
Mine tailings		X	NA	National	Moderate	Moderate	Yes	Nominal
Crusher wastes		X	NA	National	Low	Low	Yes	Nominal
Incinerator residue		X	10	Local	Moderate	Low	Yes	Yes, short
Rubber tires, granulated	X	X	3 to 5	Local	Moderate	Moderate	Yes	Nominal
Rubber tires, vulcanized	X	X	3 to 5	Local	Moderate	Moderate	Yes	Nominal
Waste glass		X	12	Local	Low	High	Yes	None
Blast furnace slag		X	30	Regional	Low	Moderate	Yes	None
Steel slag		X	10 to 15	Regional	Low	Moderate	Yes	None
Dry bottom ash		X	10	Regional	Low	Moderate	Yes	None
Bricks		X	NA	Local	Low	Low	Yes	Nominal
Tile			NA	Local	Low	Low	Yes	Nominal
Stack dust		X	NA	Local	Low to moderate	Low	Yes	Nominal
Stack dust	X		NA	Local	Low	Low	Probable	Yes, short
Resins and lignins	X		NA	Regional	Unknown	Unknown	No	Yes, long
Sulfate and sulfite sludges	X	X	5 to 10	Regional	Low	Low	Yes	Yes, long
Scrubber sludges		X	NA	National	Low	Low	Yes	Yes, short
Slag cements	X		NA	Regional	Moderate	Moderate	Yes	Yes, short
Waste oils	X		NA	National	Low to moderate	Low	Yes	None
Sulfuric acid	X		NA					
Salt water	Low		NA	Local	Low	Low	Yes	Nominal
Oil shale asphalt								
Plastic wastes	X	X	2.5 to 3.0					
Sewage sludge		X	8 to 10					
Wood chips and saw dust			NA					
Pyrolysis	X	X	NA	National	Unknown		Yes	Yes, long
Wet bottom boiler slag		X	5	Regional	Low	Moderate	Yes	None
Foundry wastes		X	20	Local	Low to moderate	Moderate	Yes	Yes, short
Alumina red and brown mud	X	X	5 to 6					
Phospogypsum	X		5					
Phosphate slimes		X	20					
Anthracite coal refuse		X	10					
Bituminous coal refuse		X	100					
Asbestos tailings		X	1					
Copper tailings		X	200					
Dredge spoil		X	300 to 400					
Feldspar tailings		X	0.25 to 0.50					
Gold mining waste		X	5 to 10					
Iron ore tailings		X	20 to 25					
Lead tailings		X	10 to 20					
Nickel tailings		X	NA					
Phosphate slag		X	4					
Slate mining		X	NA					
Waste taconite tailings		X	150 to 200					
Zinc tailings		X	10 to 20					
Smelter waste		X	NA					
Building rubble		X	20					
Ceramic wastes		X	NA					
Rice hulls								
Concrete pipe								

Note: 1 ton = 907 kg.
[a]NA = not applicable. [b]Short or long indicate whether the research has a short- or long-term payoff.

Table 2. Recycling operations.

Recylcing: From	Recylcing: To	Construction Operation	Extent of Use	Implement	Energy Required	Relative Cost
Untreated base, subbase, and thin surface	Untreated base	In place	Common	Yes	Low	Low
	Treated base	In place	Common	Yes	Low	Moderate
	Untreated base	Central plant	Rare	Yes	Moderate	High
	Treated base	Central plant	Rare	Yes	High	High
Treated base, subbase, and thin surface	Untreated base	In place	Common	Yes	Moderate	Moderate
	Treated base	In place	Common	Yes	Moderate	Moderate
	Untreated base	Central plant	Rare	Yes	Moderate	High
	Treated base	Central plant	Rare	Yes	High	High
Asphalt-aggregate surface mixture	Untreated base	In place	Common	Yes	Low	Low
	Treated base	In place	Common	Yes	Moderate	Moderate
	Untreated base	Central plant	Limited	Yes	Moderate	High
	Treated base or surface	Central plant	Rare	Yes	High	High
Portland cement concrete surface	Untreated base	In place	Limited	Yes	Low	High
	Treated base	In place	Rare	Probably	High	High
	Untreated base	Central plant	Limited	Yes	Moderate	High
	Treated base or surface	Central plant	Limited	Yes	High	High
Existing base, subbase, and thin surface plus new material	Untreated base	In place	Limited	Yes	Moderate	Low
	Treated base	In place	Limited	Yes	High	Moderate
	Untreated base	Central plant	Rare	Yes	Moderate	High
	Treated base	Central plant	Rare	Yes	High	High
Heater-planer		In place	Common	Yes	High	Moderate
Heater-scarifier		In place	Common	Yes	High	Moderate
Heater-scarifier-remix		In place	Common	Yes	High	Moderate

conserving techniques available to the transportation engineer.

RESEARCH NEEDS

A number of areas in need of research were identified. Table 4 gives a list of recent, ongoing, and proposed research projects in the general area of waste materials and recycling. In general the majority of research effort should be expended on those materials that are in large national supply and are promising aggregate replacements and binder supplements or primary binders. Sulfur research efforts, therefore, appear to be essential and should continue as scheduled. The needed research in the sulfur area should be focused in the following areas:

1. Use of sulfur as an asphalt extender or supplement, mineral filler, and primary binder;
2. Development of equipment to handle sulfur-aggregate systems; and
3. Use of foamed sulfur.

Fly ash is another promising binder. Substantial research has previously been conducted in this area. Implementation and resolution of certain problems unique to particular fly-ash supplies are needed. The use of lignins and sulfites as binders needs long-term research efforts.

Promising research associated with aggregate replacements is in the areas of fly ash, bottom ash, blast furnace slag, steel slag, and mining wastes. Although these materials are now being used, optimization of their use in terms of material and energy conservation has not been intensively explored. Since conventional aggregate supplies are ample at the present time in many areas, the use of wastes and by-products must be justified for each case on both an economic and an energy basis.

Quarry by-products including fines offer potential for use in the pavement provided existing specifications are reviewed and altered to permit their use if performance is not sacrificed. As much as possible of the products produced from a given aggregate source should be used in an acceptable manner so that both materials and energy can be conserved.

Recycling operations are in need of research programs to improve both in-place and central plant recycling equipment. The biggest need for in-place equipment is to develop a pulverization system that does not need constant repair. This is particularly critical when surfacing materials are pulverized. Air pollution problems associated with hot, central plant recycling of asphalt concrete pavements must be solved and one hopes this can be done by minor changes to existing equipment. Energy requirements and costs associated with various recycling operations must be determined to provide the necessary input to the engineering community.

Another potential research program considered to be of importance is that of determining when a rejuvenating agent is to be added to the recycled asphalt mixture, what type, and how much. Private industry should develop materials; however, testing and evaluation techniques should be developed by public agencies.

Suggested research projects of a more general nature include

1. Pavement design concepts that consider rehabilitation,
2. Energy requirements and costs of various rehabilitation alternatives,
3. Identification of materials suitable for recycling,
4. Energy and material-efficient pavements, and
5. Alternative binders from renewable resources.

Pavements should be designed such that rehabilitation techniques are energy efficient and inexpensive as possible. The pavement may have to be designed such that the surface is the weak link in the structure since repair can be effected most easily at the surface. For example, ways to design and construct the surface material for easy recycling should be investigated. The energy requirements and costs for various re-

Table 3. Recycling projects.

