2099

ENERGY USE AND CONSERVATION IN HIGHWAY CONSTRUCTION AND MAINTENANCE

by

Woodrow J. Halstead
Consultant

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway and Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

March 1978

VHTRC 78-R42

2190

ENERGY TASK GROUP

MR. M. H. HILTON, Chairman, Research Engineer, VH&TRC

MR. E. D. ARNOLD, JR., Research Engineer, VH&TRC

MR. F. L. BURROUGHS, Construction Engineer, VDH&T

MR. R. E. CAMPBELL, Asst. Transportation Planning Engineer, VDH&T

MR. R. V. FIELDING, Materials Engineer, VDH&T

DR. L. S. FLETCHER, Professor of Mechanical & Areospace Engineering, UVA

MR. R. L. HUNDLEY, Environmental Quality Engineer, VDH&T

MR. C. O. LEIGH, Maintenance Engineer, VDH&T

MR. J. R. MILLER, Equipment Engineer, VDH&T

DR. W. H. MASHBURN, Asst. Professor of Mechanical Engineering, VPI&SU

MR. E. D. SLATE, General Services Supervisor, VDH&T

MR. A. J. SOLURY, Div. Planning and Research Engineer, FHWA

MR. M. E. WOOD, JR., District Engineer, VDH&T

MR. J. R. YOUELL, Electrical Engineer, VDH&T

FOREWORD

This is the final report of Task 1, "Energy Use and Conservation in Highway Construction and Maintenance", under the project "Energy Conservation in Transportation in Virginia". It is essentially complete within itself; however, for a general overview of the transportation energy situation and activities and plans of the Virginia Highway & Transportation Research Council relating to energy conservation, reference should be made to the interim report on this project entitled "The Outlook for Transportation Energy -- An Overview and Summary of Conservation Plans in Virginia".

SUMMARY

This report reviews the options available to the highway engineer for the conservation of energy in highway construction and maintenance. In general, it was found that the objective of conserving energy is closely related to long-standing objectives to reduce costs and to conserve materials. Because poorly constructed or maintained roads result in increased dollar and energy costs to the public using such roads, it is concluded that the best construction and maintenance procedures, consistent with budgetary limitations and the need to provide as many miles of adequate highways as possible for the good of the maximum number of citizens, are most likely to be the least energy-intensive in the long term.

The report reviews the potential for energy conservation with respect to (a) binding agents; (b) quality standards and quality control; (c) aggregates and other materials; (d) earthwork and existing roadway preparation; (e) use of waste materials, by-products and recycled products; (f) production and construction techniques, and (g) the possibility of new products and procedures past 1985. Energy saving opportunities in highway maintenance activities are discussed and some factors for estimating the amount of energy used in highway construction are given. Estimates for the amount of energy required to construct a rigid pavement and a flexible pavement using typical specifications of the Virginia Department of Highways & Transportation are included.

Major conclusions and recommendations are given below.

1. No major changes from present-day construction practices are needed.

2. There is no need to establish within the Department an energy research group. However, an understanding of energy factors and potential energy problems is needed in all activities relating to highway construction and maintenance. Research and development programs related to energy can best be conducted within each of the major techniques involved in highway construction (asphalt, concrete, soils, etc.).

3. The areas identified as having the best potential for conserving energy in highway construction are:

   (a) increased use of industrial mineral wastes;

   (b) increased efforts to utilize local materials;

(c) increased recycling of both asphalt and concrete pavements;

(d) substitution of emulsions for cutback asphalts; and

(e) long-range studies for minimum use of asphalt in highways.

ENERGY USE AND CONSERVATION IN HIGHWAY CONSTRUCTION AND MAINTENANCE

by

Woodrow J. Halstead
Consultant

INTRODUCTION

Highway construction and maintenance activities in the United States are estimated to consume about 2.5 quadrillion (10^{15}) Btu's (2.6×10^{18} J) per year. This is equivalent to 24 billion gallons (91 million m^3) of petroleum. Thus, an overall saving of 10% of the energy involved would represent a significant quantity of energy and a significant reduction in the costs of the activities. However, one other statistic must be kept in mind. The energy used in highway construction represents about 1.7% of the total energy used annually in the United States. Maintenance requires an additional 1.5% to 2.0%. Thus, while savings in construction and maintenance are important from the standpoint of the budgets in the highway construction industry, even large reductions in the use of energy in these areas would be only a very small fraction of the energy used nationwide, and taken alone they would do little to alleviate the energy shortage. This fact is not mentioned to minimize the importance of energy conservation in highway construction and maintenance, but rather to stress that it would be a mistake to sacrifice quality of construction, or accept less durable materials, or reduce maintenance simply for the sake of saving energy. Such action, or any action to delay construction of needed pavements, would most likely increase the overall amount of energy used because of the additional fuel that would be burned by automobiles delayed by traffic jams, rough roads, or subsequent maintenance activities. The decreased safety and increased inconvenience for the public also make this course of action unwise.

The types of materials available and the manner in which they are used control, to a considerable extent, the amount of energy required for highway construction or maintenance in any given instance. The problem has been defined as one of optimization; that is, the solution lies in selecting the procedure or material that will provide the needed performance with minimal use of materials and energy. Such selection should also result in a lower cost. Thus, the objective with respect to conserving energy is consistent with the traditional objective of reducing costs as much as possible. As the costs of energy increase (as is likely), the direct relation between the energy consumed in highway activities and the costs of these activities will become more evident. It must also be kept in mind that "first" costs of construction will diminish in relation to subsequent costs of delays to the highway user, when those delays reduce the efficiency of his fuel supply. Because of this effect of inflation and almost certain "out of proportion" fuel cost increases, it is likely that the best possible construction and the best maintenance procedures will also prove to be the least costly and least energy-intensive in the long term. However, budgetary limitations and the need to provide as many miles of adequate highways as possible for the good of the maximum number of citizens are important considerations and in many instances may be the controlling factors. Under the circumstances, it is likely also that best cost-effectiveness will continue to be the final judgement criterion for selecting the type of construction for highway projects.

POTENTIAL FOR ENERGY CONSERVATION

During the oil embargo by the OPEC nations, shortages of fuel oil for construction processes and very large increases in the costs of such fuel emphasized the dependence of the highway construction industry on petroleum products. It also became apparent that the availability and cost of a number of construction materials not derived from petroleum were also greatly affected by the energy shortage. In order to gain an understanding of the options open to the highway engineer, a conference jointly sponsored by the Federal Highway Administration (FHWA), Federal Energy Administration (FEA), and the Energy Research and Development Administration (ERDA) was conducted by the Transportation Research Board in November 1975.

The subject was "Optimizing the Uses of Materials and Energy in Transportation Construction." The report of that conference provides the general viewpoint of a broad segment of the industry at a time when the "energy crisis" as represented by the shortages of petroleum products (gasoline, diesel fuel, fuel oil, asphalt) brought about by the embargo was over.[1] However, the participants at the conference were well aware of the continuing problem with respect to both materials and energy. Since that time some of the complexities and interrelations of energy use and material supplies are better understood and some additional information is available. However, the basic ideas discussed at that time continue to represent the most valid possibilities for energy conservation in highway construction practices.

Seven workshops, each discussing a specific subject area, were conducted during the conference. The subjects of these were:

1. binding agents
2. quality standards and quality control
3. aggregates and other materials
4. earthwork or existing roadway preparation
5. waste materials, by-products, and recycled products
6. production and construction techniques
7. new products and procedures -- past 1985

The findings of the conference and a general assessment of the continuing validity of the conclusions reached based on information developed since the conference are reviewed in the following sections.

Workshop No. 1 -- Binding Agents

The first workshop of the conference identified the major binding agents available for highway construction as asphalt products, hydraulic cement, lime, and lime-fly ash. Approximately 90% of all-weather highways have asphalt surfacing of some type and the balance are surfaced with portland cement concrete. Lime and lime-fly ash are used primarily in bases and subbases for stabilization. Asphalt and portland cement may also be used in base construction.

Other possibilities discussed were sulfur, tars, wood lignins and resins, and petroleum resins. Discussions of the possiblities and potential problems with respect to each of these materials follow.

Asphalt

Perhaps the greatest potential effect of the changes in energy sources with respect to highway construction and maintenance is not the energy per se, but the fact that as the supply of petroleum diminishes the supply of petroleum asphalt will also diminish. At the beginning of the oil embargo in 1973 fears were expressed that much of the asphalt in the petroleum would be marketed as a heavy fuel oil or that refinery techniques would be changed to "crack" the petroleum to obtain maximum fuel production in the gasoline and diesel oil ranges. The residual from such processes is coke rather than asphalt. While such changes may ultimately occur, fortunately for the highway industry, certain restraints now exist that tend to make any early or sudden shift unlikely. The restraints relate to the sulfur content of the petroleum. The following quotation from the report "The Future for

Hot-Mix Asphalt Paving" prepared by Charles R. Foster, director of engineering and research, National Asphalt Pavement Association, in 1976 sums up the situation which still prevails.(2)

> Currently, asphalt cement is being refined primarily from sour crudes which contain so much sulfur that the residual cannot be refined to fuel oil. Asphalt cement being marketed today contains from 2% to 7% sulfur. The percentage of sour crude being refined in the United States is fairly high, and there is an adequate supply of asphalt cement at the present time. We expect the supply to continue to be adequate for some time for two reasons. One is that oil producing nations which have both sweet (low in sulfur) and sour crudes are requiring purchasers to take a certain quantity of sour crude along with the sweet crude. The other reason is that the sulfur in asphalt is chemically bound, and no practical means are available for removing chemically bound sulfur from heavy residuals. Even when such procedures are developed, it will take some 5 years to build the facilities, and put them on stream.
>
> Thus, barring another embargo, we are very optimistic about the supply of asphalt cement for the next several years, at least. When procedures are developed for removing sulfur, asphalt cement will be a part of the fuel supply, and paving needs will have to compete with energy needs. I don't anticipate a shortage if this occurs, but there will be an increase in price because fuel oil sells at about 1.4 times the price of crude oil, whereas asphalt cement sells at about 1.25 times the price of crude oil.

Even without the development of methods to remove sulfur, the price of asphalt will most likely rise to a greater extent than normal inflation would indicate because asphalt cement prices will rise in proportion to the increase in the price of petroleum. In addition, fuel and other energy costs in the manufacture of asphalt paving mixtures will increase accordingly. The National Asphalt Pavement Association estimates that by 1980 the average cost of asphalt cement will be $120 per ton.[3] On this basis and considering the estimated inflation rate on other components it has been estimated that the average cost of a ton of paving mix will be $23.15 in 1980. Increases beyond 1980 may be proportionally greater if the world price of petroleum continues to rise sharply.

Ultimately, in view of the almost certain "using up" of petroleum, the supply of asphalt will diminish and a new binder or extenders to be used in conjunction with asphalt will be needed. No close prediction can be made as to when this will happen. It could be as early as the latter part of the 1980's or it may be after the year 2000. Correspondence with representatives of the Asphalt Institute has indicated that the later date is the more probable. However, in view of the length of time required to budget funds for specific projects and experimental construction and the time before results are available, research planners should begin now to provide for research and experimental programs aimed at developing construction techniques that will minimize the use of asphalt so as to have such procedures available when needed. Non-asphalt maintenance procedures, especially procedures for portland cement concrete pavements, should also be explored.

It should be recognized at this time that because asphalt is a by-product of petroleum refining, it cannot economically be stored for a long period of time before use. Refineries need a turnover in the storage tank capacity based on seasonal fluctuations of demand for different products. One can visualize that as petroleum shortages increase, a system of underground storage in natural cavities and calculation of the feasibility and economics of such a system would be desirable. However, it appears that the costs of such operations would increase the price of asphalt to a point that other paving materials would be more economical. Consequently, although research and experimental construction to evaluate minimum uses of asphalt in pavements are needed, there should be no efforts to curtail arbitrarily the use of asphalt in bases or other uses when the asphalt is available and engineering judgement and economics indicate such to be the most desirable type of construction.

