ENERGY CONCERNS RELATING TO HIGHWAY CONSTRUCTION AND MAINTENANCE

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INTRODUCTION

During the past six years there has been a lot of talk about energy and the "energy situation". Changes in energy supply and costs have already affected everyone in various situations. There have been direct results in the substantial increase in the cost of gasoline for cars, fuel oil for homes, and electricity for homes and businesses. Predictions for the future range from dire forbodings of abandoned automobiles in a petroleumless society to essentially business as usual after cost adjustments and some reorganization of priorities and technology. The effects in various segments of society will vary and it is necessary to examine each situation to properly focus on the problems and the opportunities for energy conservation in each technological area or industry.

The concern in this presentation is with highway construction and maintenance. A general review of the potential problems created by changes in the energy supply and costs will be made and consideration will be given to the options available to highway engineers for solving such problems.

In order to put the problems in the proper perspective, one must first determine how the energy considerations for highway construction and maintenance fit into the total picture. Figure 1,

igure 1

taken from the NCHRP Synthesis Report No. 43,(1) illustrates the percentages of energy that were being used for various purposes as of 1976. As shown, the total direct transportation energy (TDTE) amounted to 25.3% of the total energy consumed that year in the United States. In addition to the TDTE, another 17.4% of energy requirements went into manufacturing equipment and building facilities related to transportation or represented losses in manufacturing and transporting the fuel. Figure 2, also taken from the NCHRP Synthesis Report,(1) shows how the TDTE was used in 1972. As indicated, highway uses amounted to about three-fourths of the total. Cars and light trucks used about 68% of the fuel consumed.

Figure 2

These two figures are significant from several viewpoints. First, they show the very large amount of energy involved in highway transportation and clearly point to the automobile as being the single largest user. This, in turn, indicates why improvement in miles per gallon factors in the automobile fleet is of concern at the national level. Any small improvement in efficiency that applies to each automobile is multiplied by a factor of approximately 140 million — the number of cars and trucks in use on the nation's highways at the present time. Consequently, the total effect on the national energy usage is substantial. A second observation to be made from these figures is that highway construction is shown to consume 1.7% of the energy. It is not clear if maintenance use is included in this estimate. Other sources estimate maintenance to represent between 1% and 2% of annual consumption. Thus, at the most, 3.0% to 3.5% of annual energy use is involved in highway construction and maintenance.

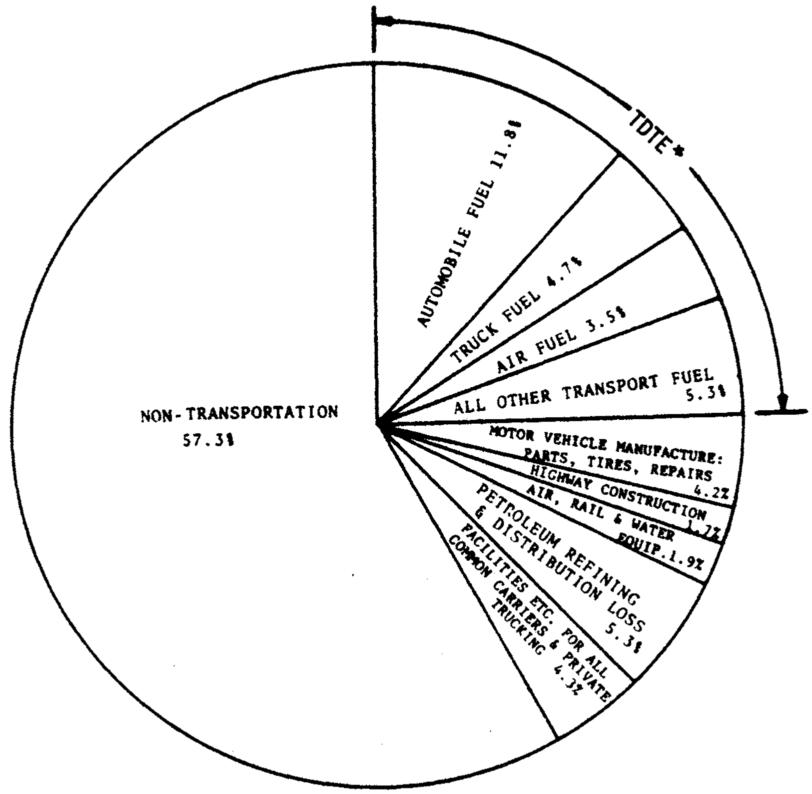

Figure 1. Components of transportation energy as a percentage of total energy used. Source: NCHRP Report No. 43.