Type of Material Recycled	Location of Project	Use of Aggregate	Remarks	Reference
Unstabilized base course	Florida	Unstabilized base		4
	Michigan	Stabilized base		5
Stabilized base course	Wisconsin	Unstabilized base	No. 8 wire mesh also processed to meet specifications	6
	Texas	Asphalt stabilized base		19
Portland cement concrete	Michigan		Predict improved skid resistance and stronger pavement	7
	District of Columbia	Aggregates in general		8
	California	Stabilized base, untreated base	Compaction tests showed crushed rubble is superior to many plant-run aggregates	9
	Wisconsin	Untreated	Crushed old paving brick	6
	California	Lean mix cement base	Excess air in mix required use of de-air-entraining agent	10
	Texas	Asphalt stabilized base		—*
	Texas	Asphalt stabilized base, asphalt concrete	Some air pollution problems experienced	3
	Texas	Asphalt stabilized base, asphalt concrete seal coat	Old airfield pavement used	—*
	Texas	Asphalt concrete seal coat	Aggregate was produced at a cost less than conventional aggregate	11
	Louisiana		Old pavement was broken, seated, and overlaid	12
Asphalt concrete	California	Stabilized base	Metradon pulverizer used	14
	Indiana	Asphalt stabilized base	Some air pollution problems experienced	—*
	Iowa	Asphalt stabilized base		6
	Utah	Asphalt concrete surface course	Some air pollution problems experienced	—*
	Massachusetts	Base material for runway	15 percent cost savings over conventional methods	13
	Nevada	Asphalt concrete surface course	New plant used that eliminates air pollution	15
			Substantial fuel and materials savings, reduced oxidation of asphalt	16
			No environmental problems	17
			Little difference in recycled and new asphalt concrete	18
	Texas	Asphalt concrete surface course	Drum mixer used	—*
	Texas	Asphalt stabilized base and asphalt concrete	Air pollution problems encountered with both conventional and drum mixer plants	25
	Texas		Cold process	—*

*Information obtained from private communication or unpublished documents.

Table 4. Summary of research in the area of waste materials, by-products, and recycled products.

Agency	Status or Year Started	Title
FHWA	Completed	Highway Litter in Highway Construction and Maintenance
FHWA	Completed	Sulfate-Fly Ash-Lime-Aggregate Mixtures at Dulles Airport
FHWA	Completed	Production of Synthetic Aggregate From Municipal Incinerator Residue
FHWA	Completed	Rubber-Asphalt Binder for Seal Coat Construction
FHWA	Under way	Incinerator Residue in Bituminous Base Construction
FHWA	Under way	Lime Treatment of Incinerator Residue for Base
FHWA	Under way	Technology for Use of Waste Sulfates as Aggregates and Binder
FHWA	Under way	Technology for Use of Incinerator Residue as Highway Material
FHWA	Under way	Use of Waste Sulfate for Remedial Treatment of Soils
FHWA	Under way	Power Plant Bottom Ash in Black Base and Bituminous Surfacing
FHWA	Under way	Availability of Mining Wastes and Their Potential for Use as Highway Material
FHWA	Under way	Production of Synthetic Aggregate by Fusion of Incinerator Residue
FHWA	1975	Advanced Technology Materials Applied to Guideways, Highways, and Airport Runways
FHWA	1975	Extension and Replacement of Asphalt Cement With Sulphur
FHWA	1975	Demonstration Project on Recycling of Asphalt Pavements
FHWA	1976	Evaluation of Wood Resins and Lignins as Substitutes for Asphalt
NCHRP	1976	The Reuse of Materials in Pavement Rehabilitation
NCHRP	1976	Upgrading Poor Performance Aggregates for Use in High Type of Pavements
FHWA	1977	Materials and Techniques for Improving Engineering Properties of Sulphur
FHWA	1978	Rapid Removal Methods for Portland Cement Concrete Pavement
FHWA	1978	Equipment for Economical Recycling of Highway Materials for Maintenance
FHWA	1978	Development of Pilot Manufacturing Process for New and Improved Aggregate
FHWA	1978	Development and Design of Flexible Sulphur-Concrete Paving Mixtures
FHWA	1978	Development and Design of Rigid Sulphur-Concrete Paving Mixtures
California	Under way	Fill Stabilization With Nonbiodegradable Wastes
Arkansas	Completed	Production of Binders and Fillers From Cellulosic and Man-made Polymeric Wastes Generated in Arkansas
North Dakota	Completed	Laboratory Evaluation of Lignite Fly Ash in Portland Cement Concrete
Arizona	Under way	Utilization of Waste Boiler Ash in Highway Construction in Arizona
Arkansas	Completed	Use of Fly Ash as Fill and Base Material in Arkansas Highways
Arizona	Under way	Investigation of Chemical and Physical Properties of Rubber-Asphalt Mixtures
Texas	Under way	Engineering, Economy, and Energy Considerations in Design, Construction, and Materials

habilitation alternatives, including the use of recycling, waste materials, overlays, and heater-planing, must be determined to allow the practicing engineer the opportunity to optimize design and rehabilitation alternatives. Not all materials and pavements are suitable for recycling. The recycling technique must match the rehabilitation need. For example, a bituminous-stabilized base that has water susceptibility problems should not be recycled without some type of acceptable treatment. Heater-planer and heater-scarifier operations are limited in their application, and these limitations should be defined. Projects 4 and 5 above were considered by other groups, and details are not presented here.

CLOSING REMARKS

Waste materials, by-products, and recycling operations offer energy, material, and cost-saving alternatives that can be immediately implemented. Additional research is required to optimize certain uses and to develop others as outlined above. Perhaps the single biggest need is to implement what is currently practiced.

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Workshop Topic 6 PRODUCTION AND CONSTRUCTION TECHNIQUES

The 3 groups that discussed this topic perceived the objective and approached the problem from different angles, but generally came to the same conclusions. The discussion, which centered on 3 main subject areas, is summarized below. The order of listing under each heading does not indicate any priority of importance.

ACCEPTABLE CURRENT PRACTICES AND TECHNOLOGY

1. Permit higher moisture contents in aggregate and lower mixing temperatures in a conventional hot-mix asphalt plant.

The range of moisture and temperature should be similar to that used in dryer-drum plants. This is now being done in Oregon. Several times during the discussion the use of dryer-drum mixers was described as an accepted practice. Dryer drums are apparently being permitted by all the states when a contractor requests their use in areas where there are a large number of fixed plants. However, dryer drums are not expected to come into widespread use in the near future.

During the discussions, the question was raised as to whether the higher moisture contents and lower mixing temperatures used in the dryer-drum mixer process could also be used in the conventional hot-mix plant operation. Everyone agreed that the moisture content of in-place hot-mixed material is much higher than the moisture content of the freshly mixed material. Oregon engineers examined this question and decided that the higher moisture contents in conventional hot-mix plant operation probably would not affect the mix most of the time. Consequently, they are not requiring the usually low moistures that have been prevalent in conventional hot-mix operations. They are also permitting mix temperatures as low as 190 F (88 C). All of this is being done with apparent successful results even in areas where the humidity is high most of the time. The main control being exercised is to reject the truck load of mix showing obvious deficiencies because of excess moisture in the mix.