Current efforts to make greater use of asphalt recycling should also be considered as a means for extending the supply of asphalt. The aspects of recycling will be discussed in a later section.

Hydraulic Cements

The portland cement industry does not face any overall shortage of raw materials. However, relatively large amounts of energy are required to manufacture portland cement. The 1976 energy report for the cement industry shows that the energy consumption in that year was 6.34 million Btu's per ton (7.38 million J/kg) of cement manufactured.(4) The cement industry is also making efforts to use coal in lieu of petroleum oil and gas. The report showed that coal and coke accounted for 55% of 1976 fossil fuel consumption within the industry. Natural gas consumption has been reduced 41% since 1972 and petroleum usage in the industry has declined 30%.

Although it will require large capital investments to replace old equipment with newer, less energy-intensive equipment and processes, further reduction in the amount of energy required to manufacture cement is possible. The 1973 figures for Germany show that only 3.6 million Btu's were used to manufacture 1 ton of cement (4.2 million J per kg). Japan also has an efficient industry -- showing the use of 3.9 million Btu/ton (4.5 million J/kg).(5)

It will likely be a long time before the U.S. industry can match these figures because of the large capital investment in the less energy-efficient plants (e.g., wet process) and the cost to build newer, more efficient plants. However, the cement industry has an ongoing program to improve efficiency in the use of energy.

A workshop sponsored by the ERDA, FEA, and the NBS was held in Washington, D.C., on October 3 and 4, 1977, on the possible contributions of cement and concrete technology to energy conservation by the year 2000.(6)

This workshop explored a large number of possibilities for energy conservation in six broad subject areas as listed below.

Group I	Clinker Production
Group II	Cement Production
Group III	Blended Materials
Group IV	Concrete Manufacture
Group V	More efficient use of concrete
Group VI	Institutional Factors

It is planned that the proceedings of this workshop will be published some time in the first half of 1978. This publication will cite a number of possible actions that could be taken immediately to reduce energy consumption in both the manufacture and use of cement and concrete, and will suggest a number of research studies to evaluate the possibilities of reducing the use of energy in a number of activities. These suggested activities cover the entire industry and all of them do not affect concrete construction relating to highway facilities, but many would have direct or indirect impact on highway and transportation department activities.

One of the more significant possibilities of reducing the amount of energy consumed per ton of hydraulic cements is the manufacture of blended cements in lieu of the regular grades of portland cement. Both fly ash and slag can be interground (or otherwise blended) with portland cement clinker to produce acceptable products meeting ASTM specifications. In general, research, as well as experimental construction projects, indicates that these products should perform well in highway construction projects. The major concern is that additional time may be required for them to develop adequate strength prior to removal of the forms when used in structures.

The greatest increase in blended cements is likely to be in the use of materials containing fly ash as the pozzolanic component. However, some uncertainty still exists as to the resistance to scaling of concrete containing fly ash, and this needs to be resolved. Several agencies, including the FHWA, are reexamining this aspect of the use of fly ash concrete.(7) There is also some interest in manufacturing cements using a smaller amount of fly ash, along with portland cement clinker, than is required to conform to ASTM specifications for blended cements (I-P). Such products apparently will meet the physical test requirements of ASTM and AASHTO standards but fail to comply with the minimum percentages of blended components. The ASTM Committee on Hydraulic Cements is studying this problem with the aim of developing suitable alternative specifications for such materials. In an article in Rock Products, October 1976, Enid Stearn summarized the interest in the use of blended cements. His article, entitled "Blended Cements Make Gains -- but Slowly," points out that a 40% reduction in manufacturing energy could be attained over that required for manufacturing portland cement (assuming 100% substitution of blended cement for regular portland cement).(8)

At present there is no significant price differential between Type I portland cement and Type I-P blended cement. Consequently, as long as portland cement is available many highway departments are reluctant to use blended cements because of the unknown behavior pattern. Inasmuch as some definite advantage in addition to energy conservation might result from the use of blended cements (such products have lower heat of hydration and possibly produce concrete with more tolerance for alkalies [$Na_2O + K_2O$] when the aggregate may be potentially reactive), this type material should be more completely evaluated for highway use.

The Virginia Department of Highways & Transportation requires the use of Type II cement in all of its structures and pavements, except in special circumstances. In anticipation of a decreasing supply of Type II cement a study of alternatives to Type II cement is being conducted at the Research Council. This study is exploring both the use of fly ash in concrete as a partial replacement of cement and the use of I-P blended cement. A report on the preliminary laboratory studies by Ozyildirim indicates satisfactory strengths with several combinations of cement types and fly ash sources.(9) These early tests also confirmed a lower resistance to scaling at equal ages of concretes containing fly ash as I-P cement during freeze-thaw tests in the presence of 2% sodium chloride solution. Tests are now under way to determine if longer curing periods for concrete containing fly ash will provide adequate resistance to scaling.

Of interest to all highway departments is the recent trend that has been noted for increasing percentages of alkalies in cements. The higher alkalies result from the recycling of flue stack dusts into the kiln in connection with efforts to both reduce pollution and to save energy. This trend introduces a need to reexamine the need for "low-alkali" cements. Generally, the recycling of flue dusts (which are high in alkali content) cannot be carried out when low-alkali cements are manufactured. Consequently, optimum efficiency in energy use cannot be achieved in manufacturing these cements. At the present time many purchasers of cement specify a low-alkali content just to be on the safe side if reactive or potentially reactive aggregates are being furnished in the area. The usefulness of blended (pozzolan) cements for avoiding potentially dangerous combinations needs to be considered.

A problem that must be dealt with by the consumers of cement and concrete is the pre-evaluation of new hydraulic cements for the particular use intended. While considerable reliance is placed on laboratory strength tests, such tests might not always be adequate for accepting substitution of materials of different composition. For example, two types of cement might develop the same strengths after 28 or 90 days but the rate of strength development at 1 to 7 days could be sufficiently different to affect the time at which forms can be removed. Differences in the long-term durability such as differences in freeze-thaw resistance might also occur. Chemical reactivities between the alkalies of the cement and silica or carbonate in the aggregate could also be different. State transportation departments should not continue indefinitely to retain specification requirements that prohibit the use of new energy conservative materials, but it is important that the potential behavior of such new materials be evaluated before there is a complete commitment to their use. In this connection research is needed to develop accelerated evaluation procedures that are not dependent on the composition of the cement.

Fly Ash and Lime

Although "binders" in the broadest sense, fly ash and lime are usually thought of as stabilizing materials and will be discussed in later sections.

Sulfur

The only potential new source of a binder identified by the conference was sulfur. This material could become available in large amounts as a by-product of the removal of sulfur from crude oils and from its removal from stack gases where high sulfur coals or other fuels are being burned. Present research results show that satisfactory pavements can be built using a combination of sulfur and asphalt as the binding agent. However, a major concern in the use of sulfur is the potential hazard of the generation of hydrogen sulfide (H_2S), which is highly toxic. At high temperatures sulfur and asphalt can react to form appreciable amounts of this gas. Researchers studying the use of sulfur and asphalt for highway purposes are well aware of this potential hazard and have carefully monitored mixing and construction sites for the presence of H_2S. No appreciable amounts of H_2S have been detected in any field trials. Laboratory tests indicate that at 300°F (149°C) the reaction proceeds very slowly but accelerates above that level. Consequently, although the process appears safe at normal working temperatures, there is some concern that accidental overheating could result in a problem. In addition to this, the odor of hot sulfur-asphalt mixes could cause objections from the public. These negative features of the sulfur-asphalt combinations tend to discourage acceleration of research on the use of sulfur in this country by state transportation departments, and it is not likely that a high level of interest will develop as long as asphalt supplies remain adequate and reasonably priced. However, should asphalt become scarce and appreciably more expensive than now, interest in the use of sulfur would increase.

The FHWA is sponsoring research on sulfur as a highway material. Its program involves the use of sulfur both in combination with asphalt and as the primary binder. The latter research is primarily seeking a plasticizer to eliminate brittleness of sulfur concretes. A breakthrough in this area could greatly increase the interest in sulfur as a road building material. In Canada, there is also considerable interest in the development of new uses for sulfur, and more extensive experimental sulfur-asphalt pavements have been constructed there. The Canadian interest stems from the availability of excess sulfur stemming from its removal from crude oil -- with the prospects of a continuing increase in their supply. The Canadian research is being monitored by the FHWA and others in the United States, and most of the results will be applicable to United States conditions.

Should findings of the FHWA or the Canadian programs indicate the development of a significantly better or less expensive material, the possibility of using it should be explored. However, on the basis of present knowledge, involvement by the Virginia Department of Highways & Transportation in research on sulfur or sulfur-asphalt binders is not recommended. Only a small amount of sulfur is produced in Virginia, and the cost is relatively high.

Tars

Many of the early roads in this country were constructed using tars that were residuals either from the coke oven process or from gas generating plants using coal and petroleum enrichments in some cases (water gas). Such tars are excellent wetting agents and, when used as primes, penetrate well into the base. Tar concretes have greater resistance to damage from fuel spillage than do asphaltic concretes and have been used to advantage around airports. Tars also generally perform well in base courses and as primes. However, they are susceptible to a much faster rate of hardening through both evaporation of lower molecular weight (lighter) constituents and through chemical reaction (oxidation and/or polymerization). Petroleum asphalts were found to be much less susceptible to these changes and they have performed much better than tars in pavement surfaces. As the asphalts became plentiful, they also became cheaper than tars in the United States and were used in preference to tars. Consequently, only a small amount of tar has been used in highway construction in the United States in recent years. The supply of tar available for highway construction also decreased because all water-gas generation was replaced by natural gas for home use. In addition, coke was partially replaced in the manufacture of steel so that less coke oven tar was available as a by-product of coke manufacture.

The demand for tars as raw products in the chemical industry also increased. In addition, many coke oven plants found it advantageous to burn the tar as fuel in their own installations. Tar has higher Btu's per gallon than comparable petroleum products, and consequently can demand a higher price when sold as a fuel. These facts generally eliminate tar from consideration as a competitive road binder under present conditions and in the near future. However, should a substantial industry to generate gas or manufacture synthetic gasoline from coal be developed over the next 10 to 20 years, the residues from such processes may well become cost-competitive as a road material.

Should tars become available at a competitive price in this country, there is a large body of technical literature that would serve as a guide for evaluating the different products and for construction techniques. South Africa and, to some extent, Australia have long been in the position that tars were less costly than asphalts and have done considerable research on means to upgrade the durability of tar roads by the use of additives such as rubber or polyvinyl chloride. The recent experiences of these countries as well as earlier European and United States experience represent "on-the-shelf" technology that could be utilized quickly in the United States should the need develop.

Wood Resins and Lignins

Some research is being sponsored by the FHWA to determine if a suitable road binder can be prepared from wood resins or lignins. Interest in this possibility stems from the fact that such wood sources are renewable energy forms. Early reports indicate that a product can be manufactured, but as yet no analysis of its probable cost or its performance has been published.

Petroleum Resins

Polyester and other generic type resins derived from petroleum make excellent binders with good durability, and they have an application for special problem areas. However, their high cost and the fact that they are derived from petroleum rule them out of consideration as a general binder for highway pavements.

Workshop No. 2 -- Quality Standards and Quality Control

The second workshop of the conference dealing with quality standards concluded that "All states should be urged to review critically all of their geometric and structural designs, 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."

The specific suggestions included were:

a) Reduction in mixing temperature for asphalt mixtures.

b) Use of drum mixing.

c) Use of aggregate blends that call for the least volume of asphalt per mixture.

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

e) Use of plain concrete instead of reinforced concrete.

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

Although considerable comment was made at the conference concerning the inadequacies of quality standards from the standpoint of maximum energy efficiency, it is questionable that all of the proposed changes would conserve energy on a long-term basis. As discussed earlier, it would be a mistake to sacrifice quality of construction merely for the sake of saving energy during construction. Comments on each of the suggestions are made below.