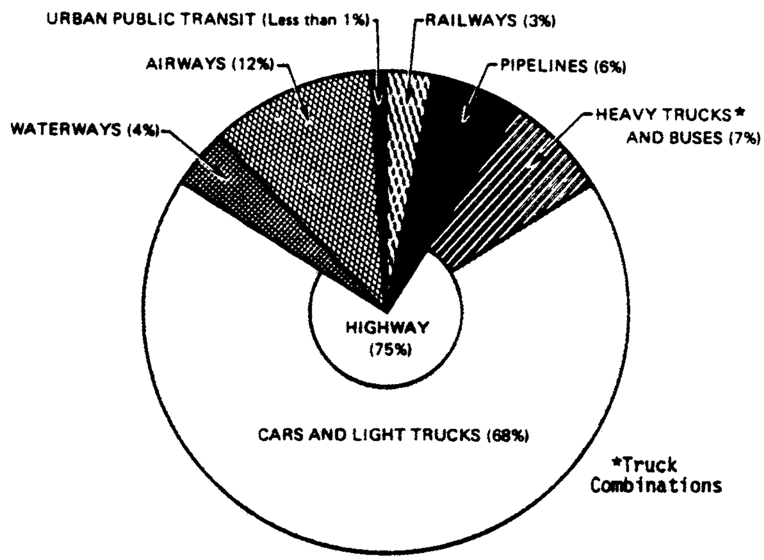

Figure 2. Components of direct transportation energy, 1972. Source: NCHRP Report No. 43.

This amount is certainly not insignificant. It is equal to about 2.5 quadrillion (10^{15}) Btu's per year, which is equivalent to the energy contained in about 24 billion gallons of petroleum. If only 5% of the energy used in this area could be saved it would amount to enough gasoline to operate 1.5 million cars for a year. But on the other hand, even complete elimination of the activity would not solve the national energy problem. 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.

From these observations it is possible at the outset to establish that the major concern with energy use and conservation in highway construction and maintenance is to hold down costs to the maximum extent possible as energy costs increase. Decisions as to what type of highway facility is to be built should continue to be based primarily on fulfilling the needs of the community and on overall cost-effectiveness rather than energy considerations. Nevertheless, an understanding of the energy situation is important as a guide for indicating future cost trends as well as potential shortages of fuel and materials.

In dealing with energy computations and predictions of what may happen in the future one must also recognize the limitations involved. A quote by Susan H. Coughlin of the League of Women Voters of the United States sums up the situation nicely. She states, "Estimates of energy resources are imprecise, future energy requirements are nebulous, the consequences of emerging technologies are unpredictable". The recent events in Iran also point to the fact that political changes and the consequences of such changes are also unpredictable.

It is customary in analyses of energy uses to express the energy used in terms of Btu's without consideration of its primary source. However, as someone has said, "All Btu's were not created equal". We can also add that, "All Btu's are not interchangeable."

A study reported in Science magazine recently showed that the energy required to supply the extra food calories to maintain the estimated 2.3 billion pounds of excess weight the American public is carrying around is enough to run 900,000 average U. S. autos for a year — or to supply the annual residential electrical demands of Boston, Chicago, San Francisco, and Washington, D. C.

These facts make interesting trivia for conversation but have no true bearing on the situation. There is no way that Btu's saved by a reduction in food calories, many of which are derived from solar energy, can be economically converted to either vehicle fuel or electricity. Thus a simple calculation of the Btu's involved does not tell the whole story or properly reflect the relative problem with respect to energy use. When Btu's are derived from solar sources, the amount used is of little importance.

Only the costs and energy required to establish and maintain a solar facility are of concern. The "operating" Btu's from the sun are "free" in terms of using up natural resources. On the other hand Btu's derived from petroleum and petroleum fuels are of major concern. At the national planning level these concerns are important and must be considered with respect to allocating available resources and research and development funds. However, the highway engineer cannot control such decisions — and his input to them is likely to be minimal. It is necessary, therefore, that the highway community react to such decisions and be guided by what is available for its use and how much it costs.