2. Permit uniform width ramps on interchanges with tapered ends to be defined by paint or seal coats.

The construction of interchange ramps is an expensive operation because of the long delays required. Because this is slow work, energy is undoubtedly unnecessarily expended while the pieces of equipment have to wait. Participants in the discussion speculated that, if the interchange ramps could be placed in a uniform width, using the same slip-form equipment as is used on the main line, the whole operation could be speeded up. This would result in fewer delays during construction, a smoother ride on the finished surface, lasting benefit to the driving public, no apparent loss of efficiency, and possible lower cost.

3. Standardize repetitive dimensions on bridge designs to permit maximum reuse of forms.

Bridge contractors have long made the point that designers have failed to standardize repetitive dimensions on things such as columns, footings, beam spacing, bridge curbs, and bridge skews. All of these things cause waste of form lumber, of specially built metal forms, of carpenter time, and of energy used for air compressors, portable generators, and other pieces of equipment used in the operation. Standardizing many of these dimensions would not affect the appearance of the structures and could well result in considerable saving of material and possible saving of energy.

4. Permit surfaces for structural concrete to be painted with epoxy, acrylic, or other plastic materials instead of being rubbed.

Although epoxies, acrylics, and plastics are energy intensive, the amount of these materials needed to coat concrete surfaces is relatively small. There is also considerable energy involved in running air compressors or portable generators for long periods of time during the slow, laborious process of rubbing concrete surfaces. In addition, many felt that the process of rubbing structural concrete reduces the durability of the surfaces and results in a loss of material effectiveness. The other obvious alternative, of course, is to eliminate any surface treatment of the structural concrete.

5. Reexamine hot-mixed asphalt lift thickness requirements to reduce passes with lay-down equipment and permit maximum use of vibratory rollers.

Many states and contracting agencies have limitations on lift thicknesses for hot-mixed asphalt that may be a result of historical problems caused by low plant production, underpowered pavers, or compaction difficulties due to the types of rollers being used. There has been a rapid development in all of these types of equipment, and the maximum lift thickness should be determined after attempts have been made to place much thicker lifts using equipment currently available.

6. Reexamine restrictions on cold weather construction to determine whether changes are possible as a result of recent equipment developments and protective materials now available.

Because of the need to complete many projects, much work is done during the cold weather season. Working during cold weather allows maximum use of equipment and reduction of peak load demands on equipment manufacturers, material producers, and labor. Spreading the use of equipment and labor over a longer time period is certainly more efficient. Most of the cold weather specifications were prepared for protective materials used during World War II. Since then, plastic insulation with extremely long surface life and equipment that permits cold weather operations with no sacrifice in quality of the finished work have been developed. A complete reexamination of the specifications is not advocated, but a serious review of the efficiencies of these new methods should begin as soon as possible.

7. Develop procedures to routinely use hydrated lime and quicklime, cement, fly ash, and other available products to modify or stabilize earth materials in subgrade locations or in areas that will permit work to continue in wet weather or in wet materials found on the site.

The availability and suitability of agents such as quicklime, fly ash, and conventional additives have opened up new possibilities for continuation of construction work during inclement weather. In addition, there is a growing belief among many engineers that subgrade stabilization or strengthening of the earth support of pavement structure is a necessary element in proper pavement design. The possible benefits to be gained from procedures for inexpensively strengthening the earth subgrade are exciting. More practical effects include solving availability problems, providing readily available trucking facilities for these materials, and providing an opportunity for the contractors and engineers in the field to gain experience and understand the use of these materials. Contractors have said many times that the states will save money in the overall construction cost when they agree to provide a stable working platform that the contractor can use as a haul road and as protection against rains, which cause delays in construction operations and associated loss in money and wasted energy.

8. To minimize equipment delays, use nuclear density gauges and nuclear moisture gauges on a routine basis for inspecting and accepting materials.

The construction operations today move at a much faster speed than those of a few years ago. The equipment is more sophisticated, the materials are better understood, and production schedules require a rapid construction operation. The contractor can no longer be expected to wait several hours for a test result that will determine whether a large-scale operation can be continued. Energy is wasted when equipment is idling. Demonstrations have shown that nuclear equipment can be used for many construction control tests, and states or contracting agencies should make the maximum possible use of this equipment. It reduces the costs of personnel, equipment, and materials and delays to the contractor. Information on the types of tests that can be made with nuclear equipment should be made available to all states so that they can use this equipment without a long introductory period.

9. Permit surge bins and storage bins for hot-mixed asphalt so that plant capacity is fully used and permit minor plant adjustments so that truck fleets are more fully used.

The batch hot-mix plant appears to be the predominant type of equipment used in the United States. This type of plant results in periodic delivery of the mix and a set amount of material being ejected from the plant at any time. These and other factors cause problems in scheduling trucks and fully using their carrying capacity. The use of surge bins or storage bins between the plant and the truck provides a flexibility to the plant operation so that the truck fleet is fully used and energy is not wasted. Information on methods for using these bins should be made available to all states and contracting agencies so that regional restrictions will not be placed on their use because of unfamiliarity with them.

10. Make greater use of in-place mixing of on-site materials.

One of the results of the development of sophisticated equipment appears to be elimination of in-place mxing of on-site materials. A few years ago a common sight was a traveling mixer incorporating cement, lime, bituminous materials, and water into materials that existed on the site. Although this type of operation is inexpensive, provides exceptional uniformity, and likely uses a low amount of energy, it is seldom used now because of the availability of more sophisticated equipment and the tendency to require an imported aggregate. The structural capacity of the facility that is being built should determine whether improved methods are needed. Engineers should examine the product desired to make sure that it cannot be built by using the old-fashioned but still effective methods.

11. Provide specifications to permit and encourage slip-form placement of barrier walls, bridge curbs, curb and gutters, and other miscellaneous items.

The use of the slip-form paver has had difficulty in gaining approval throughout the country, but now appears to be universally accepted. Experience has shown that the items mentioned above, which are built of concrete or hot-mixed asphalt, can be formed, consolidated, and finished effectively with a slip-form operation. Specifications should be examined to remove any restrictions to this type of operation. The last paragraph of article 108.05 in the AASHTO guide specifications adequately covers the possibility for changes in operation by the contractor.

12. Provide stability in the work program from year to year and in the types of work and specifications.

The items of construction progress and specifications appear to be highly related to the energy use of a contractor. Workshop participants, however, indicated that the overall operations of a construction contractor are seriously affected by fluctuations in the type of work being advertised on lettings and by sudden chances in major specifications. These large variations make it difficult for the contractor to plan equipment purchases, organizational changes, and operating capital needs and to retain supervisory personnel who understand the state's specifications. Major changes in any of these items may require complete change in equipment types, relocation of contracting operations, opening or closing of quarry operations, and resultant loss of money, time, and energy in making all of these adjustments.

INNOVATIONS THAT MIGHT BE TRIED

1. Design bridge decks that will permit pavement operation to be continuous across the structure to eliminate costly approach construction and lost time in

moving across or around the structure with equipment and materials.