Reduction in Mixing Temperature

A reduction in the mixing temperature results in a significant reduction in the amount of fuel needed to operate the dryer. The Virginia Department of Highways & Transportation revised its specifications in 1975 to permit lower mixing temperatures with possibly increased moisture in the mixture. In a report to the Bituminous Research Advisory Committee in October 1975, Morris Hecht gave the results of a study of lower mixing temperatures.[10] It was found that temperatures in the range of 230°-240°F (110°-116°C) were adequate for drying aggregates even when initial moisture contents (for sand) were as high as 7%. He reported some minor problems from incomplete coating using normal mixing times. However, adding five seconds to the wet mixing cycle cleared up the problem. Compaction gave no problem. But it was necessary to change the rolling pattern for the cooler mixes. In general, during hot weather rolling is delayed until mixtures heated to 265°-300°F (135°-149°C) (the often-used "high" mixing temperature) have cooled somewhat. This wait is eliminated by mixing at 230°-240°F

(110°-116°C) and rolling must begin immediately after laydown. Hecht's results also showed significantly less asphalt hardening at the lower mixing temperature. About 0.5 gallon of fuel oil per ton (2 liters per metric ton) of aggregate dried was saved in the projects studied. No significant problems have been encountered in using the lower mixing temperatures over the past two construction seasons.

It must be realized that the problem of optimizing fuel consumption during the preparation of asphalt mixes involves much more than reducing the mixing temperature. The amount of moisture to be removed has a major effect on fuel consumption, so that the initial moisture content of the aggregate is very important. The air flow in the dryer and the temperature of the exhaust gases also have significant effects. The National Asphalt Pavement Association has issued a booklet on "Theoretical Computation of the Fuel Used and the Exhaust Produced in Drying Aggregates" (Information Series 61).[11] This booklet gives detailed factors and charts showing the theoretical fuel consumption for different conditions to enable the mixing plant manager to optimize his controls for his own conditions. An important indication from these charts is that, in addition to the direct fuel saving, the production capacity of a dryer can be increased substantially by a reduction of the amount of moisture removed from the aggregate.

The needed mix temperature is determined not only by the pugmill mixing requirements, but consideration must also be given to having the material hot enough for proper laydown and compaction. Conditions during cool weather may, therefore, differ from those during hot weather. The problem of optimizing fuel consumption is one to be worked out by each contractor with his own equipment and aggregate. It is important that the state establish the end results needed and remove any unnecessary restrictions with respect to the moisture content and temperature of the mixes. Virginia's present policy appears to accomplish this objective.

Use of Drum Mixing

The proposal that drum mixing be used to save energy is valid under some conditions, but under other conditions the energy saving (compared to conventional pugmill mixing) might be borderline. Interest in permitting mixing at a lower temperature and higher moisture contents in the mix discharged at the plant was generated largely by the successful application of the drum mixing process. In early production with the McConnaughay process, water was actually introduced into the mixer along with the asphalt at the beginning of the cycle. This produced relatively violent foaming of the mixture which, according to McConnaughay's patent, assists in obtaining a thorough coating. The foaming subsides as moisture is driven off so that at discharge the asphalt mix handles about the same as pugmill mixed material, even though the residual moisture content may be relatively high (1%-3%) by previously used standards.

Later developments in drum mixing have generally eliminated any actual introduction of water other than that contained in the aggregate, and it has been shown that satisfactory products can be attained with essentially dry aggregate. Potential energy savings are related to the amount of water that must be removed from the aggregate. When drum mixing is being utilized for "dry" aggregates and at the same mixing temperature as a pugmill mixer, there is relatively little difference in the theoretical amount of energy required. Heat losses within the plant would be the only theoretical difference. For normal operation of pugmill mixers, hot and essentially dry aggregate is necessary for proper mixing. While a small amount of moisture in the pugmill can be tolerated, too much moisture will cause foaming in the mixture with subsequent difficulties at discharge.

Experiments with the drum mixing process in North Dakota in 1972 demonstrated that satisfactory mixes could be made at temperatures as low as 200°-210°F (93°-99°C).(12) On these jobs a vibratory roller was operated close to the paver, and proper compaction was attained. In similar experiments in Iowa with mixing temperatures in the 190°-220°F (88°-104°C) range difficulty was experienced in obtaining proper compaction with a static roller. However, Granley reported that the roller on this job lagged as much as 1/2 mile (.8 km) behind the paver, which may have been a significant factor in the failure to attain proper compaction. For this project the temperature was increased to 245°-255°F (118°-124°C), and proper density was attained. There is some evidence that for drum mixing there is a moisture/vapor related phenomenon in the 220°-250°F (104°-121°C) temperature range that inhibits compaction of the mixture on the roadway. This is believed to relate to moisture being emitted from the coarse aggregate after laydown. At higher mixing temperatures most of this moisture is removed during mixing, and at lower temperatures volatilization of internally trapped moisture does not occur. Conversations with a number of highway engineers from various states have confirmed that there has been a trend to use the higher temperature range (250°-260° F [121°-127°C]) for most drum mixing because compaction difficulties are avoided at the higher temperature.

Experience in Virginia with the limited number of drum mixers available has been that relatively dry aggregates are being used at high temperatures (275°-300°F [135°-149°C]). Under these conditions there would be no saving of fuel compared to batch mixing with pugmills, except for that resulting from lower heat losses or better overall plant efficiency, should that be the case.

Inasmuch as the energy required for drying and mixing varies significantly with the amount of moisture removed, research is needed to determine the optimum conditions for dryer-drum mixes, taking into account the need for adequate compaction as well as the energy saving potential of removing less water.

Use of Aggregate Blends for Minimum Asphalt Content

The suggested use of aggregate combinations requiring less asphalt is concerned primarily with saving asphalt rather than energy. Careful evaluation of its effects should be made before it is adopted. Recent studies in Georgia and elsewhere have shown that the fatigue life of the pavement could be shortened by too low an asphalt content.

Thickness Design Requirements

The suggestion that design criteria be modified to permit thinner pavements also needs to be studied with care before adoption. While overdesign does increase the use of energy and materials on a first-cost basis, the full life cycle must be considered. Any decrease in the life expectancy of a pavement most likely would result in an overall energy loss.

Use of Unreinforced Concrete

There are a number of uncertainties associated with the substitution of plain (unreinforced) concrete for reinforced concrete. Specific study would be needed for each application to ascertain whether or not potential problems from cracking and misalignment of unreinforced concrete outweigh the material and energy saving aspects of eliminating steel.

Energy Spent on Cosmetic Aspects of Roadside

The energy saving aspects of eliminating highway plantings or of decreased mowing, etc. must be weighed against the appearance of the highway and its effect on the enjoyment of the public. A severe reduction of activities in this area could adversely affect the quality of the environment. However, a number of states have taken action to reduce the frequency of mowing and are investigating types of plantings that would require minimum care.

Revision of Specifications

In general it is agreed that quality standards and specifications need to be reviewed from the standpoint of energy conservation. It is expected that only a relatively few material specifications unnecessarily require expenditures of large amounts of energy. However, complaints center on the "recipe" type construction procedures that limit the thicknesses of lifts for base course or surface materials, along with stated compaction procedures. Existing minimum temperature requirements for asphalt mixtures may also be unnecessary under some conditions. Acceleration of the trend to establish end-result requirements in these areas is needed. A basic problem appears to be the need to optimize the process by better design and adjustment of asphalt mixing plants to avoid wasting heat and energy. As the cost of energy rises, it is expected that the trend for more energy-efficient plants and more attention to optimum operating conditions will develop since the payoff in reduced production costs will be greater.

Workshop No. 3 -- Aggregates

Workshop No. 3 covered discussion of energy use in connection with the production and use of aggregates. The energy needed to produce natural aggregates is primarily the energy needed to crush stone or , in the case of gravel, oversize rock. It is possible that an appreciable saving in energy could be made by adopting specifications using larger size aggregates than is now the custom, and states should review their procedures from this viewpoint. However, a more significant energy concern relating to aggregates is the energy used in transporting the aggregates from the quarry to the job site. Aggregates constitute 70% to 100% of the solid volume of pavement structures, and moving the large amounts of materials required over long distances can result in high costs, with the cost of transportation being the major part. Consequently, the availability of suitable aggregates close to the job site is of paramount importance in the initial design of a project. Ways must be found to utilize local borderline materials through upgrading or stabilization procedures. This consideration is one of long standing for which conservation of materials and reduced costs have been the primary motivation. Thus, energy considerations are additional and increasingly important incentives for accomplishing existing objectives. It has been shown that the energy for producing (crushing, screening, and stockpiling) aggregates is low compared to that required to produce other materials used in highway construction (asphalt, cement, etc.). Crushed stone base courses may rate favorably on the basis of energy considerations when the material must be transported for reasonably short distances. The advantages for longer hauls are greatly reduced because of the greater volume of material needed to provide the equivalent of stabilized bases. In making a decision among different types of bases, careful consideration must be given to the relative durabilities of the structures obtained by various types of construction. Under present circumstances, decisions need to be based on the estimated minimum costs for the level of performance required. However, there does appear to be a need to reassess the potential performance of base courses requiring the use of minimal amounts of energy derived from petroleum or natural gas. A primary need in this area is the development of realistic energy and equivalency factors that could be universally applied to calculate the energy used for different alternatives.

The workshop also considered the use of by-product (slag) and waste materials (concrete rubble, etc.) to augment aggregate supplies. Where such materials are available close to the job site, they offer a significant potential for overall energy conservation.

Synthetic lightweight aggregates have an advantage from the standpoint of reduced mass to be moved, but these materials are made by sintering processes and require large amounts of energy in manufacture. A number of companies find themselves unable to compete with natural materials as the cost of energy rises.

Workshop No. 4 -- Earthwork or Existing Roadway Preparation

The most important factor in this subject area is the use of on-site materials to minimize the expenditure of energy. The cost and energy requirement for stabilization procedures must be compared with costs of energy required to remove and replace unsuitable materials. One significant factor in earthwork construction such as embankments is the optimum utilization of equipment that can place and compact material in thicker than usual lifts; however, in many cases state specifications continue to require limited thicknesses with the expenditure of appreciably more energy.

The workshop also recommended reconsideration of requirements to remove stumps and topsoil from areas to be filled. A number of states now permit such materials to be left in place where grade lines are more than six feet above the existing surface.

The workshop suggested alternatives of geometric design standards, such as steeper side slopes and altered grade and sight distance requirements, to reduce earthwork volumes. However, such actions could adversely affect safety and might also lead to overall expenditures of greater amounts of energy, since vehicles using the finished roadway would each consume larger amounts of energy in travel. In most cases, the energy in the additional fuel used by each of the thousands of vehicles using the pavement with steeper grades would quickly exceed the extra energy needed for constructing flatter grades.

Workshop No. 5 -- Waste Materials, By-Products, and Recycled Products

Interest in the use of waste materials in highway construction grew from the fact that on the one hand very large volumes of certain industrial and mining wastes accumulate each year, and on the other hand very large volumes of aggregates are required for constructing highways. Thus, when solid wastes can be utilized in lieu of conventional aggregates both problems are solved. It is also generally assumed that the use of waste products will be more economical and require less energy than the use of conventional materials, because the waste is "free" and no energy is required for its manufacture. However, this assumption is often incorrect. The cost and energy required for processing and delivering the waste product to a job site can often exceed the cost and energy requirements of conventional materials. A good example is the use of reclaimed ground rubber from tires. The cost of collecting the tires and removing and processing the rubber makes the product relatively expensive compared to the cost of the usual components of the mixture. Consequently, it is necessary to show significant benefits from the rubber in order to justify its use in highway construction.

The waste products that have the best potential for use in highways are the mineral wastes. These usually result from a mining operation or a manufacturing process and are usually available in large quantities at a single site. When such products can be used near their original location, there are three factors justifying their use:

1. They provide an additional source of aggregate, thus conserving natural resources;

2. they save energy where conventional materials would have to be quarried and hauled to the job site; and

3. their use removes unsightly piles of material and thereby improves the environment.