ENERGY CATEGORIES

To get a useful picture of energy use and the possibilities for conservation in highway construction and maintenance operations, one needs to consider four categories of energy, namely; embodied energy, transport energy, construction energy, and indirect energy.

Embodied energy is a term used by the Center for Advanced Computation of the University of Illinois in its report on energy used in building construction. It is defined as the amount of energy that has been used (or otherwise made unavailable for other uses) to manufacture or process a material up to the point it is to be used for the project concerned. For example, embodied energy for portland cement would include the Btu's used in manufacturing the cement and storing it at the distribution point for sale. In the case of reinforcing steel, it would be the Btu's consumed in manufacturing the steel and fabricating it into bars. In regard to asphalt, there are different schools of thought. Under one definition embodied energy includes the Btu's in the asphalt itself, since that amount of energy was originally considered a part of the available energy in the petroleum from which it was refined. Under another definition, which is endorsed by the Asphalt Institute and others, the asphalt is considered to be a construction material that is removed from petroleum by the refining process, and therefore they count only the prorated share of the refining energy as manufacturing or embodied energy. Still others consider the Btu's in the asphalt as not being used up, but only being stored in the highway. Another view would be to class the high sulfur asphalt as a waste by-product of the refining process — in which case the embodied energy includes only the energy used in processing and storing asphalt cement for sale. The differences in these views are essentially of academic interest to the highway builder, because engineering factors along with availability and costs generally control decisions as to whether he will use asphalt in lieu of suitable alternative materials for a given project. However, as will be discussed later, there are certain public relation concerns with respect to the method of calculation.

Energy in the second category — transport energy — is the energy needed to move material from the point of manufacture or final processing to the job site or the plant at which it is to be used. Primarily, this is the fuel required to operate loading, hauling, and unloading equipment.

Construction energy is the energy required to process the material, move it to job site, and complete the job. For asphalt used in highway construction it includes energy to heat and dry the aggregate, operate the plant, haul the mix to the job site, place it on the roadway, and compact it.

The fourth category of energy — indirect energy — includes the energy involved in the work force getting to and from the job site; the increased energy used by users of the highway because of construction related delays, etc.; the energy involved in manufacturing equipment, etc.

Transport and construction energy are the categories of major interest to highway contractors and engineers. These categories consist of the fuel used in hauling materials and in the operation of equipment for processing materials and manufacturing the finished product for the highway facility. Conservation in these areas has a direct bearing on reducing the costs of highway construction (or preventing cost increases). Embodied energy is of primary concern in the overall consideration of national energy usage. It also concerns highway planners and engineers to the extent that costs and availability of alternative materials may be affected by changes in energy costs. Consideration of indirect energy is necessary to obtain a complete national evaluation of all energy uses, but an evaluation of such energy is not considered within the scope of this paper and no consideration will be given to it here.

ENERGY CONSIDERATIONS IN HIGHWAY CONSTRUCTION

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 (TRB) 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.[(2)] However, the participants at the conference were well aware of the continuing problem with respect to both materials and energy. At present, 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

A recent study conducted for the Virginia Department of Highways and Transportation reevaluated the ideas presented at that conference and the report "Energy Use and Conservation in Highway Construction and Maintenance" has been widely distributed.[(3)] A more specific evaluation of the major ideas suggested at the conference was also made by the Texas Transportation Institute for the FHWA. The following information essentially represents a synthesis of the information provided by the Virginia and Texas studies from the standpoint of several major highway construction operations, the use of waste materials, recycling, and maintenance activities.

Base Courses and Embankments

The most important factor in the construction of base courses and embankments is the use of on-site materials to minimize the expenditure of transport energy. The cost and energy requirement for stabilization procedures must be compared with costs and energy requirements for removing and replacing 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 some cases state specifications continue to require limited thicknesses with the expenditure of appreciably more energy.

The workshop previously mentioned 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 6 ft. above the existing surface.

Suggestions have also been made that changes be permitted in geometric designs to allow steeper side slopes and altered grade and sight distances 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.