For many years, a problem throughout the country has been the bump at the end of the bridge. No state has completely and successfully solved this problem although a large amount of money is spent every year in attempts to solve it. In addition, the serious hindrance to continuous paving is the necessity to move equipment and materials across a bridge or around it. The state of Texas, among others, has tried the innovation of continuing the regular pavement operation across the structure. This pavement probably does not provide any structural support to the bridge and, in fact, may cause an additional dead load to the bridge. To determine whether there is a saving in energy with this type of operation will require much more experience with it.

2. Design bridge decks to use precast, prestressed thin concrete panels to serve as bridge deck forms and also as part of the load-carrying capacity of the bridge.

Several bridges in the state of Texas and elsewhere have been constructed with precast panels, which offer the possibility of continuing work during inclement weather and also eliminate time-consuming operations at the job site. In addition, both the amount of concrete and the amount of steel placed at the job site are reduced. The result is a saving of time, and an investigation should determine whether there is a saving in energy.

3. Adapt high-pressure water tunneling excavation technique to roadway rock excavation operations in urban areas.

The successful use of high-pressure water tunneling is relatively new and is still being developed. If successful, the process may be adaptable to roadway rock excavation in urban areas or in areas where explosives are not usable because of objectionable noise from the rock drills and damage from blasting. This high-pressure water method might require a large amount of energy, but it could well be energy in a form more available than that used in blasting.

4. Use laser beams for grade and line controls on excavators and pavers.

Use of laser beams with curvilinear alignment might require minicomputers to control grade properly.

5. Build dense mats or bituminous base courses with emulsion.

This will provide an opportunity to gain experience regarding aggregate-emulsion compatibility, effects of weather conditions, emulsion consistency, effect of water quality, effect of crude base on emulsion, and possibility of making emulsion on site immediately before use to eliminate the need to transport large water quantities.

6. Adapt aggregate dryers to burn coal.

A contractor in Texas is working on the use of coal to provide heat in the aggregate drier for a hot-mix plant operation. The coal is burned in a powdered state and in a controlled atmosphere. This type of burner is difficult to start but has no serious technological problems. Power plants throughout the country are using this type of burner to power generators, and an Ohio contractor stated that his company's asphalt plants have used coal as a power for dryers. Whether the Btu requirement is any less and may, in fact, be greater is not known, but the trade-off from a scarce energy source to a readily available energy source might have great advantages.

APPLICABLE RESEARCH NEEDS

1. Develop ways to minimize handwork wherever it is still performed.

Elimination of handwork at first glance may not appear to offer any savings in energy, but the use of handwork in construction operations seldom occurs by itself. Handwork in a construction operation usually occurs in the middle of the massive mechanized operations. The handwork also is, in many cases, not so exact or reproducible as mechanical work. Eliminating handwork would reduce energy loss in preceding and subsequent operations that are delayed or made less efficient by handwork.

2. Determine the maximum thickness of hot-mixed asphalt that can be successfully placed under various conditions and applications.

Workshop participants had various opinions as to the proper dimensions for the maximum thickness of hot-mixed asphalt that could be placed. Many limitations and present specifications do not appear to be based on actual field experience. The result is that equipment may be underused or that additional energy is being used to provide aggregate at a smaller size merely for the purpose of accommodating a thinner lift. In addition, the capability of pavers or rollers may be wasted if they are never used to maximum capability.

3. Develop a test method to measure consolidation of concrete to permit proper use of consolidation equipment, maximum paver speed, and proper finishing methods that will ensure good rideability and skid-resistant pavement texture.

4. Determine objective and reproducible tests to measure noise, air quality, water quality, and safety requirements that give proper attention to energy and material requirements to attain standards.

5. Develop methods, equipment, and additives to permit more efficient drying of earth materials being placed in compacted embankments.

It became obvious during the discussions that the problem of drying earth materials is a major deterrent to construction progress. Much of the time spent on a construction project is consumed during the building of the earth embankments or earth cuts. This operation is almost totally dependent on the weather for any drying action that occurs in the material. Excavating wet material and pulling disks or tillers through it require a great amount of energy. An improved method might require more money or materials, but it may save energy.

6. Make a complete systems analysis of quarry operations or crushing operations in the production of aggregates to determine the energy requirements needed for various gradations and quality of aggregates so that energy needs of aggregates can be considered during specification preparation.

7. Update the report on fuel usage factors.

The report could be enlarged by the TRB Committee on Construction Equipment to include other features that users might find desirable.

8. Prepare a state-of-the-art report on performance specifications or end result specifications.

This report would demonstrate where this type of specification could best be used and would also discuss the amount or type of data base needed for implementing successful performance specifications.

CLOSING REMARKS

The 3 major ideas that resulted from discussions under this topic are

1. Using higher moisture contents and lower temperatures in a conventional hot-mix plant,
2. Burning coal in an aggregate dryer, and
3. Developing a state-of-the-art report on performance specifications and associated data base.

John L. Beaton, Sacramento, chairman

Workshop Topic 7
NEW PRODUCTS AND PROCEDURES POST-1985

The workshop objectives were to consider energy conservation by (a) identifying acceptable current practices and technology, (b) suggesting innovations, and (c) delineating applicable research needs. Participants in this discussion group decided that item a was not applicable to this topic. In addition, transportation construction was viewed in the broadest sense, covering the planning, design, building, operation, and maintenance of transportation construction. Another point of broad policy determined by the group was that, in the design of a highway, the energy requirements should be determined for the entire life of the project and not just for the construction phase. In other words, operational and maintenance energy requirements including vehicle operating needs should be considered. The following is a summary of the group discussions supplemented by the workshop chairman from other sources of information.

1. At present a great deal of general information has been published on the energy requirements of producing certain items of construction. Unfortunately, there is insufficient detailed information on which local discussion can be based. For instance, if a designer were to make a selection of materials for a roadway structural section on an energy basis rather than cost, he or she would have to know the exact energy use to produce each item used in that locality. Such information should be gathered on a local basis.
2. Any comprehensive transportation plan requires that decisions be made concerning the mode to best serve any particular corridor. For such decisions to be made on an energy basis, the basic energy demands or the factors involved should be determined for each mode of transportation.
3. Research should be initiated into the energy requirements of moving heavy loads by highway trucks to determine optimum energy versus load information. This should include data to determine the effects of varying load and speed. This systems research should include the effect on energy usage by both heavy and light vehicles of various degrees of pavement roughness.
4. Assuming that a pavement structure will transmit wheel loads to the earth well into the twenty-first century, then research should be initiated to discover a completely new binder to use with rock products to create hard surfaces for vehicular traffic. The structure should be distortion free, relatively inelastic, and water resistant; have no latent energy; and provide a surface with low maintenance requirements and good skid and tractive resistance. The materials should also provide a permanently smooth grade but be subject to grade adjustments.
5. Research should develop a low energy material with no latent energy for quick traveled-way maintenance repairs. This could either be precast or cast in place. Because of high energy losses during traffic delays, the material must minimize such interference.

6. Research is needed into the energy expenditures of the total transportation system. Such information is needed to make objective decisions. For instance, should a passenger train be subsidized in parallel competition with a highway, or should an industrial highway be built parallel to a railroad line?

7. Research should be done on the possibility of using asphalt pavements as solar cells to create transportable energy available at the roadside.

8. Management research should develop a procedure to optimize cooperation among those who are involved in the transportation industry: manufacturers, labor unions, government representatives, engineers, planners, teachers, and students. This is the only way that the use of energy can be minimized in the complete system.