The conference report cited the findings of the NCHRP study on potential replacements for highway aggregates.(13) Annually about 3.5 billion tons (3,174 billion kg) of these solid wastes are being generated. The materials with the largest tonnage include fly ash, blast furnace slag, steel slag, foundry wastes, coal refuse, copper tailings, dredge spoils, phosphate slimes, taconite tailings, and iron ore tailings. Another potential source of waste material is the sludges from limestone scrubbers used in the removal of sulfur dioxide from stack gases.

Blast furnace slag and fly ash are the two by-products that have been used most extensively in highway construction, and each has considerable potential for further use with energy saving payoff.

Slag

Slags are probably the best known of industrial by-products finding utilization in highway construction. However, slags derived from different processes can behave quite differently. Blast furnace slags are the kind most often encountered and are in such demand that they are fully utilized. According to Emery, the world consumption of blast furnace slag is in the order of 120 million tons (110 billion kg) a year.(14)

Steel slags are also useful, but they require more care in their selection and use because of their potential for expansion. Expansive tendencies can be offset by treatment with acids prior to use. (When available, pickle liquids are useful for this purpose.) Steel slags contain 10%-20% steel by weight of the slag, and they are normally processed to recover part of this steel. Since the crushed material from this initial recovery is still high in iron, lime, and manganese, in many operations much of this secondary residue is reused as a part of the blast furnace burden. Slags from other metallurgical processes are also available and can be utilized for construction purposes.

Because of their hydraulic properties there is increasing interest in the use of slags in slag cement or in stabilization projects making use of the hydraulic cementing nature of the slags. It is expected that such usage will increase, leaving less of this material for use as aggregate. When slags are used in lieu of other hydraulic cements, there is significant energy conservation in that the energy to manufacture the material has already been spent as a part of the metal manufacture, and relatively little extra energy is needed for processing.

Fly Ash

To the power plant manager, fly ash is generally a nuisance waste material that must be disposed of, but to the highway engineer this material has a significant potential for applications as a highway material. When used under proper circumstances, fly ash can provide substantial savings of energy and money while at the same time providing performance better than that obtained with a number of conventional techniques or materials. The versatility of fly ash is derived from its pozzolanic nature. When mixed with lime or cement, the silica of the fly ash in the presence of water reacts with the calcium hydroxide (lime) added or the calcium hydroxide released from portland cement during hydration to form a solid mass of considerable strength. Much research has been done on ways to utilize fly ash. The results are given in an implementation package published by the FHWA.(15) The purpose of that report is to encourage the utilization of fly ash in highway construction. It includes discussions of the characteristics of fly ash and guidelines to its use as

- —lime- or cement-fly ash-aggregate pavements;
- —stabilized fly ash pavements (lime fly ash aggregate or cement fly ash aggregates);
- —soil stabilizers and soil modifiers (lime-fly ash or cement-fly ash);
- —fly ash-soil bases and subbases;
- —fly ash embankments;
- —structural backfill; and
- —a grouting material.

In addition to these uses, the use of fly ash in blended cements or as a component in concrete has already been discussed. All of the applications mentioned have been successfully carried out in full-scale production either here in the United States or in Europe. Europe has utilized its available fly ash to a much larger extent than has the United States.

The need for utilizing high tonnages of fly ash stems primarily from the large cost and environmental problems associated with its disposal and the need to find the economic substitutes for conventional construction materials. The National Ash Association and Edison Electric Institute have recently compiled a summary of the amounts of fly ash, bottom ash, and boiler slag collected and used in the United States in 1976. This summary is given in Table 1. As indicated, only about 13% of the total fly ash is now being used. Consequently, much greater utilization is possible. However, there are several problems whioh prevent complete utilization.

Ash is being produced continuously as a by-product of power production. Since utilization is generally intermittent, provisions must be made for disposal or storage. In some instances disposal is in a sluice pond along with the bottom ash and pyrites. When disposal or storage is accomplished in this manner, the ash is very difficult to use in highway construction because further processing becomes costly. However, John Faber, executive director of the National Ash Association, points out that even though about one-half of the ash is now disposed of in ponds, 70% of the plants could deliver dry fly ash separated from bottom ash and pyrites. This 70% of the plants generate more than 80% of the ash. Thus, if markets were available, sufficient quantities of usable material could be supplied.

It must also be kept in mind that all fly ashes are not the same. Therefore, for many uses the characteristics of the available material must be determined and selection made accordingly. ASTM Committee C-9 has adopted a specification (ASTM C-618) for pozzolanic materials including fly ash to be used in concrete, and a number of sources will supply fly ash meeting this specification. Other evaluation procedures are included in the Implementation Package 76-16 previously mentioned. This manual may be used as a guide for a wide range of applications.(15) The NCHRP synthesis report on "Lime-Fly Ash Stabilized Bases and Subbases" also provides excellent guidelines on design and construction procedures for the subject application.(16) Although the Virginia Department of Highways and Transportation has utilized fly ash in a number of regular construction and experimental applications, the strong likelihood that the amounts of fly ash available within the state will increase suggests that greater and more extensive efforts to utilize fly ash should be made. A program to evaluate the properties of the fly ash being produced within the state and experimental construction of projects utilizing such materials should be conducted.

Mining Wastes

A number of wastes are suitable for use in highway embankments, bases, and subbases, or can be made suitable with relatively little effort. There are cases on record where a state has gone to considerable trouble to remove large quantities of mining wastes from the

Table 1 - Ash Collection & Utilization 1976

(Million Tons)
(1 ton = 907 kg)

	Fly Ash Tons x 10^6	Bottom Ash Tons x 10^6	Boiler Slag (if separated from Bottom Ash) Tons x 10^6
1. TOTAL ASH COLLECTED	42.8	14.3	4.8
2. ASH UTILIZED	5.7	4.5	2.2
3. UTILIZATION PERCENTAGE			
A. COMMERCIAL UTILIZATION			
a. Used in Type 1-P cement-ASTM 595-71 or mixed with raw material before forming cement clinker	9	2	2
b. Partial replacement of cement in concrete or concrete products	16	---	---
c. Lightweight aggregate	2	2	---
d. Stabilization and roads	4	15	10
e. Fill for roads, reclamation & ecology dikes, etc.	26	---	---
f. Filler in asphalt mix	4	---	---
g. Ice control	---	10	5
h. Blast grit and roofing granules	---	---	55
i. Miscellaneous	9	20	14
B. ASH REMOVED FROM PLANT SITES AT NO COST TO UTILITY	5	23	8
C. ASH UTILIZED FROM DISPOSAL SITES AFTER DISPOSAL COSTS	25	28	6
	100	100	100

COMPARATIVE RESULTS

ASH COLLECTED	1966*	1973	1974	1975	1976
Fly Ash	17.1	34.6	40.4	42.3	42.8
Bottom Ash	8.1	10.7	14.3	13.1	14.3
Boiler Slag		4.0	4.8	4.6	4.8
TOTAL ASH COLLECTED - TONS x 10^6	25.2	49.3	59.5	60.0	61.9
ASH UTILIZED					
Fly Ash	1.4	3.9	3.4	4.5	5.7
Bottom Ash	1.7	2.3	2.9	3.5	4.5
Boiler Slag		1.8	2.4	1.8	2.2
TOTAL ASH UTILIZED - TONS x 10^6	3.1	8.0	8.7	9.8	12.4
PERCENT OF ASH UTILIZED					
% Fly Ash	7.9	11.4	8.4	10.6	13.3
% Bottom Ash	21.0	21.9	20.3	26.7	31.5
% Boiler Slag		44.3	50.0	40.0	45.8
PERCENT OF TOTAL ASH UTILIZED	12.1	16.3	14.6	16.4	20.0

*First year that data was taken
1967-1972 data omitted from tabulation because of space limitation.

ASH DISPOSAL DATA

1. 49% of the ash is trucked to the disposal area and 51% is sluiced.
2. 28% of the fly ash and bottom ash is separated before disposal and 72% is disposed of together.
3. 35% of the disposal ponds have some form of floating ash reappearing.
4. 68% of the power plants have dry collecting and loading facilities for fly ash.

Compiled by the National Ash Association and Edison Electric Institute.

right-of-way and brought in conventional materials which, from the standpoint of performance, were in reality no better than the material moved in that particular application. Obviously, the removal of suitable material and replacement with other materials constitute a waste of both money and energy. The FHWA sponsored a study to locate the major sources of mineral wastes in the United States and a general evaluation of their properties. A three-volume report of this study is now available.(17) These reports show that in Virginia the major mining wastes are from coal mines. More detailed information concerning the locations and characteristics of these materials appears needed.

Recycled Materials

Recycling has been promoted as a means of conserving materials and as a way to avoid a disposal problem with the rubble or other debris from old pavements being rebuilt. It has often been assumed that energy will be saved also. However, the energy saving potential is highly dependent on the distance the recycled material must be moved.

Both asphalt concrete and portland cement concrete pavements have been recycled in a number of ways.

Recycled Portland Cement Concrete

Portland cement concrete may be broken up and crushed to usable sizes and used as an aggregate in either base course or asphalt paving. Recent experiences in projects utilizing crushed portland cement concrete pavements as aggregate for lean concrete subbases ("econocrete") under new portland cement concrete pavements were reported at the January 1978 TRB meeting.(18, 19, 20, 21) The reports showed successful application of the principle. Economy resulted from both the elimination of the need to dispose of the old pavement rubble in fills or dumps and from the decreased need for new aggregates. From the preparation standpoint, little energy is saved by processing rubble from old concrete, but when hauling distances for the rubble to the job site are small compared to the hauling distance for conventional materials, a significant amount of transportation energy can be saved.

Also presented at the 1978 meeting of TRB was a paper on the economic feasibility of recycling concrete on a commercial basis for use as aggregate. This paper examined the costs of processing rubble from buildings as well as pavements. Rubble from buildings included wood, metals, plaster, and the debris that must be removed before reuse in concrete. It was shown that the recycled aggregate was competitive with natural aggregate in urban areas generating large amounts of rubble.(22) The crushing of old pavement made with plain concrete does not create any unusual problems, but where reinforcing steel is present, the task is considerably more difficult since such steel must be removed. However, the NCHRP synthesis report shows that manual removal of reinforcing steel can be accomplished satisfactorily. Such steel can be sold for scrap so that the cost of removal is partially recovered.[23] In a report on the rehabilitation of a runway at the Jacksonville International Airport,[18] it was reported that approximately 80% of the dowel bars were recovered in excellent condition and could have been reused in new pavement.

Recycled Asphalt Pavement

Within the past few years much interest has developed in the recycling of asphalt pavements. Recycling is accomplished in a number of ways. To assist in avoiding confusion, the National Asphalt Pavement Association (NAPA) and the Asphalt Institute have jointly recommended definitions applicable to recycling. These follow.[24]

"Recycling--The reuse, usually after some processing, of a material that has already served its first-intended purpose.

Hot-Mix Recycling--One of several methods where the major portion of the existing pavement structure, including in some cases the underlying untreated base material, is removed, sized and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate and/or a softening agent. The finished product is a hot-mix asphalt base, binder, or surface course.

Cold-Mix Recycling--One of several methods where the entire existing pavement structure, including in some cases the underlying untreated base material, is processed in-place or removed and processed at a central plant. The materials are mixed cold and can be reused as an aggregate base, or asphalt and/or other materials can be added during mixing to provide a higher strength base. This process requires that an asphalt surface course be used.

Surface Recycling--One of several methods where the surface of an existing asphalt pavement is planed, milled or heated in place. In the later case, the pavement may be scarified, remixed, relaid and rolled. Additionally, asphalts, softening agents, minimal amounts of new asphalt hot-mix, aggregates, or combinations of these may be added to obtain desirable mixture and surface characteristics. The finished product may be used as the final surface or may, in some instances, be overlaid with an asphalt surface course."