Stabilization of Base Courses

For equal volumes of materials moved equal distances, obviously less energy is required for graded aggregate bases than those stabilized with either asphalt or portland cement, because of the big differences in embodied energy between the materials. However, because different thicknesses are required for equal performance, different volumes of material must be moved. Consequently, stabilization may prove to be the most energy-conservative approach in the long term. Whether or not this is true depends to a great extent on the distances involved and the layer equivalency factors used. Extensive studies have been made of alternative types of base courses and their roles in the overall structural adequacy of the pavement. The debate concerning equivalancies of various types under different conditions is considered beyond the scope of this paper; however, in any consideration of relative energy use for various types of base course construction, it must be recognized that adequate performance of the base is the primary consideration in selecting a design. A base that does not perform as expected can generate dollar and energy costs well beyond the cost of the energy initially saved. Under present circumstances cost, or cost-effectiveness, and availability of materials continue to be the major elements in the decision as to the type of base to be used. However, a recognition of the relative energy impacts is believed useful as a guide to further research and also as an indicator of possible changes in costs or availability of the alternative materials. It is not possible to indicate the relative amounts of energy consumed for different types of bases that apply to all situations. Because of differences in hauling distances, each project must be analyzed separately. It is possible, however, to provide estimates of energy required for various steps in the process that can be used in such analyses.

To illustrate the relative energy use for different types of base course construction and also to show the category of energy involved, calculations were made for three types of base course assuming two sets of conditions. For the short-haul situation, assumptions were made of distances that would be somewhat typical of urban areas with sources of crushed stone reasonably close by. For the long-haul situation, assumptions were made that represent a rural situation where the source of crushed stone is rather remote. These assumed distances probably approach the upper limit at which highway transportation would be employed for the materials. Tables 1, 2 and 3, taken from a report entitled "Opportunities for Conserving Energy in Asphalt Paving Processes",(5) show, respectively, the energy calculated in terms of equivalent gallons of gasoline used for crushed stone base, emulsion treated base using local aggregate and plant mixing, and black (hot mix) base. Table 4 shows similar calculations for a lean concrete base (econocrete). Details of the energy factors used and how each value was calculated are given in the Appendices.

Tables 1, 2 & 3

Table 4

The significance of transport energy for crushed stone base is clearly illustrated by Table 1. For the short-haul situation this category of energy represents 75% of the total. For the long-haul situation transport energy is 95% of the total.

A comparison of the relative amounts of energy required for the same thickness and same hauling situation by the different types of construction in Tables 1 through 4 shows the effect of embodied energy and how it is defined. If only the transport energy and construction energy are considered the ratios of the

Table 1

Energy Used to Construct Crushed Stone Base Course
(Figures shown are energy requirements to construct
1 mile - 24 feet wide at indicated thickness.
Energy is expressed as equivalent gallons
of gasoline [125,000 Btu/gal])

Category of Energy	Thickness of Base - inches					
	1	6	8	10	12	18
	(Short-Haul Situation)					
Transport (T)	1,022	6,130	8,180	10,220	12,260	18,400
Construction (C)	128	770	1,020	1,280	1,540	2,300
Embodied (E)	203	1,220	1,620	2,030	2,440	3,650
T + C	1,150	6,900	9,200	11,500	13,800	20,700
T + C + E	1,353	8,120	10,820	13,530	16,240	24,350
	(Long-Haul Situation)					
Transport (T)	6,644	39,860	53,150	66,440	79,370	119,590
Construction (C)	128	770	1,020	1,280	1,540	2,300
Embodied (E)	203	1,220	1,620	2,030	2,440	3,650
T + C	6,772	40,630	54,170	67,720	81,270	121,890
T + C + E	6,975	41,850	55,790	69,750	83,710	125,540

(Source: Reference 5)

Table 2

Energy Used to Construct Emulsion Treated Base Course
(Figures shown are energy required to construct
1 mile - 24 feet wide at indicated thickness.
Energy is expressed as equivalent gallons
of gasoline [125,000 Btu/gal])

Category of Energy	Thickness of Base - inches					
	1	6	8	10	12	18
	(Short-Haul Situation)					
Transport (T)	751	4,510	6,010	7,510	9,010	13,520
Construction (C)	644	3,860	5,150	6,440	7,730	11,590
Embodied E_1a	2,029	12,170	16,230	20,290	24,350	36,620
E_2b	11,727	70,360	93,820	117,270	140,720	211,090
T + C	1,395	8,370	11,160	13,950	16,740	25,110
T + C + E_1	3,424	20,540	27,390	34,240	41,090	61,630
T + C + E_2	13,120	78,730	104,980	131,220	157,460	236,200
	(Long-Haul Situation)					
Transport (T)	5,619	33,710	44,950	56,190	67,430	101,140
Construction (C)	1,654	9,920	13,230	16,540	19,850	29,770
Embodied E_1a	2,029	12,170	16,230	20,290	24,350	36,520
E_2b	13,265	79,590	106,120	132,650	159,180	238,770
T + C	7,273	43,630	58,180	72,730	87,280	130,910
T + C + E_1	9,302	55,800	74,410	93,020	111,630	167,430
T + C + E_2	20,538	123,220	164,300	205,380	246,460	369,680