9. Insufficient funding is available to complete the research needed to prepare for a petroleum-short society. Available funds should be markedly increased. Estimates vary from fourfold to tenfold.

William B. Ledbetter, Texas A&M University, moderator

GENERAL DISCUSSION

JOHN L. BEATON: In the motion picture shown during the workshop, reclaiming of reinforced concrete pavement was difficult because it was full of steel. Why do we put steel or even dowels in concrete pavement? In California there are miles and miles of good unreinforced and nondoweled concrete pavement on every type of soil and in every type of weather condition that exists in the United States. There are no problems with it. Reinforcing steel consumes energy when it is made, when it goes into the pavement, and when it comes out of the pavement.

LEDBETTER: This question must be asked not only about steel in concrete but also about every design, construction, and maintenance decision we make in light of the impending energy shortages that we are going to face in this country. Every decision that we have made during the past 30 to 50 years in the transportation field is going to have to undergo careful scrutiny in the 1980s. The question is an appropriate one. The answer must be given after appropriate study of this question as well as of all the other questions related to this overall energy and materials optimization.

W. S. MENDENHALL: One report recommended that larger size aggregate be used to decrease the amount of binder used. Another recommended that more mineral filler be used to fill up the void so that less binder would be needed. Is there a conflict here?

GRANT J. ALLEN: Benefits have been derived from design with larger size aggregates in terms of reduction in amount of binder. This has not been a great reduction, but there is some benefit. We would not, on the other hand, put in mineral fillers to inhibit in any manner the reduction that we could get from a proper gradation of the larger size aggregate.

WOODROW J. HALSTEAD: I believe that we are talking about a different mix design in each case. The suggestion that additional filler be used is based on designing a mix in which one has a given percentage of voids in the aggregate and, rather than filling the void with asphalt only, one partly fills with filler; that is, the asphalt plus filler forms the binding mortar. The alternate suggestion, which seems contradictory, is to use larger aggregate, which means that one has less total surface area to cover with the asphalt. I believe that the significant point to be made is that we should look at each individual type of mix design to decide how best to minimize asphalt usage.

ROBERT D. SCHMIDT: A question that arose in my session about producing aggregates was whether it is true that the least energy required will result when the largest rock possible is produced in the plant. Put another way, the larger the rock produced and the less crushing required result in less energy used. Generally the producers agreed that the largest size gradation that one could possibly call for would result in less energy requirement. However, there was disagreement when this was considered in the ultimate use of this large rock in the finished product. Primarily the discussion was about an asphalt mix, but there was a definite disagreement as to whether this would really result in an end saving of energy by using larger rock. This is one of the reasons for the recommendation that a complete system analysis be made of producing operations to find out where the energy requirements were. The producers did not seem to know how much energy is required to produce a 4-in. (102-mm) rock versus a ½-in. (13-mm) rock.

CHARLES R. FOSTER: The reason is that the larger size rock increases the unit weight, and this applies to untreated base course as well as to hot mix. A typical unit weight for a ½-in. (13-mm) top size surface course is 144 lb (65 kg). A typical unit weight for a 1½-in. (38-mm) top size binder course with essentially the same gradation will be 150 lb (68 kg) so that, although a little may be saved on crushing cost, the additional 5 or 6 percent stone has to be processed all the way through.

VAUGHN MARKER: Larger stone may be less energy consumptive than smaller stone, but in many places in this country one can dig a hole and not find any stone more than 1 in. (25 mm) in size. I think the significant thing to stress is the importance of designing a mix around materials that are locally available. It may not always be true to say that using a larger rock is more economical or energy efficient. It might be true if the larger rock is available; but, if it must be hauled in to accommodate the so-called energy conservation in the mix itself, the energy cost of hauling may exceed the energy conservation of the mix design.

VERDI ADAM: Instead of saying the larger size rock, I would like to change it to the lowest degree of crushing because, if one has small gravels, one wants to crush them to consume the least amount of energy. Therefore, it might be better to use the term, perhaps, the lowest degree of crushing rather than the larger size rock.

Schmidt mentioned that we should use uniform width ramps on interchanges. I agree, but what are the effects of these on energy consumption if it will use more energy and more materials? And with regard to masonry coatings, I do not see the relation between energy and materials in the use of masonry coatings. I am a proponent of using masonry coatings for bridge finishes rather than rubbing, but I do not see the relation between energy savings and such coatings.

SCHMIDT: I may not be able to answer that question because I did not make that suggestion but reported it. In addition, the subject was never really resolved in our discussions. We all had different opinions, but I am sure you could develop a relation between money, time, and energy. If something costs more money, it costs more energy, at least in some relation. If it costs more time, it costs more energy. That was the basic reason for this type of suggestion. People in the industry felt that certain things were costing either a lot of time or a lot of money and, using the rationale I mentioned, concluded they were probably costing energy.

HALSTEAD: It seemed to me that your recommendation was to use certain resinous products to apply those coatings. To me, this seems contrary to the aim of this workshop, which is to look for ways to conserve petroleum products or petroleum chemicals. Since the resins are derived from petroleum and require large amounts of energy in their manufacture, it does not seem useful to devise solutions requiring increased use of such materials. As petroleum becomes scarce or more limited in supply, we would have to seek another solution in any event.

PHILIP E. McINTYRE: This relates to the subject of binders. I did not attend that session, but nowhere have I heard in our discussions any possibility of looking at the aspects of developing a binder strictly for its cementitious ability instead of for both that and its weatherability. Perhaps there is some material that can be developed strictly from a cementitious vantage point, but will require further protection.

HALSTEAD: I think that the basic reason we have not considered this approach is that almost all of the various possibilities are based on petroleum products such as petroleum resins and for that reason have been dismissed out of hand. We should start with the idea of using nonpetroleum products. This is why in the federal highway research program we included a long-range feasibility of wood resins and lignin products as a possible highway binder. Some early indications are that a product can be obtained, but whether it is suitable for large-scale operations is not yet known.

BEATON: That research suggestion was made by my discussion group. I have a question related to painting of concrete in lieu of rubbing. All good paints with durability are petroleum derivatives, and all paints need maintenance. If you must finish concrete, why not just form finish it and forget this energy expenditure of either painting or rubbing?

SCHMIDT: I agree that, if you have a choice of rubbing or not rubbing, obviously you can save energy by not rubbing. How many Btus does it take to rub a concrete surface on a bridge? And how many Btus does it take to furnish a gallon of paint to paint the bridge? These are the kinds of questions for which no one has an answer. If you spend 6 weeks with a generator rubbing a concrete bridge, you may well spend more Btus of energy than you would painting it. These are the answers we need.

DONALD R. SCHWARTZ: I believe we should address the energy and money expended for aesthetics. We are currently spending considerable amounts of energy and money to improve the appearance of new highways without adding anything to the utility or life of the facility. We need better guidelines on how much we should be spending, or can afford to spend, for this purpose. The performance of the concrete structure is not affected by a decision to rub, paint, or form finish the concrete, but its total cost and energy consumption certainly are.

LEDBETTER: What new thing should we be doing that has not been discussed to save, or to optimize, energy and materials in transportation construction?

ADAM: We have not heard anything about mowing or realistic standards for mowing. Some agencies mow the right-of-way like a lawn. I think we need to look at some more realistic standards for mowing of the right-of-way. Mowing costs a lot of money in some states; costs range from $500,000 to $14,000,000 per year.