The NCHRP synthesis report[23] does not completely follow this classification. That report discusses recycling from the standpoint of--

1) Surface recycling--defined as reworking the top inch of pavement;

2) in-place surface and base recycling--defined as the pulverization of more than 1 inch of the pavement and base followed by reshaping and compaction; and

3) central plant recycling--which requires the removal of material from the roadway, mixing in a plant, and laydown and compaction.

A relatively large body of literature on asphalt recycling has been published, and a number of activities are under way in this area. The FHWA is conducting a demonstration project on "Recycling Asphalt Pavements" (Demonstration Project 39) and also a National Experimental and Evaluation Program (NEEP Project 22, "Recycled Asphalt Pavements"). Hopefully, these projects should lead to guidelines for optimum design, construction techniques, and specifications for recycled asphalt pavements. The NAPA has also issued guideline reports to its members. These include a special report by Dr. Richard Smith on "Considerations for Producing Quality Recycled Hot-Mixed Asphalt"[25] and a "State of the Art: Hot Recycling." The latter report is Vol 1, No. 1 of a planned series titled "Recycling Report." Additional reports will be issued as material becomes available.[26] This report describes several techniques for using conventional pugmill mixers, drum mixers, and specialized plants for recycling hot-mix. The chief problems reported that must be overcome are those of material buildup on the metal surfaces of the equipment and the smoke generated when heating the reclaimed material. A detailed report on the operations of the specialized plant is available. This is the FHWA Implementation Package 75-5 on "Recycled Asphalt Concrete."[27] A later report describing some additional plant improvements has also been published in an AAPT Proceedings.[28] The more comprehensive State of the Art report prepared as a part of NCHRP synthesis project 20-5 has already been referenced.[23]

A conference session on the recycling of asphalt pavements was held during the 1978 TRB meeting. At that session, five presentations were made concerning the experiences with asphalt recycling in a number of states.

Denton and Tunnicliff discussed recycling with conventional plants and equipment;(29) Welsch discussed the experience in Texas;(30) Ingberg discussed Minnesota's experience;(31) McGhee and Judd discussed Arizona's efforts;(32) and Brown covered Iowa's experience.(33)

In general, these presentations confirmed the difficulties with respect to controlling emissions indicated by the earlier reports just mentioned. Different approaches were taken to solve problems encountered, and each had reasonable success. Equipment manufacturers and contractors are still experimenting, and it is likely that further improvements will be made.

Some recycling has been done in Virginia. Hughes reported on the "Evaluation of Recycled Asphaltic Concrete."(34) In this project, the Minnesota heat transfer method was used. That is, virgin aggregate was heated to a very high temperature (450°F [232°C]) and this hot aggregate and cold pulverized reclaimed mix were introduced into the pugmill mixer--a dry mixing cycle of 15 seconds and a wet mixing cycle of 45 seconds were used. The resulting mix temperature was about 280°F (138°C). With this procedure, up to 50% reclaimed mixture was used. It is noted, however, that computations showed the use of this technique on this project required essentially the same amount of energy as would have been required with 100% new material mixed in the conventional manner. These computations were based on a 30-mile (48-km) haul of the required asphalt cement, a 12-mile (19-km) haul of the virgin material, a 24-mile (38-km) haul of the reclaimed material to the crusher, and a 12-mile (19-km) haul of the crushed material to the plant. The large amount of energy consumed in transporting the reclaimed material from the roadway to the crusher and then to the plant was the determining factor in this project. Although the report on the FHWA's demonstration project 39 is not yet available, advance indications are that substantial energy savings were shown for all of the projects included in that study.

In all recycling projects the conservation of energy is only one of several considerations. The cost and availability of virgin raw materials, and the cost and difficulty of disposing of any removed material will most likely be the controlling factors rather than energy savings per se in a decision to recycle. However, as the cost of energy increases, and should asphalt become scarce, it is expected that recycling will become more attractive and will be used to a greater extent. Rather obviously, energy savings will be maximized by keeping the hauling distances at a minimum. Costs also should be minimal under these conditions.

The Department should continue to explore the benefits of recycling and work towards developing guidelines for judging the potential saving under the circumstances encountered for specific projects. The possibility of reduced life for reclaimed pavements carrying high traffic volumes should be a factor in making the judgment. The findings of the national programs being conducted by the FHWA and NCHRP should be monitored and utilized for Virginia conditions where applicable. In such studies, emphasis should be given to processes that can be performed at or near the job site to avoid high expenditures of energy in transportation.

Workshop No. 6 -- Production and Construction Techniques

Workshop No. 6 suggested 12 possibilities of using existing technology to reduce energy consumption during the construction of highways and bridges.

A large number of these suggestions involve increased efficiency of operations to avoid idle time for equipment with the reasonable assumption that such efficiency reduces both costs and energy use. However, the extent of energy saving has not been determined for most of the suggested operations. Comments on the items listed in the conference report follow.

(1) Permit higher moisture contents and lower mixing temperatures.

This same suggestion was made by the workshop on quality standards and has been discussed under that section of this report. (See page 12.)

(2) Permit uniform ramp widths on interchanges with tapered ends to be defined by paint or seal coats.

The conferees concluded that any such standardization of requirements from job to job would permit a speed-up of operations and energy saving by decreasing greatly idle time for men and equipment.

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

Traditionally, bridge designers do not standardize repetitive dimensions of such things as "A" columns, footings, beam spacing, bridge curbs, and bridge skews. It was the conferees' opinion that by standardizing these dimensions much energy and materials could be saved through the reuse of forms and reduction in labor needed to construct nonstandard sections.

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

Discussions at the closing session of the conference questioned this suggestion. It was pointed out that the application of paints required maintenance which would likely eventually lead to more energy being used. In addition, it was pointed out that the resinous materials mentioned were based on petroleum products and were energy-intensive. The consensus was that form finishing without either painting or rubbing would be the most energy-conservative policy.

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

There has been a general recognition in recent years that thicker lifts of asphalt paving than have been considered feasible with older equipment are now placeable and can be properly compacted. States should remove arbitrary requirements and allow the contractor to use the optimum system with his equipment.

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

This suggestion is based on the idea that modern equipment is able to place and compact large volumes of hot paving materials quickly, thus avoiding problems brought about by rapid cooling of the mixture in cold weather. Whether or not the engineer could take advantage of this characteristic to save total energy for the project would depend upon the conditions existing for each project. As a general rule, other things being equal, cold weather construction would be less energy efficient than hot weather construction since more heat would be required to maintain materials in a workable condition. However, completion of a facility in cold weather to eliminate traffic delays would probably result in a energy saving as compared to continued delays until the next paving season.

(7) <u>Develop procedures routinely to 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.</u>

This is also an area where decisions must be made on the merits of each situation. Where there is no urgency to complete or move ahead with a project, the least expenditure of energy to obtain dry workable conditions is to allow the sun (solar energy) to do the drying. However, where time is a factor elimination of a bottleneck such as too-wet subgrade by the expenditure of a limited amount of energy might result in a significant overall saving by avoiding delays in other stages of construction.

(8) <u>To minimize equipment delays, use nuclear density gauges and nuclear moisture gauges on a routine basis for inspecting and accepting materials.</u>

More rapid testing is needed in all phases of construction and there is considerable interest in developing such rapid tests. However, the direct saving of energy from such testing may be minimal. Time, and consequently money, would be saved by more efficient utilization of equipment.

(9) <u>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.</u>

This suggestion relates to more efficient planning and utilization of trucks and equipment. Obviously, any fuel (or energy) spent while equipment is idling is fuel wasted. Surge tanks provide a means for minimizing lost time in loading trucks, etc.

(10) <u>Make greater use of in-place mixing of on-site material.</u>

As was discussed in the section on earthwork, the use of in situ materials saves large amounts of energy that would normally be required for removing the material for processing and return to the job site. In-place mixing for soil stabilization should be employed to a greater extent. The development of new and better stabilization procedures has long been a priority objective in this area, and energy conservation is only an added incentive for accomplishing the objective.

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

The use of this type of form provides for a more efficient operation. However, the greatest saving may be in labor rather than energy.

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

Discussions of this suggestion pointed out that the contractor would be in a better position to plan operations and purchase equipment under a continuing program and with no changes in specifications. However, such a "stand pat" policy by a state may destroy initiative on the part of the contractor and state alike in making use of new developments and in devising energy-conservative procedures.

In addition to these 12 suggestions, the conferees also reported 6 other innovations that appeared to have energy saving possibilities.

The first of these suggested a study to determine if energy saving resulted from designing a bridge so that paving operations could be continuous over it. Savings in such operations would most likely be in time and labor rather than in total energy required.

The second suggestion related to the use of precast panels for bridges. The energy saving in such operations may depend greatly on the size of the bridge. In a report on "In-house Fabrication of Precast Concrete Bridge Slabs," Michael Sprinkel discusses the energy saving potential of precast panels for small bridges.[35] Savings in cost would most likely vary considerably depending on whether the work is done in-house or by contract. From the energy viewpoint one of the more significant findings of the report was the saving in fuel costs for the crews travelling to and from the job site. Sprinkel reported that fuel consumed in such travel was reduced by 50% to 75%.

The use of prefabricated laminated wood panels treated to eliminate decay and destruction by termites also has a potential for saving critical energy in that the wood represents a renewable source derived from solar energy. Experimental "Glulam" bridges are now being considered for use in Virginia. Virginia has also recently installed the world's first "Press-Lam" bridge, using elements made by a process for fabricating laminated wood members which are essentially competitive in cost with treated timbers and lumber. If performance is satisfactory, these elements may become very useful for small rural bridges.

A detailed analysis should be made to show the relative energy use and cost for cast-in-place portland cement concrete bridges and precast decks. This analysis should include the several classes and designs of bridges as well as the size of the spans. Such an analysis should establish guidelines as to the type of construction likely to be most economical and least energy-intensive under given conditions.

Suggestion 3 on the use of high pressure water tunneling techniques for roadway rock excavation in urban areas, and suggestion 4 on the use of laser beams for line control on excavators and pavers were based on conjecture. Consideration, of course, should be given to all new techniques, but it is doubtful if energy use would be a major consideration for the adoption of such procedures.

Suggestion 5 was to build dense mats on bituminous base courses with emulsion instead of cutbacks or hot asphalt. This suggestion is very often made on the basis that a large amount of energy is used to heat aggregate in preparing a hot-mix and that this energy can be saved by use of emulsions in cold mixes. However, a wide range of possibilities, which may or may not lead to energy saving, exist. These will be discussed in the following section on "Use of Emulsions to Conserve Energy."

The final suggestion for innovations in this area was to use coal to provide heat in the aggregate dryer for a hot-mix plant operation. Some trial experiments have demonstrated that such operation is possible, but under present conditions where fuel oil and gas are still available at reasonable prices contractors have relatively little interest in shifting to coal. It is believed that such interest is not likely to develop in the near future. From the standpoint of the Department, there should be little concern other than to assure that such equipment performs satisfactorily.

The Use of Asphalt Emulsions to Conserve Energy

As is well known, asphalt emulsions have been available for use in highway construction and maintenance for some time. The extent of use for various purposes has varied considerably among the different states, depending partly on the conditions in the state and partly on the personal preferences of the highway engineers and contractors involved. However, a renewed interest in the use of emulsions developed in 1973 with the petroleum shortage. Most of this interest centered on the substitution of emulsions for cutbacks. Such substitution represents a saving of gasoline or kerosene that would otherwise be wasted by evaporation into the air. Since such evaporation also contributes to air pollution, there is further incentive to make this change. The FHWA issued a notice in January 1974 which indicated that, based on the quantity of cutback asphalt used in 1972, 309 million gallons (1.17 million m^3) of petroleum products then in critical supply could be saved.[36] A 1977 report by Kirwan and Maday[37] of the U.S. Environmental Protection Agency discusses the air quality and energy conservation benefits from using emulsions to replace cutback asphalts in certain paving operations. This report estimates that energy equivalent to 465 million gallons (1.76 million m^3) of gasoline went into cutbacks during 1975. The evaporation of most of this into the air accounted for 2.3% of the estimated national hydrocarbon emissions, and in some states cutback emissions were as high as 15% of the hydrocarbon emissions. It was also pointed out that most of the cutbacks are used in hot weather when air stagnation problems are at their worst and when the formation of oxidants from photochemical synthesis of hydrocarbon emissions is most likely.