a - Caloric energy in asphalt cement not included

b - Caloric energy in asphalt included.

(Source: Reference 5)

Table 3

Energy Used to Construct Hot Asphalt Base (Black Base)
(Figures shown are energy requirements to construct 1 mile - 24 feet at indicated thickness. Energy is expressed as equivalent gallons of gasoline [125,000 Btu/gal])

Category of Energy	Thickness of Base - inches					
	1	6	8	10	12	18
	(Short-Haul Situation)					
Transport (T)	691	4,150	5,530	6,910	8,290	12,440
Construction (C)	2,266	13,600	18,130	22,660	27,190	40,790
Embodied E_1[a]	371	2,230	2,970	3,710	4,450	6,680
E_2[b]	10,448	62,690	83,580	104,480	125,380	188,060
T + C	2,957	17,750	23,660	29,570	35,480	53,230
T + C + E_1	3,328	19,980	26,630	33,280	40,930	59,910
T + C + E_2	13,405	82,670	110,210	137,760	166,310	247,970
	(Long-Haul Situation)					
Transport (T)	5,694	34,160	45,550	56,940	68,330	102,490
Construction (C)	3,312	19,870	26,500	33,120	39,744	59,620
Embodied E_1[a]	371	2,230	2,970	3,710	4,450	6,680
E_2[b]	10,448	62,690	83,580	104,480	125,380	188,060
T + C	9,006	54,030	72,050	90,060	108,070	162,110
T + C + E_1	9,377	56,260	75,020	93,770	112,520	168,790
T + C + E_2	19,825	116,720	155,630	194,540	233,450	350,170

a - Caloric energy in asphalt cement not included.

b - Caloric energy in asphalt cement included.

(Source: Reference 5)

Table 4

Energy Used to Construct Lean Concrete Base (Econocrete)
(Figures shown are energy requirements to construct 1 mile - 24 feet wide at indicated thickness. Energy is expressed as equivalent gallons of gasoline [125,000 Btu/gal.])

Category of Energy	Thickness of Base - inches					
	1	6	8	10	12	18
	(Short-Haul Situation)					
Transport (T)	775	4,650	6,200	7,750	9,300	13,950
Construction (C)	59	350	470	590	710	1,060
Embodied (E)	2,565	15,390	20,520	25,650	30,780	46,170
T + C	834	5,000	6,670	8,340	10,010	15,010
T + C + E	3,399	20,390	27,190	33,990	40,790	61,180
	(Long-Haul Situation)					
Transport (T)	6,112	36,670	48,900	61,120	73,340	110,010
Construction (C)	59	350	470	590	710	1,060
Embodied (E)	2,565	15,390	20,520	25,650	30,780	46,170
T + C	6,171	37,020	49,370	61,710	74,050	111,070
T + C + E	8,736	52,410	69,890	87,360	104,830	157,240

energy to construct emulsion treated base to the energy required to construct graded aggregate base are 1.2:1 and 1.1:1, respectively, for the short-haul situation and the long-haul situation. A comparison of the energy use for hot mix (black base) to that used by graded aggregate base shows that the ratios are 2.6:1 for short-haul and 1.3:1 for long-haul at equal thicknesses. The transport and construction energy for lean concrete base is calculated to be appreciably less than that for crushed stone base — the ratios being 0.7:1 for the short-haul situation and 0.9:1 for the long-haul situation, primarily because of the low construction energy calculated on the basis of making the concrete mixture on the site with mixed-in-place mixers.