J. F. McLAUGHLIN: Mowing was discussed at some length under the topic that dealt with quality standards. It is not just mowing, but all roadside plantings and perhaps, more generally, the attention that has to be given to the quality standards that we have set for the cosmetic aspects of the roadside. My report referred to these cosmetic aspects but did not mention mowing specifically or fertilization or transplanting trees from Alaska to Texas. The group did look at this item and suggested that we ask ourselves how much cosmetic attention can and should be afforded to the roadside in the name of beautification and at the expense of energy.

MARSHALL R. THOMPSON: Moore indicated in his summary report that there are certain problems associated with subgrade stability and construction on unstable grades. Certain contractors maintain that perhaps if we had improved grades or took steps to provide improved working platforms their construction costs could be minimized. With improved subgrades, they spend more time on the job as opposed to waiting for subgrade stability to improve so they can operate. What positions have various agencies taken on the idea of incorporating the concepts of improved subgrades or working platforms into design in order to provide the contractor the opportunity to maximize the use of sophisticated and costly equipment?

SCHMIDT: Most Illinois agencies are considering this type of thing, but there are all kinds of problems involved. One of them is attitude. When you provide the haul road, whom are you benefiting? the contractor or the agency? Until each agency resolves this question, haul roads probably will not be used to any great degree. For example, I understand that some states are lime stabilizing the subgrade area from shoulder to shoulder, and I am sure that represents an energy saving to the contractor. But the question is, Is there an overall energy saving to the project or an overall dollar saving to the contractor? This gets back somewhat to the question raised previously: Is a time saving an energy saving? Is a dollar saving an energy saving? I think there is definitely a relation. If you are saving a lot of time and a lot of money, you have to be saving some energy. On the other hand, you can spend energy to save time, and that is one of the things we are worrying about. But the biggest problem is attitude: Are you really saving energy, or are you benefiting the contractor? We should look at the states that have large programs of subgrade treatment to see whether their costs are higher than others. I suspect they are not.

FRANK P. NICHOLS, JR.: I would like to raise the same question: Does subgrade stabilization really save energy or merely benefit the contractor? Certainly the provision of a good working platform is worth something to the contractor and must save some energy in operating the equipment. It must also be worth something to states that provide subgrade stabilization at the design stage. Some states use mechanical stabilization by incorporating in the project plans a certain amount of road stabilization aggregate. This is done mostly in the south, but I do not know why it could not be applied almost anywhere. A good deal of data in North Carolina, Alabama, and other southern states show that it only adds 30 or 40 cents/ton to the in-place price of crushed stone to haul it, spread it, and mechanically mix it with farm equipment or more sophisticated devices. Thus, by improving the soil support, you will not only benefit the contractors in their compaction operations, but you will also permit a somewhat lighter design to be used and save both materials and energy.

LYNDON H. MOORE: In the workshop discussion on stabilization of subgrades, an additional consideration was brought up that could contribute to material and energy savings. If the subgrade soil could be upgraded in strength by stabilization, then the strength increase could be considered in the pavement design resulting in a possible volume reduction of the more expensive materials in the overlying pavement section. This should be another factor that goes into the evaluation of the total problem.

MENDENHALL: An interesting suggestion was made concerning the conflict between various specifications in a local area. In urban areas and particularly large urban areas, a number of jurisdictions, such as counties, states, and city governments, are responsible for design and construction for various highway facilities. What is the best way of getting more uniformity of gradations used for common types of materials in paving structures in local geographic areas? What forum can we use to get everyone to accomplish this?

ALLEN: In the Phoenix area, the prime source of aggregate is the Salt River, which traverses the valley for a great distance. Many aggregate suppliers work in that particular deposit. The cities and county and other government units in the area formed the Maricopa Association of Governments, which developed a specification to govern material produced from that area. It has been well accepted and has accomplished the purpose of a unified specification. I am sure this could be done on a larger scale, particularly where one supplier is supplying one or more states from a single source.

DAVID G. TUNNICLIFF: This problem is already being partly handled through ASTM standards, which most people do not use, and those of us who work in ASTM would like to know why because we think there is a benefit in having some uniform standards. Some ASTM standards could solve part of this problem.

MARKER: Allen mentioned recycling portland cement and asphalt concrete pavements for use in rigid pavement construction. Is this related to research?

ALLEN: This was in the area of innovation rather than research, but the suggestion was that recycled materials from both portland cement concrete pavement and bituminous concrete pavement could be recycled and used in composite rigid pavement design for the entire structure or for lower levels.

MARKER: What is meant by composite rigid pavement design?

ALLEN: It is pavement in which poor-quality material is used in the bottom levels and a better quality is used in the upper levels. Someone else may have a better answer.

LEDBETTER: Composite pavement might be considered to be pavement in which the highest quality materials are used in those areas where there is highest stress, which may be at the top and the bottom. In the center portion, weaker materials may be used for bulk and overall stability, but not stress.

Of the areas of needed research that have been mentioned, which are the most important, assuming that we have limited funds and limited resources to carry out the research? Which ones ought we to tackle first during the next year?

BUD A. BRAKEY: One of the most important areas of research is to develop methods to seal cracks in existing pavements and to glue the pavement back together. We need to rehabilitate pavement not only to optimize use of energy and materials but also to optimize the use of the taxpayer's dollar. In Colorado, we have thousands of miles of neglected secondary and primary roads, and in 1975 we budgeted only $1.5 million for contract maintenance. At that rate, we will get around to overlaying our existing pavements once in about every 90 years. Considering this, we simply cannot afford to place 1½ to 2½ in. (38 to 64 mm) of overlay on top of these existing pavements.

FOSTER: I do not doubt that repairing cracks is a pressing need, but the objective of this workshop was to optimize energy use and materials. We will never decide where to conserve energy until we know where it is being expended. Our most urgent need is energy requirements for each operation in the construction and maintenance of transportation construction to permit engineers to make decisions on energy conservation.

BRAKEY: One of the questions sent to us before the workshop was, If you had all the money you needed, how would you save energy and materials? If we had the money, I am sure we would lay 3 or 4 in. (76 or 102 mm) of asphalt concrete over all these secondary and primary roads. And that would take a tremendous amount of energy and materials. We do not have the money, but nevertheless we can save energy and materials if we can find a satisfactory method of rehabilitating those roads by placing a thin layer of something on them.

T. C. PAUL TENG: We need some procedure for optimizing the total design, construction, and maintenance procedure because obviously there are a lot of things that some people are doing that some other people are not doing. We need some research to put all these together into general guidelines that are related to energy input. I think this is the most urgent need in the research area.

LEDBETTER: Do you mean design, construction, and maintenance of a new facility or the design, construction, and maintenance of existing facilities or both?

TENG: For the new facilities, we need to start at the beginning. For existing facilities, we can look at what is available now and decide what we should do. For instance, mowing is a big portion of the maintenance fund; in Texas grass is mowed 12 times a year. Just how much mowing is needed and just how much mowing cost can we tolerate?