For these reasons, in addition to energy considerations, there are incentives to reduce the use of cutbacks as much as possible. Adequate technology is available for most construction and maintenance operations such as seal coats, tack-coats, and surface treatments — the major drawback in these areas is a reluctance to change. However, for priming and mixing of dense-graded aggregate mixtures, the technology in the use of emulsions has not progressed to the state that these materials can be considered completely reliable. Research in these areas is continuing with considerable emphasis being placed on eliminating the use of petroleum distillates in mixing emulsions for dense-graded base courses. Satisfactory priming is attained with CMS type emulsions although, generally, penetration into dense bases is less than that obtained with cutbacks.

In September 1974, 42 states permitted emulsions to be substituted for cutbacks[38] and probably a greater number now have such a provision. However, the extent to which this shift has been made is not known. In some areas an attitude of "We'll use cutbacks as long as we can get them" has been expressed. At the same time, some asphalt suppliers have taken the attitude that "We'll furnish cutbacks as long as customers ask for them." These attitudes mean that governmental regulations may be needed to eliminate unnecessary use of petroleum distillates in cutbacks with its consequent waste. It is likely that such regulations will be established by the EPA as an antipollution measure. In Virginia action has already been taken to phase out the use of cutbacks for most applications. Perhaps the greatest need is to develop expertise among state maintenance forces and contractors in the use of emulsions. It is well established that expertise in using cutbacks does not provide the knowledge necessary to use emulsions properly. In particular, where cold maintenance mixes are involved there is a need to understand the interaction between the various types and grades of emulsions with the aggregate being used so that handling and compaction conditions can be optimized.

Workshop No. 7 -- New Products and Procedures - Past 1985

The purpose of this workshop was to consider long-range possibilities or needs without necessarily evaluating the probabilities. The general recommendations of the workshop were 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. Consideration should be given to the energy requirements for operations and maintenance, including vehicle operating needs. This viewpoint was taken in the discussions and literature search leading to the preparation of this report. However, there may be a need for emphasizing such considerations throughout all the operational activities of the Department. In particular, the possibilities of saving energy by using flatter grades to minimize fuel use by vehicles should be explored. Even though the initial expenditure of energy during construction might be greater for constructing flatter slopes, the saving in energy for vehicle operations could outweigh this disadvantage.

It is believed that the suggestions made that better information be obtained on the energy required to produce various components of the highway and information on the energy requirements of different modes of transportation are being followed. A number of reports concerning these matters have been published since the conference and such studies are continuing. The TRB task force that was primarily responsible for organizing the conference has remained in being and is continuing to monitor developments with respect to the optimization of the use of energy and materials in highway construction.

One of its activities is to prepare recommendations for energy-use factors in the manufacture of different type highway materials and for various construction operations, including the transport of materials. The recommended factors would be used by all parties making estimates of energy requirements so as to obtain consistent comparisons. The Texas Transportation Institute is preparing for the FHWA a synopsis of the energy conservation potential for a number of the suggestions made at the conference. It is expected that this publication will serve to define the most promising areas for further consideration.

There is considerable research under way to discover better maintenance techniques and materials, and such research does consider the speed at which repairs can be made to be very important. However, serious consideration of the suggestion made that asphalt pavements be used as solar energy collectors is still in the future.

ENERGY SAVING OPPORTUNITIES IN MAINTENANCE ACTIVITIES

General Maintenance Strategy

Because of the shortage of energy and money, it has sometimes been suggested that maintenance activities be delayed. However, in a study conducted by the Utah Department of Transportation, this veiwpoint has been shown to be fallacious. In his report entitled "Good Roads Cost Less," Petersen showed that both energy and money would be saved by prompt maintenance and overlays to maintain Utah roads at a good level of performance.(39) He used the pavement service index (PSI) as a guide and showed that the lowest annual average cost for maintenance was obtained when overlays were made at frequencies sufficient to maintain good service levels. A PSI of 2.5 was used as the criterion for overlaying high volume roads and a PSI of 2.0 for low volume roads. Petersen also showed significant increases in fuel costs to motorists when pavements were allowed to deteriorate. He stated that bad roads increased fuel consumption by 25%.

Use of Emulsions in Lieu of Cutbacks

As has already been discussed, the substitution of emulsions for cutbacks in all suitable applications is being urged by the FHWA and EPA, both as a means for conserving energy and as an antipollution measure. As stated, the Department is already making the transition from cutbacks to emulsions.

In general, it is considered that the technology in using emulsions in lieu of cutbacks for such activities as chip seals, tack-coats, and maintenance patching is well established. However, as indicated earlier, maintenance crews must become familiar with the behavior of emulsions, and the proper selection of type and grade of emulsion for specific purposes will control to a great extent the successful utilization of emulsions.

Reduction of Mowing Operations and Other Cleanup Activities

The high cost of roadside maintenance has already led to a reduction of mowing frequency in a number of areas, and Virginia is in a transition period of reducing mowing to a considerable extent. Obviously, the energy saving is in direct proportion to the amount of reduction in miles mowed. The need in this area is to balance environmental and safety considerations with the cost of mowing. Also associated with environmental considerations is the need to pick up and dispose of highway litter. Litter has long been recognized as a nuisance, and many efforts have been made to reduce the amount of litter with only modest success. Further efforts need to be made. Any reduction in the frequency of cleanup operations that is possible without serious detriment to the environment saves energy and money by elimination of a nonproductive activity.

Guardrail Straightening and Salvage of Metal Posts and Signs

The NCHRP report on "Recycling Materials for Highways" shows that at least 33 states regularly straighten and reuse guardrails.[23] This practice represents a significant saving in energy as well as money since the manufacture of new metal products is very energy-intensive. The straightening and rebuilding of guardrails requires only a fraction of the manufacturing energy. The report indicates that sign blanks are also regularly reused by a large number of states. Only a very few states reported reuse of sign posts and delineator posts. Such salvage and reuse of metal products generally provide an opportunity to save significant money, and a decision for reuse is made on this basis. However, under present circumstances where overall energy conservation is desirable, greater utilization of salvage and reuse of metal products should be made even when direct costs may be near the break-even point, since the net result would be indirect energy conservation. The Department should review its maintenance procedures to determine if greater potential exists for saving materials and energy than is now being realized.

Minimization of On-site Repair Time

Also already discussed to some extent has been the need to develop maintenance and repair techniques that minimize disruption to traffic. Traffic delays, especially on busy highways, tend to cause the public to waste many gallons of fuel in start and stop driving through congested areas. The use of rapid setting cements or prefabricated repair panels needs to be studied further.

COMPUTATION OF ENERGY USED IN HIGHWAY CONSTRUCTION AND MAINTENANCE

As already indicated elsewhere in this report, energy considerations alone do not dictate the type of highway construction or the materials to be used in the construction and maintenance of highways. It is recognized that different agencies that use the same procedure or that manufacture the same material do not always use exactly the same amount of energy. Operating efficiency, plant design and layout, local environmental conditions, among other factors, will greatly influence the amount of energy needed. Nevertheless, it is becoming increasingly important to be able to estimate the relative energy use for alternative systems as one element of the decision process. In order to do this it is necessary to establish reasonable estimates for the "average" energy required in the various activities relating to construction and maintenance.

In 1975 the Asphalt Institute published a report on Energy Requirements for Roadway Pavements.[40] This document has proved to be very useful and represents the most complete document as yet available for estimating the energy used in most usual highway operations. However, as stated in the document, information with respect to some activities was very limited at the time the report was prepared, and a number of assumptions were made. At present, several TRB committees and task groups are reexamining a number of factors with the hope of improving the accuracy of the estimates, but until their reports become available the Asphalt Institute report remains the best basis for estimates, with the exceptions listed below.

1. Btu content of portland cement--The Asphalt Institute report gives a figure of 7.57 million Btu per ton (8.81 million J/kg) of cement. This is based on 1971 Bureau of Mines estimates. However, the portland cement industry has conducted a campaign to reduce energy consumption and has reported that in 1976 the average amount of energy consumed in manufacturing a ton of cement in the United States was 6.34 million Btu's (7.38

million J/kg). Until figures for 1977 become available, the 6.34 figure should be used.

2. The energy required to "produce" 1 ton of crushed stone varies greatly because of a number of factors. The Asphalt Institute reported a value of 70,000 Btu per ton (81,000 J/kg) of aggregate. However, reports from the National Crushed Stone Association show estimates ranging from about 25,000 Btu per ton (29,100 J/kg) to a high of 58,000 Btu/ton (67,500 J/kg). The "best" median figure from the information now available appears to be 35,700 Btu/ton (41,600 J/kg).

The most controversial aspect of the Asphalt Institute report is that the caloric energy of the asphalt is not included as a part of the energy of manufacture. This decision is based on the fact that asphalt is a residual product from the refining of petroleum and when placed on the market becomes a construction material. Under this concept only the prorated energy used to refine the petroleum is counted as energy of manufacture, since this prorated figure is viewed as the energy used to make the construction material, asphalt, available for use. The opposing view is that the energy in asphalt is originally included as part of the energy in the total barrel of petroleum, and that after the refining process the energy in the asphalt is no longer available for other uses. Consequently, it has been used up and should, therefore, be charged against the asphalt. The energy involved is sizeable, representing 3%-4% of the total in each barrel of petroleum. The Asphalt Institute report shows that the energy required to produce asphalt is 587,500 Btu per ton (685,000 J/kg) disregarding the caloric energy in the asphalt itself. However, when asphalt is burned, it yield, about 158,000 Btu per gallon (44 million J/l), or 37,130,000 Btu/ton (43.2 million J/kg). On this basis, the total manufacturing energy for asphalt is 37,130,000 Btu + 587,500 Btu (the amount used in refining) for a total of 37,717,500 Btu/ton (43,200,000 + 684,000 = 43.9 million J/kg). The "manufacturing" energy is often referred to as "embodied" energy.

This extremely large difference in the two estimates creates problems for those attempting to evaluate relative energy uses for different types of highways. However, as already mentioned, the highway engineer faced with the need to decide on the alternative types of pavements must make his decision on the basis of needed performance, availability of materials, and costs.

An additional factor supporting the view that the caloric energy in the asphalt should not be included as part of the manufacturing energy is that once a decision has been made to refine the petroleum in a manner that yields asphalt as a residual, the asphalt becomes a by-product of the gasoline or other distillate manufacture and the energy "lost" in the asphalt becomes a part of the refining costs. The efforts of the TRB task force may eventually lead to a compromise position which would consider the "net" energy that would have been available from the asphalt had the refining process been selected to yield the maximum amount of light fuel.

A few of the most useful factors taken or derived from the report "Energy Requirements for Roadway Pavements" are given in the Appendix.[40]

Comparison of Energy Requirements for Rigid and Flexible Pavements

To illustrate the levels of energy consumed in constructing both flexible and rigid pavements, Table 2 shows the estimated energy used for a typical section of reinforced portland cement concrete pavement as constructed in Virginia. Table 3 shows similar estimates for a flexible pavement. Except as noted in the Appendix these estimates are based on factors given in Reference 40. The amount of energy required for hauling materials will of course depend on the assumptions made concerning the distances the materials are hauled and the type of hauling equipment used. However, the assumptions made as shown in Table 2 are believed somewhat typical of Virginia practice. Tables 2 and 3 include estimates based on both the Asphalt Institute's factor for the manufacturing energy of asphalt and estimates based on including the caloric energy of the asphalt as part of the maufacturing energy. In the first case (asphalt energy not included), the equivalent gallons of gasoline per yd^2 of pavement is 4.09 (13.0 liters per m^2), about 2/3 of the amount used for portland cement concrete (6.37 gal/yd^2 [20.2 liter/m^2]). But in the second case (asphalt energy included) the energy is equivalent to 12.6 gallons of gasoline per yd^2 (40.0 liters per m^2), a little under twice that used for portland cement concrete (6.52 gal/yd^2 [20.7 liter/m^2]). Obviously, the assumptions made regarding the asphalt energy greatly affect any conclusions drawn as to the relative energy-intensiveness of the two types of pavements. Hopefully, the work being done by the TRB task force previously mentioned will establish acceptable guidelines between these two extremes.