The total of transport and construction energy represents areas in which the highway contractor has some control for energy conservation. The figures given represent the relative amounts of fuel needed to operate the construction equipment and mixing plants for each type of construction. As mentioned previously, neither the highway contractor nor the engineer has any control over embodied energy. The alternative calculations shown in Tables 2 and 3 for embodied energy greatly affect the conclusions drawn concerning the total energy-intensiveness of the different types of construction. If the caloric energy in the asphalt is not included as embodied energy, the ratio of total energy consumption for emulsion treated base and asphalt base are 2.5:1 in each case for the short-haul situation and only 1:3 to 1 in each case for the long-haul situation. Thus, it could be concluded that the break-even point as far as energy is concerned would be at 2.5:1 for the short haul and 1.3:1 for the long haul. Under these conditions both stabilization procedures are shown to be energy-conservative. However, if the caloric energy in the asphalt is included, these ratios approach 10:1 for the short-haul and 3:1 for the long-haul; so here it might be concluded that the crushed stone base is more energy-conservative. When embodied energy is included for the lean concrete base, the energy requirements are significantly higher than the total for crushed stone for equal thickness — the ratios being 2.5:1 for the short haul and 1:2 to 1 for the long haul.

The advantage of being able to utilize local materials through stabilization with emulsions is shown by comparisons from Tables 1 and 2. If a long haul were necessary to obtain suitable crushed stone aggregate, the transport and construction energy requirements for a 10-inch base would be equivalent to 67,720 gallons of gasoline. However, if emulsion stabilization for local materials (short haul) were possible, energy equivalent to only 13,950 gallons of gasoline would be needed, for a difference equivalent to almost 54,000 gallons of gasoline for each mile of construction. Again, however, if the total embodied energy in the emulsion, including the caloric energy of the asphalt cement, were included in the calculations, the energy used in the stabilization procedure would be considered to be equivalent to about 131,000 gallons of gasoline, which is almost twice that for the crushed stone.

Although it is important to recognize the possibility that refining techniques could change so that the hydrocarbons now contained in the asphalt would be converted to usable fuel, under the present marketing conditions, the lower figure for embodied energy in asphalt appears to be more realistic for comparing relative energy uses for different procedures in highway construction and maintenance. In fact, only the relative amounts of transportation and construction energy are of direct concern to the highway contractor. These are the categories that affect most directly highway construction costs.

As discussed earlier, requirements other than energy must enter into the decision as to the type of base to be constructed. In any given instance where alternate designs are feasible, estimates of energy use need to be based on the actual conditions for the project and the hauling distances involved. However, the approximations given in Tables 1, 2, and 3 illustrate the large potential for saving transport and construction energy if travel distances can be significantly reduced through the use of natural materials plus stabilization. The use of natural aggregates in such situations also conserves high quality materials for more critical uses. The potential energy advantages for lean concrete base indicates that further study of the usefulness of this type of construction needs to be made. Such construction would be particularly desirable where the aggregate used is primarily crushed concrete for which a disposal problem would otherwise exist.

Flexible Pavement Construction

Asphalt Supply and Costs

Perhaps the greatest potential effect of the changes in energy sources with respect to flexible 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 there now are certain restraints that tend to make any early or sudden shift unlikely. The restraints relate to the sulfur content of the petroleum. In 1976, Charles R. Foster, then director of engineering and research for the National Asphalt Pavement Association, summed up the situation in a report entitled "The Future for Hot-Mix Asphalt Paving".[6]

Foster pointed out that at present asphalt cement is being refined primarily from sour crudes which contain so much sulfur that the residual cannot be economically refined for use as fuel oil. Asphalt cement being marketed in 1976 contained from 2% to 7% sulfur. Foster also pointed out that since the percentage of sour crude being refined in the United States was fairly high, there was an adequate supply of asphalt cement at that time. He expected that the supply would continue to be adequate for some time for two reasons. One was that oil producing nations having both sweet (low in sulfur) and sour (high in sulfur) crudes were requiring purchasers to take a certain quantity of sour crude along with the sweet crude. The other reason he noted was that no practical means were available for removing the chemically bound sulfur from heavy residuals. He said that even when such procedures were developed, it will most likely take 5 or 6 years to build the facilities and put them on stream.