THOMPSON: Implicit in the idea of using new and novel materials and our desire to conserve energy and use marginal materials is the idea that we can assess how well they will perform. This means that we need suitable procedures for evaluating those new materials in terms of strength, durability, and stiffness. The property evaluation data will be put into some kind of a structural model and we will attempt to predict performance. In many instances we find that our criteria relate to experiences derived from the use of "high-quality" and "excellent" materials. To arbitrarily extrapolate those criteria to all new materials may be a difficult and perhaps a dangerous thing to do. I suggest that we have to maintain or increase our activities in the area of material evaluation so that we can handle these new materials and make good judgments concerning their probable behavior. One area where this particularly shows up is in unbound granular bases and subbases. Many of these materials behave under dynamic load (resilient behavior) about the same whether one has gravel or crushed stone. However, permanent deformation accumulation under repeated loading is quite different for the gravel and crushed stone materials. The higher shear strength crushed stone will display better permanent deformation response than the gravel. This is just an example of the type of pitfall that we may get into in using marginal materials. I am not discouraging the use of them. I am saying that we need to carefully examine their characteristics and behavior and sharpen our skills for effectively using them in pavement systems.

MENDENHALL: Many comments during this workshop were about research that could be implemented tomorrow. For example, somebody indicated that we can use lower mixing temperature and allow a little moisture in conventional hot-mix plants. If the research community is satisfied this can be done, how can we do it tomorrow? How do we get the word out? Implementation of currently available technology would be worth spending some money on.

NICHOLS: We should be able to determine how much is expended for energy in terms of highway materials and construction from information that is already available. Asphalt Institute data show that the greatest energy is required for heat to manufacture products like cement or lime, to refine asphalts from crude petroleum, and to dry aggregates for use in hot mixes. The second greatest energy input is probably for hauling materials around the country. Farther down the line is the energy required to process aggregates, either in place on the roadway or at the source. If we take a systems approach to all elements of quarry operations, we will be spinning our wheels looking at one of the smaller aspects of the whole materials and energy optimization picture. If we can look at ways to cut down on the energy required in the various materials that go into pavement components, we will find where we can get the best return in terms of energy saving.

K. H. McGHEE: When we look at the whole system, we must keep in mind the energy consumed by the user as well as the builder. When we look at the design of a facility, we must consider such things as grades in terms of the energy consumed by the user during, say, a 20-year design life. So we must look at not only the energy we will use in building the facility but also the energy the user is going to expend in using the facility.

HALSTEAD: Are we going to assign different weights for energy units derived from different sources? Btus seem to be the common denominator, but Btus from solar energy, in my mind, would be absolutely free because if we do not use them they will be wasted anyway. Btus from coal may be a less critical drain on our natural resources than Btus from petroleum or natural gas. For example, the cement industry is converting to the use of coal rather than the use of gas or oil. In analyzing energy usage, do we still "charge" the same for Btus regardless of the energy source? Perhaps we are talking about a situation in which in making the final decision the numbers game must give way to good, sound engineering judgment and common sense.

LEDBETTER: Should we be making a more definitive effort toward determining the actual cost of the various aspects of our designs in much the same way contractors determine their costs in terms of labor, equipment, and materials so that we can make decisions in this interim period before we get acceptable energy data? For example, when you look at the cost of an item like, say, concrete pavement in place and its unit price and use that as a basis for judgment in comparison with the costs of asphalt concrete in place and its unit price, you do not know what the relative cost of the asphalt is, what the relative cost of the rock is, and what the relative cost of the construction is. All you know is the total in-place cost. As a highway department decision maker, should you consider what the relative costs of the materials and their construction are to help you in the decision-making process of what materials should go into a particular design?

ALI S. KEMAHLI: This gets to be a very complex question and involves economics, long-range economic programming, availability of funds, and many other things. At this time, highway departments do not have the resources or the personnel to implement something like this or do such long-range thinking. So possibly one way of handling the situation would be by allowing alternates, whether concrete or hot mix or whatever, and let the contractor and the availability of the materials, supply, suppliers, the time of year, the construction season, and so on determine the situation. That may not be the best answer but is an available expedient answer.

SCHMIDT: I think that you are saying that we should estimate a job not only in dollars, which I think most states do, but in energy. The problem is we do not know what units to use in energy. We do not know what a ton of rock costs in Btus. Someone said it was 500,000 Btu/ton of rock; another person said it was 50,000 Btu/ton of rock. I am back to my original dilemma of whether we are concerned about saving time or dollars or energy. I still think they are interrelated. I guess we need to start estimating our jobs on what I would call the "Btu dollar." We should find out the total cost in Btu dollars. If it is high in dollars or high in energy, we need to balance the two. I do not believe that we can design a total energy conservation project if it is going to cost 10 times more in energy than it costs in dollars. So I am promoting the Btu dollar as our new standard.

LEDBETTER: In this area right now, when we do not have all the answers, should we not be trying to provide the options so that those who do have the answers can select options? We can thereby optimize materials and energy through the use of options even to the point of looking at some sacred cows, like asphalt concrete versus portland cement concrete, deciding somewhere down the line what the equivalencies are in their design and, then, whenever feasible and possible, providing options so that at the time a project is constructed the contractor can use the most effective materials and energy to construct the project.

LARRY G. WALKER: A point that keeps coming up is that, if you save dollars, you save energy. We have not been able to say that that is entirely true, but I think the consensus is that it is true in most cases. This generalization should become more accurate as the cost of energy becomes more realistic and is not artificially restrained. But it seems that even now there may be some notable exceptions to this rule. I agree with the idea of total system evaluation. But maybe as a short-range project, we can identify the things that we are now doing that waste energy even though they may save dollars. Identification of such exceptions is a quick research effort that needs to be attended to.

FOSTER: The alternate bid procedure was followed by the U.S. Army Corps of Engineers from about 1950 to 1957. There is a good body of evidence that shows that the bid price, or the profit really, is inversely proportional to the number of bidders on any job. This is something difficult to analyze because one does not know how many bidders there are going to be on the job. The Corps of Engineers recognized this to some extent, and the instructions during that period of time were make the designs alternate, estimate them as accurately as possible, and if they deviate by 15 percent take the lower price; but if they are within 15 percent of each other put them out for alternate bids and let the contractor decide. This was a relatively simple thing for the Corps to do, but it is a difficult thing to do on a highway. Opposition will come from both the highway department because of extra work and from the contractors' association or the individual contractors because of alternate bids. As I recall, alternate bids were let on a job in Louisiana and succeeded only in reducing the price of concrete by about $\$2/yd^2$, and this made no one happy, particularly the contractors.

THOMPSON: I think that some rather complex technology is involved in making decisions concerning the conservation of energy and materials and providing adequate pavement systems for the future. In this era when engineering talent is available, I think that perhaps administrative people in the U.S. Department of Transportation should seriously consider increasing their engineering staffs and using engineering analyses and design to a greater extent. Not that we are not doing a good job now, but I am sure that we can do a better job. New technology and concepts can be brought to bear on the critical problems of conserving energy and materials in transportation construction.

SUGGESTIONS FROM STATE TRANSPORTATION AGENCIES ON WAYS TO MINIMIZE THE IMPACT OF ENERGY AND MATERIAL SHORTAGES

During 1974, the Federal Highway Administration through its regional offices asked state transportation and highway departments to submit suggestions on how to minimize the impact of energy and material shortages on the construction of transportation facilities in the United States. Altogether 80 suggestions were made by 1 or more states. FHWA circulated these suggestions to all state departments and asked that they continue to submit suggestions as they developed. The suggestions were first received on a quarterly basis and are now received on an annual basis. The original 80 suggestions are given below for informational purposes only. No endorsement or recommendation for their use is implied. Readers must make their own analyses of the effectiveness of each in the light of the particular situation toward which the suggestion may be applied.