Table 2

2143

Energy Requirements for a Typical Rigid Pavement
Construction 24 Feet Wide, No Shoulders
(See Appendix for S.I. Conversion Factors)

Basic Design	Quantity Per Mile
9 inch reinforced concrete surface	14,080 $yd.^2$ (3,520 $yd.^3$)
4 inch aggregate subbase	1,564 $yd.^3$
6 inch cement treated subgrade	2,347 $yd.^3$
Sand cover at 15 $lb./yd.^2$	100 tons
Emulsion prime (CAE-2) at 0.2 $gal./yd.^2$	2,816 gal.

Assumptions

All hauling vehicles make round trip; therefore, distances hauled are multiplied by 2 for total vehicle travel.

Cement, asphalt, steel, hauled 50 miles in 5-axle diesel rigs at 70.75 ton-miles per gallon of diesel oil equivalent to 66 ton-miles per gallon of gasoline.

Sand and all aggregates hauled 10 miles in 4-axle diesel rigs at 42.51 ton-miles per gallon diesel oil equivalent to 39 ton-miles per gallon of gasoline.

Batched concrete hauled 5 miles in 3-axle rigs at 29 ton-miles per gallon of gasoline.

One gallon gasoline equivalent to 125,000 Btu.
One gallon diesel oil equivalent to 135,000 Btu (1.08 gallons gasoline).
CAE-2 emulsion equivalent to CRS-2 AASHTO designation contains 3% distillate and 65% base asphalt.

Energy requirements for each unit of construction

	Equivalent gallons of gasoline
1. Cement treated subgrade	
a. Cement	
Production (298 tons x 6,340,000 Btu/ton)	15,114
Haul (298 tons x 50 mi. x 2 ÷ 66 ton-mile/gal.)	451
Spreading, mixing, compacting (300 $Btu/yd.^2$ in.. x 14,080 $yd.^2$ x 6 in.)	203
b. Prime	
Production (2,816 gal. x 6,150 Btu/gal.)	139(a)
Haul (2,816 gal. ÷ 241 gal./ton x 50 mi. x 2 ÷ 66 ton-mi./gal.)	18
Distribution (2,816 gal. x 144 Btu/gal.)	3
c. Sand Cover	
Production (100 tons x 15,000 Btu/ton)	12
Haul (100 tons x 10 mi. x 2 ÷ 39 ton-mi./gal.)	51
Spreading, compacting (100 tons x 17,000 Btu/ton)	14
Total for cement treated subgrade	16,005
2. Aggregate subbase - 4 inch	
a. Aggregate	
Production (1,564 $yd.^3$ x 2 $ton/yd.^3$ x 35,700 Btu/ton)	893
Haul (3,138 tons x 10 mi. x 2 ÷ 39 ton-mi./gal.)	1,609
Spreading, compacting (3,138 tons x 17,000 Btu/ton)	427
Total for 4 in. aggregate subbase	2,929

Table 2 continued.

3. Reinforced concrete pavement

a. Cement

Production (3,520 yd.^{3} x 564 lb./yd.^{3} ÷ 2,000 lb./ton x 6,340,000 Btu/ton)	50,347
Haul (992.6 tons x 50 mi. x 2 ÷ 66 ton-mi./gal.)	1,504

b. Aggregate

Production (3,520 yd.^{3} x 1 ton/yd.^{3} x 35,7000 Btu/ton)	1,005
Haul (3,520 yd.^{3} x 10 mi. x 2 ÷ 39 ton-mi./gal.)	1,805

c. Sand

Production (3,520 yd.^{3} x 0.5 ton-ton/yd.^{3} x 15,000 Btu/ton)	211
Haul (1,760 tons x 10 mi. x 2 ÷ 39 ton-mi./gal.)	903

d. Batching operations (3,520 yd.^{3} x 2 ton/yd.^{3} x 11,970 Btu/ton)	674
e. Haul concrete (3,520 yd.^{3} x 2 ton/yd.^{3} x 5 mi. x 2 ÷ 29 ton-mi./gal.)	2,427
f. Placing concrete (3,520 yd.^{3} x 5,420 Btu/yd.^{3})	148

g. Steel

long.	— No. 4 at 12 in. spacing (24 x 5,280) 126,720 ft. x .668 lb. per ft.	84,449 lb.
trans.	— No. 2 at 6 in. spacing (24 ft. x 10,560) 253,440 ft. x .167 lb. per ft.	42,324 lb.
dowels	— (2,640 x 4.916 lb. each)	12,978 lb.
		139,751 lb.

139,751 lb. x 10,500 Btu per lb.	11,739
Total for 9 in. portland cement concrete	70,698
Total for 1 mi. pavement	89,697
Total per yd.^{2}	6.37

(2) Energy in base asphalt not included. When energy in base asphalt is included, energy in emulsion prime is equivalent to an additional 2,270 gal. of gasoline. The total energy for 1 mile of pavement is then equivalent to 92,030 gallons of gasoline, or 6.54 gallons per yd.^{2}.

Table 3

Energy Requirements for a Typical Flexible Pavement Construction 24 Feet Wide, No Shoulders (See Appendix for S.I. conversion factors)

145

Basic Design	Quantity per mile
9.5 inch asphalt concrete	7,640 tons
Prime (MC-70) - .4 gal./yd.^{2}	5,650 gal.
6 inch crushed aggregate base	2,347 yd.^{3}
Sand cover at 15 lb./yd.^{2}	100 tons
Prime (CAE-2) - .2 gal./yd.^{2}	2,816 gal.
6 inch cement treated subgrade	2,347 yd.^{3}

Assumptions

(Same as Table 2)

Energy requirements for each unit of construction	Equivalent gallons of Gasoline
1. Cement treated subgrade (same as Table 2)	16,005
2. 6 inch aggregate base (6/4 x 2,929[from Table 2])	4,394
2. Prime (MC-70)	
Production (5,650 gal. x 63,200 Btu/gal.)	2,857[(a)]
Haul (5,650 gal. ÷ 250 gal./ton x 50 mi. x 2 ÷ 66 ton-mi./gal.)	34
Distribution (5,650 gal. x 144 Btu/gal.)	7
Total for prime	2,898
4. 9.5 in. asphalt concrete	
a. Asphalt cement (assume 5% = 382 tons)	
Production (382 tons x 587,500 Btu/ton)	1,795[(a)]
Haul (382 tons x 50 mi. x 2 ÷ 66 ton-mi./gal.)	579
b. Aggregate (assume 95% = 7,258 tons)	
Production (7,258 tons x 35,700 Btu/ton)	2,073
Haul (assume no haul)	0
c. Plant mix (assume 5% = 7,640 tons x 385,000 Btu/ton)	23,531
Haul (7,640 tons x 10 mi. x 2 ÷ 29 ton-mi./gal.)	5,269
Placing, compacting (7,640 tons x 16,700 Btu/ton)	1,020
Total for asphalt concrete surface	34,267
Total for 1 mile flexible pavement	57,535
Total per yd.^{2}	4.09

(a) Energy in base asphalt not included. If energy in base asphalt is included at 155,000 Btu/gal. then 2,270 additional gallons are required for emulsion prime; 4,569 additional equivalent gallons of gasoline are required for MC-70 prime; and 113,430 additional equivalent gallons for asphalt cement would be required for 1 mile of pavement. Total energy required per mile is then equivalent to 177,629 gallons of gasoline, or 12.62 gal. per yd.^{2}.

CONCLUSIONS AND RECOMMENDATIONS

This general review of the considerations relating to the use of energy in highway construction and maintenance leads to the following conclusions and recommendations with respect to the Virginia Department of Highways and Transportation.

1. To a considerable extent, the objective of conserving energy in highway construction is related to the objective of either conserving conventional high quality materials or reducing costs. Future fuel shortages or shortages of petroleum-based materials such as asphalt may require the development and use of alternative procedures. The need to minimize the use of energy may alter the priorities of ongoing research and development programs, but no radical departure from present construction practices or existing research programs is needed.

2. There is no need to establish a research group within the Department to deal solely with energy problems. However, an understanding of energy factors and potential energy problems is needed in all activities relating to highway construction and maintenance. Needed research and development programs can best be conducted within each of the major technologies involved. That is, energy studies relating to portland cement concrete construction should be conducted within a concrete section and energy studies relating to asphalt construction should be conducted in an asphalt section. In many cases, objectives with respect to energy will be closely related to other, non-energy related objectives. There is a need, however, for liaison between those concerned with energy related projects within each technology or program so as to provide proper communication between groups, to avoid possible duplication of effort, and to serve as a ready source of information on the status of energy related activities for the Department's management personnel.

3. While consideration is already being given to some of the subject areas discussed below, and it is recognized that a high priority cannot be established for studies in all areas mentioned, it is believed that the areas cited are those in which efforts toward energy conservation in highway construction in Virginia are most apt to achieve significant success, and that in planning future programs, the Virginia Department of Highways and Transportation should give special attention to each consideration.

a. Increased use of industrial mineral wastes in highway construction

The increasing national interest in utilizing industrial wastes is based on conserving supplies of natural aggregates as well as economically disposing of materials that might be harmful to the environment. The possibility of also conserving energy adds a third factor which makes it desirable to evaluate carefully the materials available in Virginia. The materials of major concern in Virginia are the wastes from coal mining and fly ash and bottom ash from coal burning plants. Coal mine refuse is likely to be useful only as fill and embankment material or base course aggregate in areas relatively close to the present stockpiles. Similarly, bottom ash has limited possibilities for use as aggregates and base material. However, fly ash is much more useful and has more varied possible uses.

To determine the overall potential for utilizing fly ash in Virginia, efforts are needed to inventory present supplies and to determine the significant characteristics of the available materials by laboratory studies and, possibly, field evaluation. In addition to ongoing efforts for the utilization of fly ash in concrete, consideration should be given to experimental projects involving embankment construction or base stabilization with fly ash and lime, or fly ash and cement. Greater utilization of blended cements (especially those containing fly ash as their pozzolanic component) should also be explored.

b. Increased effort to utilize local materials

In situ base and subbase stabilization and utilization of local aggregates have long been objectives of soils and foundation studies and are already practiced to a considerable extent in Virginia. Traditionally, the concern has been to reduce costs, but inasmuch as cost reduction stems mostly from elimination of the need to transport large volumes of unwanted materials from the job site and to bring in large amounts of suitable replacement materials, such cost reduction results primarily from energy conservation. The choice of alternative stabilization procedures that are available is now based on relative costs to obtain the performance desired. While it is not expected that radical changes would result, energy analyses should also be made so as to select the most energy-efficient procedures consistent with the needed performance and low cost. In particular, stabilization with by-product materials that have a zero energy of manufacture (all energy use is chargeable to the basic process) should be carefully evaluated.