Foster's optimistic view concerning the supply of asphalt has been shown to be correct up to the present time and is supported by the news release from the Asphalt Institute issued on August 23, 1978. That news release is quoted in part as follows:

> College Park, Md. — In contrast to reported shortages of some other road construction materials, there is an adequate supply of asphalt to meet normal requirements in the United States, Joseph R. Coupal, Jr., President of The Asphalt Institute, said here today.
>
> Coupal was responding to concerns expressed by highway engineers and transportation officials following news reports about critical shortages of other commonly-used roadbuilding products. His comments were made after surveying major refiners of petroleum asphalt.
>
> The Institute President, reaffirming a statement he made in May, gave assurances that "supplies

> of asphalt for the near future appear to be ample and, barring some unforeseen occurrence such as interruptions in the delivery of foreign crude oil, they will be adequate to meet current and future needs."
>
> Coupal cautioned that some other factors could adversely affect the situation. For example, he said, "problems with transportation or unforeseen production disruptions could create temporary supply shortages in a few localities. Government regulations or mandates could also adversely affect the supply of asphalt."
>
> However, Coupal added, "The Institute is unaware of any current government proposals which would cause a supply shortage."

The potential effect of changing political situations is difficult to determine. For example, the Iranian situation was not foreseen at the time Mr. Coupal made his evaluation. To what extent this or other political upheavals will affect asphalt supply will always be an unpredictable factor.

The Substitution of Emulsions for Cutbacks

The Bureau of Mines estimates that in 1975, 4.1 million tons of cutback asphalt were used for paving purposes. This amount of cutback contains about 345 million gallons of petroleum distillates, which are equivalent in Btu's to about 360 million gallons of gasoline. It doesn't seem to make sense to pour this average of almost one million gallons of gasoline per day on U. S. roads and streets and let most of it evaporate into the air and thus add significantly to the hydrocarbon pollution. Yet this is what is being done by the continuing, unnecessary use of cutback asphalts for highway construction and maintenance.

Although there are some situations for which best results within present technology require the use of cutbacks, much of the distillates so used could be saved by the use of emulsions in lieu of the cutbacks. Many states have recognized this possibility by revising their specifications to permit the use of emulsions as an alternate to cutbacks, and within the last three years some have made significant progress in reducing the amounts of cutbacks used. An often used expression is that for maintenance operations, cutbacks form a "forgiving" mix. That is, with cutbacks, dirty aggregates or other than optimum grading and bitumen content can be used with reasonably satisfactory results. This is not true for emulsions — the type and amount of emulsion and the characteristics of the aggregates are very important. Since many maintenance crews are not trained in the use of emulsions, this situation has led some to express an attitude of "I'll use cutbacks as long as I can get them". Some producers, on the other hand, have taken the position that "I'll furnish cutbacks as long as there is a demand for them." Obviously, some additional incentive for eliminating cutbacks is needed.

The additional incentive in this case is the reduction of air pollution. According to one report, prepared for the Environmental Protection Agency (EPA), the evaporation of distillates from cutbacks 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 for that state.[(7)] 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.

NCHRP Synthesis Report No. 30 provides an excellent state-of-the-art report on emulsions.[(8)] In addition, considerable research is in progress to improve design procedures for the use of emulsions as well as efforts by emulsion manufacturers to improve emulsions themselves and by equipment manufacturers to improve emulsion construction techniques.

Drum Mixing

A calculation of the energy requirements for mixing hot asphalt products has shown that a saving of construction energy equivalent to almost 1 gallon of gasoline for each ton of mix is theoretically possible by substituting drum mixing at low temperatures for pug mill mixing at high temperatures. On a nationwide basis, 350 million tons of hot asphalt mixes are produced annually. Accordingly, theoretical energy savings equivalent to over 300 million gallons of gasoline per year are possible. There is also evidence that overall costs for drum mixing may be as much as $1.00

per ton lower than costs for pug mill mixing. However, there are several indications that this level of saving is not realistic.

Capital investment in existing plants and local conditions makes a complete shift to drum mixing plants uneconomical for reasons other than energy. In addition, trends in drum mixing are to mix at higher temperatures so that the theoretical advantage of not using as much energy for removal of less moisture is lost.