1. Permit and encourage the use of the dryer-drum process for bituminous concrete;
2. Eliminate hot screens and use plants with cold feed controls only;
3. Reduce mixing temperatures of asphalt plants;
4. Reduce mixing time of asphalt plants;
5. Reduce asphalt content in lower lifts;
6. Replace part of the asphalt in bituminous mixes with sulfur;
7. Use emulsified asphalts instead of cut-back asphalts wherever possible;
8. Eliminate asphalt prime under full-depth asphalt pavements;
9. Use emulsified asphalt instead of cut-back asphalt for curing cement treated granular bases and soil-cement bases;
10. Use chip seals instead of a plant mix wearing course on low-volume highways;
11. Evaluate the use of sodium chloride and lignosulfonate for soil stabilization;
12. Use wood chips, wood fiber, or chopped straw mulch as a substitute for asphalt-coated straw;
13. Permit specification changes on a project basis if the need arises to overcome shortages of supply of certain scarce material;
14. Revise aggregate specifications to conform to those used by contiguous states;
15. Provide asphalt mix designs to permit use of material sources nearest a project;
16. Revise specifications for asphalt aggregate mixtures and design mixes to make greater use of local aggregates;
17. Recycle asphalt pavements;
18. Permit the placing of asphalt concrete in thicker lifts;
19. Prohibit the use of fuel oil as a releasing agent on the beds of trucks hauling bituminous mixes;
20. Use plain concrete or conventional jointed concrete instead of continuously reinforced concrete to reduce steel required for pavement construction;
21. Permit use of a single coarse aggregate for portland cement concrete pavement;
22. Where practicable, allow the use of fly ash as a substitute for a portion of the cement in the concrete;

23. Reduce the air temperature where concrete aggregates must be heated;
24. Recommend that contractors use insulated forms instead of heated enclosures for cold weather concreting operations, excluding bridge decks, and limit cold weather concreting to those critical items affecting the efficiency of other major operations or to avoid major delays in project completion;
25. To the extent possible, use slip-form construction for curb and gutter, traffic separations, barrier walls, and concrete pavement and thus reduce the need for wood and steel forms;
26. Increase maximum allowable thickness of base and embankment lifts;
27. To the extent possible, haul materials directly from the source to the roadway and thus avoid stockpiling and double handling;
28. Encourage the use of equipment according to the manufacturer's recommendations;
29. Use a fuel allocation program and establish goals for fuel reduction;
30. Recommend to contractors that they salvage and strain used motor oil and use it as an additive to furnace or fuel oil or other construction uses;
31. Reduce unnecessary dressing of slopes and establish grass slopes early to eliminate frequent reworking and reseeding;
32. In clearing and grubbing operations, burn or otherwise dispose of waste materials within project boundaries where feasible instead of hauling them away;
33. Minimize use of fuel for brush burning, perhaps, by use of forced air burning;
34. Monitor the use of project vehicles, travel only when necessary, and combine trips when feasible;
35. Replace some project pickup trucks with subcompact pickup trucks and increase the use of compact cars;
36. Do not use air-conditioners in cars;
37. Encourage the shutdown of engines during lunch periods and other work breaks rather than letting them idle;
38. Reduce travel by efficient use of communication equipment such as 2-way radios and radio-telephones;
39. To the extent possible, assign project staff to projects close to their homes and encourage car-pooling by providing reserved parking areas;
40. Recycle extraction solvents;
41. Decrease the stripe-gap ratio or decrease the width of pavement striping;
42. Use A-588 steel to reduce the demand for paint and cost of maintenance;
43. Use high-pressure sodium lighting because of energy efficiency;
44. Reduce the number of lighting installations by installing minimum lighting where marginally warranted;
45. Use laminated timber bridges on secondary projects to conserve steel, concrete, and aggregates;
46. Permit use of alternate species of timber, providing strength and other pertinent requirements are met;
47. Permit the use of larger cross sections in timbers for sign and barrier posts to allow for the use of material of lower stress grading or weaker fiber stress;
48. Eliminate the top strand of barbed wire and eliminate top rails from chain link fence design where feasible;
49. Use precast concrete piling as an alternate to steel shell piles;
50. Revise standards for guardrail to permit alternate sizes of steel posts to ensure an available supply;
51. Permit aluminum posts to be substituted for steel in fencing contracts;
52. Permit concrete and timber posts in lieu of steel I-beams for guardrail support;
53. Revise standards for steel plate beam guardrail to permit an alternate cold-rolled steel C-shaped post;
54. Permit changes in asphalt grade where the change will not be detrimental to the end product and modify mix designs to obtain satisfactory mixtures compatible with the substitute grade of asphalt;
55. Add mineral filler to selected asphalt mixes to reduce the liquid bitumen required;
56. Substitute other types of curb for bituminous concrete at recreational sites;
57. Use concrete or Econocrete shoulders as an alternate to asphalt shoulders;

58. Where practicable, use portland cement or lime-pozzolan treated bases as alternates to asphalt stabilized bases;
59. Allow the optional use of pitch resin or plastic polyethylene instead of asphalt coatings on corrugated pipe;
60. Increase strength requirements of concrete where design stress is an important factor;
61. Optimize compactive effort and reduce fuel consumption through the use of vibratory compactors;
62. Increase security for fuel storage facilities and equipment fuel tanks;
63. Where possible, use temporary runarounds instead of marked detours at bridge construction sites and thus reduce fuel requirements for materials;
64. Grade by the station on low types of projects in flat terrain;
65. Reclaim metal guardrail through use of a guardrail straightener;
66. Permit the use of foreign steel;
67. Specify the most available grade of structural steel;
68. Reduce the minimum taper requirement on light standards to increase the potential supply for this item;
69. Match turf fertilizer to small area soil types;
70. Revise specifications to permit the use of polyvinyl chloride conduit in lieu of steel for underground utilities and underdrain systems;
71. Eliminate joints in concrete median barriers;
72. Improve inlet designs to reduce size of culverts;
73. Revise standards for right-of-way markers and drainage markers to permit more effective use of stock lengths of No. 3 reinforcing bars;
74. Use elliptical placement of reinforcing steel in concrete culvert pipe;
75. Revise construction details for precast concrete piles to provide wider choice of pile type;
76. Reduce required thickness of galvanized coating on some items, such as fencing fabric, and accept alternate use of aluminum coating;
77. Reduce specification requirements for zinc coating on rigid electrical conduit, which will likely increase the number of potential suppliers;
78. Promote long-range materials management [one state is considering a 4-element, long-range materials plan that will include (a) maintenance of an inventory of crucial construction materials, (b) estimates of future construction and maintenance demands for crucial materials, (c) establishment of feasible substitutes for traditional materials and designs that have satisfactory performance qualities, and (d) research to develop new materials, alternate designs, better processing, and recycling];
79. Permit the use of alternative types of at-grade railroad crossings such as rubber, steel, precast concrete, and structural form, as substitutes for full-depth timber plank crossings; and
80. Change standards for right-of-way markers to a metal type.

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