In this area, studies should also be made of the usefulness of "econocrete." Econocrete is defined as low strength concrete made with locally available materials or crushed rubble and designed with a relatively low cement content to provide adequate strength for the needed service as a base course but not sufficient for surface conditions. The Department will now accept econocrete as an alternate to cement treated base courses, but no projects have been built using this option. Consideration should be given to constructing experimental projects to establish the cost-effectiveness and energy-intensiveness of econocrete as compared with other type bases.

c. Increased recycling of both asphalt and concrete pavements

The energy saved in recycling pavements is usually incidental to costs and the need to conserve supplies of high quality aggregates or to avoid the accumulation of solid waste. There is a need to develop fully optimum techniques for recycling and to establish procedures for accurately estimating energy and cost advantages for different approaches. This should be done by encouraging recycling projects where applicable and carefully monitoring results from the standpoint of costs, energy conservation, and materials conservation.

d. Substitution of emulsions for cutback

A decision has already been reached to substitute emulsions for cutback in Virginia, and the necessary training is being conducted in the use of emulsions for highway maintenance procedures. Evaluations are also being made to determine the best types of emulsions for specific purposes.

e. Long-range studies for minimum use of asphalt in highways

Since the long-range outlook is that asphalt will be less plentiful and more costly, research and experimental projects are needed to establish suitable procedures for designing and constructing pavements utilizing a minimum of asphalt but retaining a comparable level of performance at equal or lower costs.

REFERENCES

1. Transportation Research Board, "Optimizing the Use of Materials and Energy in Transportation Construction," Special Report No. 166, Washington, D.C., 1976.

2. Foster, Charles R., "The Future of Asphalt Paving," National Asphalt Pavement Association, Riverdale, Md., December 1976.

3. Foster, Charles R., "Study of Effect of President Carter's Energy Program on Cost of Asphalt Cement and Fuel Oil," Special Report, National Asphalt Pavement Association, Riverdale, Md., April 1977.

4. Portland Cement Association, "1976 Energy Report, U.S. Portland Cement Industry," Skokie, Ill., April 1977.

5. Federal Energy Administration, "Energy Conservation in the Cement Industry," Conservation Paper No. 29, U.S. Government Printing Office, Washington, D.C., 1976.

6. ______________ "Possible Contributions of Cement and Concrete Technology to Energy Conservation by the Year 2000," in press.

7. ______________ Personnel Communication. FHWA report, in press.

8. Stearn, Enid W., "Blended Cements Make Gains--but Slowly," Rock Products, October 1976.

9. Ozyildirim, H. Celik, "Alternatives to Type II Cement, Part 1--Preliminary Laboratory Studies," Virginia Highway & Transportation Research Council, Charlottesville, Va., February 1977.

10. Hecht, Morris, "Low Temperature Bituminous Mixes," Virginia Department of Highways and Transportation, Richmond, Va., October 1975.

11. National Asphalt Pavement Association, "Theoretical Computations of the Fuel Used and the Exhaust Produced in Drying Aggregates," Information Series 61, Riverdale, Md.

12. Granley, Edwin C., "Dryer Drum Operations." Presented to Committee on Construction, Southeastern Association of State Highway and Transportation Officials, New Orleans, La., September 1976.

13. Miller, R. H., and Collins, R. J., "Waste Materials as Potential Replacements for Highway Aggregates," NCHRP Report No. 166, Transportation Research Board, Washington, D.C., 1976.

14. Emery, J. J., "Waste and By-product Utilization in Highway Construction," Resource Recovery and Conservation, 1, 1975.

15. Meyers, James F., Pichumani, Ramon, and Kopples, Bernadette S., "Fly Ash, A Highway Construction Material," Implementation Package 76-16, FHWA, Washington, D.C., June 1976.

16. National Cooperative Highway Research Program, "Lime-Fly Ash Stabilized Bases and Subbases," NCHRP Synthesis Report No. 37, Transportation Research Board, Washington, D.C., 1976.

17. Federal Highway Administration, "Availability of Mining Wastes and Their Potential for Use on Highway Material, Vol. I--Classification and Technical and Environmental Analysis, Vol. II--Location of Mining and Metallurgical Wastes and Mining Industry Trends, Vol. III--Annotated Bibliography," Washington, D.C., May 1976.

18. Dresser, Jay, "Rehabilitation of Runway 13-31, Jacksonville International Airport, Jacksonville, Fla.--A Concrete Recycling Project." Presented at annual meeting of Transportation Research Board, Washington, D.C., January 1978.

19. Beck, Allen, "Research on Recycled Concrete," U.S. Army Engineers Waterways Experiment Station. Presented at annual meeting of Transportation Research Board, Washington, D.C., January 1978.

20. Britson, Ralph, "Iowa Experience with Concrete Pavement Recycling", Iowa Department of Transportation. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

21. Ray, Gordon K., and Halm, Harold J., "Energy Savings through Concrete Recycling", Portland Cement Association and American Concrete Paving Association. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

22. Frondistou - Yannas, Stamatia, "Economic Feasibility of Concrete Recycling", Massachusetts Institute of Technology, Cambridge, Massachusetts. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

23. "Recycling Materials for Highways", NCHRP Synthesis Report No. 50, Transportation Research Board, Washington, D.C., 1977.

24. Smith, Richard W., "NAPA--Asphalt Institute Committees Agree on Recycling Definitions", Special Report by NAPA, Riverdale, Md., 1977.

25. ________________, "Considerations for Producing Quality Recycled Hot-Mixed Asphalt", National Asphalt Pavement Association, Riverdale, Md., 1977.

26. National Asphalt Pavement Association, "State of the Art: Hot Recycling", Recycling Report, Vol. 1, No.1, May 1977.

27. Federal Highway Administration, "Recycled Asphalt Concrete", Implementation Package 75-5, U. S. Department of Transportation, Washington, D. C., September 1975.

28. Dunning, Robert L., Mendenhall, Robert L., and Tischer, Kenneth K., "Recycling of Asphalt Concrete--Description of Process and Test Sections", Proceedings, AAPT, Vol. 44, 1975.

28. Denton, James F., and Tunnicliff, David G., "Recycling Asphalt Pavements with Conventional Plants and Equipment", Warren Brothers Company, Cambridge, Mass. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

30. Welsch, Roger, "Recycling of Bituminous Concrete", Texas State Department of Highways and Public Transportation, Austin, Texas. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

31. Ingberg, Richard C., "Recycling Bituminous Concrete by Continuous Mixer in Minnesota", Minnesota Department of Transportation, St. Paul, Minn. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

32. McGhee, James A., and Judd, A. James, "Recycling of Asphaltic Concrete--Arizona's First Project", Arizona Department of Transportation, Phoenix, Arizona. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

33. Brown, Bernard C., "Iowa's Experience in Asphalt Recycling", Iowa Department of Transportation. Presented at annual meeting of Transportation Research Board, Washington, D. C., January 1978.

34. Hughes, C. S., "Evaluation of Recycled Concrete," VHTRC 78-R9, Virginia Highway and Transportation Research Council, Charlottesville, Va., August 1977.

35. Sprinkel, Michael, "In-house Fabrication of Precast Concrete Bridge Slabs," VHRTC 77-R33, Virginia Highway and Transportation Council, Charlottesville, Va., December 1976.

36. "Use of Emulsified Asphalts in Lieu of Cutback Asphalt in Highway Construction and Maintenance Operations," FHWA Notice N 5080.5, January 17, 1974.

37. Kirwan, Francis M., and Maday, Clarence, "Air Quality and Energy Conservation, Benefits from Using Emulsions to Replace Asphalt Cutbacks in Certain Paving Operations," U.S. Environmental Protection Agency, Research Triangle, N.C., May 1977.

38. "Bituminous Emulsions for Highway Pavements," NCHRP Synthesis Report No. 30, Transportation Research Board, Washington, D.C., 1975.

39. Petersen, Dale E., "Good Roads Cost Less," UDOT-MR-77-8, Utah Department of Transportation, Salt Lake City, Utah, October 1977.

40 "Energy Requirements for Roadway Pavements (Misc-75-3)," The Asphalt Institute, College Park, Md., April 1975.

Appendix

Useful Energy Factors Relating to Highway Construction
(Except as noted, factors shown are based on Reference 40)

Btu contents of various fuels:

Gasoline	=	125,000 Btu/gal.
Kerosene & Fuel Oil No. 1	=	135,000 Btu/gal.
Fuel Oil, No. 2 (diesel)	=	139,000 Btu/gal.
Fuel Oil, No. 6 (Bunker C)	=	154,500 Btu/gal.
Natural Gas	=	1,000 Btu/ft.^{3}
Propane Gas	=	91,000 Btu/gal.

Manufacturing energy for highway materials:

Asphalt cement	=	587,500 Btu/ton
at 235 gal./ton	=	2,500 Btu/gal.
(Btu's in asphalt itself not included)		
Btu's in asphalt cement	=	158,000 Btu/gal.
" " " "	=	37,130,000 Btu/ton
Emulsions		2,000 Btu/gal.
(Average figure — amounts vary with type. For cationic emulsion add 135,000 x percent distillate present ÷ 100)		For
Assume 241 gallons per ton		487,500 Btu/ton
Cutbacks		
MC-70	=	63,200 Btu/gal.
RC-250	=	46,200
MC-250	=	47,000
SC-250	=	58,100
For general estimates, use a median figure of 47,000 Btu/gal., 249 gal./ton		
Portland cement	=	6,340,000 Btu/ton (adjusted figure)
Lime	=	6,000,000 Btu/ton
Crushed stone	=	35,700 Btu/ton (adjusted figure)
Natural, or uncrushed aggregate	=	15,000 Btu/ton
Crushed gravel	=	35,700 Btu/ton (adjusted figure)

Energy for mixing plant operations:

To remove 1% moisture from aggregate	=	28,000 Btu/ton
To raise temp. of aggregate 1°F	=	470 Btu/ton
To operate conventional asphalt mixing plant	=	19,820 Btu/ton
To operate drum-mixing plant	=	16,550 Btu/ton
To mix cold asphalt mixes at central plant	=	6,630 Btu/ton
To provide aggregate to portland cement concrete mixer	=	4,650 Btu/ton
To mix concrete	=	3,580 Btu/yd.^{3}

Energy for hauling:

Gasoline powered equipment		
3-axle trucks	=	29.29 ton-mi./gal.; 4,270 Btu/ton-mi.
4-axle conbination rigs	=	24.80 ton-mi.,/gal; 5,040 Btu/ton-mi.
5-axle conbination rigs	=	43.07 ton-mi./gal.; 2,900 Btu/ton-mi.
Diesel powered equipment		
4-axle combination rigs	=	42.51 ton-mi./gal.; 3,270 Btu/ton-mi.
(gasoline equivalent)	=	39.36 ton-mi./gal
5-axle combination rigs	=	70.75 ton-mi./gal; 1,960 Btu/ton-mi.
(gasoline equivalent)	=	65.51 ton-mi./gal.

For this report asphalt products, cement and steel being hauled from manufacturing site are assumed to be hauled in 5-axle diesel powered rigs. It is also assumed that vehicle must travel round trip so that distances hauled are multiplied by 2 for estimating energy use. Asphalt mixtures and portland cement concrete are assumed to be hauled in 3-axle gasoline powered trucks.

Spreading, Placing, Compacting:

Asphalt hot mixes	=	16,700 Btu/ton
Cold stabilized mixes (asphalt)	=	17,000 Btu/ton
P.C. concrete	=	5,240 Btu/yd.^{3}
Travel plants	=	3,000 Btu/ton
Blade mixing	=	396 Btu/yd.^{2}-in.
Compaction cold mixes, aggregates, etc.	=	120 Btu/yd.^{2}-in.

Factors for converting to S.I. units

1 gal. = .00379 m^3
= 3.71 l
1 gal./yd.^{2} = 3.17 l/m^2
1 gal./ton = .00417 l/kg = 4.17 l/metric ton
1 Btu = 1056 J
1 Btu/gal. = 279 J/l
1 Btu/ton = 1.164 J/kg
1 Btu/yd.^{3} = 138k J/m^3
1 yd.^{2} = .836 m^2
1 Btu/yd.^{2}-in. = 497 J/m^2-cm
1 Btu/lb. = 2324 J/kg
1 mile = 1.61 km
1 Btu/mi. = 676 J/km
1 ton = 908 kg = .908 metric tons
1 Btu/ton-mi. = .723 J/kg=km