Drum mixing can be conducted at significantly lower temperatures than can pug mill mixing when the aggregates contain large amounts of moisture. The early development of drum mixing was based on the addition of moisture to the aggregate. The foaming at the time of introduction of the asphalt was considered beneficial to the mixture and was dissipated prior to discharge of the mix from the drum. As reported by Granley, early experience (1972) in North Dakota demonstrated that mixing at 200° - 210°F was practicable.[9] Under these circumstances about 2% moisture is in the mixture at discharge and the moisture serves as an aid to compaction. Considerable fuel for drying the mixture is saved, since a large portion of the water present is not vaporized. However, experience has shown that there are some difficulties in mixing at low temperatures that can be avoided by mixing at high temperatures. For low temperatures (190°-210°F), if the initial stockpile is too dry some moisture must be added to assist in compaction. In the 220° - 250°F range there is a moisture/vapor related phenomenon which impedes compaction. This is probably related to moisture vapor being emitted from the coarse particles of the aggregate after laydown.

These problems are essentially eliminated by increasing the mixing temperature at discharge from the drum to over 260°F. It has also been shown that the initial foaming thought to be beneficial is not necessary to attain proper mixing. For these reasons, most drum mixing is now conducted at the higher temperature range.

Under these circumstances the fuel saving for drum mixing over the use of conventional pug mills is reduced considerably. If the aggregate is being heated to the same temperature in both cases and the same amount of water is being removed, only the difference in the construction energy used to operate the plant provides a savings. A summary of energy requirements for various

Table 5 conditions is shown in Table 5, which is reproduced from reference 5. It should be noted that the gallons per ton indicated are based on theoretical factors and not actual plant usage.

Table 5 shows that operating both the pug mill and drum mixer at 260°F and removing 5% moisture from the aggregate requires energy equivalent to essentially the same amount of gasoline per ton (1.97 for drum mixing and 1.99 for pug mill mixing). The total for pug mill mixing for removing 5% water and heating to 320°F is shown to be 2.24 equivalent gallons of gasoline; a difference of about 1/4 gallon per ton. If drum mixing were conducted at 210°F and 3% water removed, the equivalent requirement would be 1.33 gallons per ton and the potential saving

Table 5

Equivalent Gal/Ton of Gasoline
Required to Mix at Different Temperatures
and Remove Different Percentages of Water
for Drum Mixing and Pug Mill Mixing

Percent Water Removed	Aggregate heated to — 210°F Drum	210°F Pugmill	260°F Drum	260°F Pugmill	320°F Drum	320°F Pugmill
1	0.88	0.91	1.07	1.10	1.32	1.34
2	1.11	1.13	1.29	1.32	1.54	1.57
3	1.33	1.36	1.52	1.55	1.76	1.79
5	1.78	1.80	1.97	1.99	2.21	2.24
7	2.23	2.25	2.41	2.44	2.66	2.69

would be 0.91 gallon of gasoline per ton of mixture over that required for pug mill mixing at 320°F. A saving of 0.66 equivalent gallon over that required for pug mill mixing at 260°F is indicated. For the "typical" mixing temperature of 300°F often used in asphalt construction the equivalent saving would be about 0.83 gal/ton. From the standpoint of conservation of construction energy alone it appears that further efforts to utilize drum mixing at lower temperatures should be made. However, the potential use of greater amounts of energy in the laydown and compaction of the cooler mixes must be weighed against direct saving during mixing. Construction energy is involved in both cases so that the contractor is in a position to make the decision most advantageous to him. Better performance from better compaction may also be a benefit from mixing at higher temperatures.

Improved Efficiency in the Operation of Conventional Asphalt Plants

There are a number of possibilities for adjusting conditions at conventional asphalt plants so as to obtain significant energy savings. Energy saved in these cases is construction energy and it contributes directly to reduced production costs, unless difficulty is encountered in compaction because of low temperatures.

Reduction of Mixing Temperatures

Interest in lowering the mixing temperatures for conventional pug mill mixers was generated partly by the successful use of drum mixing in the West at temperatures around 190° - 220°F, which left 1% to 3% moisture in the mix as it came from the mixer, and partly by the fuel oil shortage during the 1973 embargo. While it is recognized that extremely high moisture contents in the aggregate cannot be tolerated for pug mill mixing because of foaming, the findings with respect to drum mixing prompted experiments to reduce the mixing temperatures for conventional pug mill mixing and to relax the requirements for moisture in the mix. A report of a Virginia study by Hecht showed that temperatures in the range of 230° - 240°F were adequate for drying aggregates (sand), even when initial moisture was as high as 7%.[(10)] He reported some minor problems for incomplete coating using normal mixing times. However, adding 5 seconds to the wet mixing cycle cleared up the problem. Hecht reported that for the cooler mixes the rollers could (and should) work immediately behind the laydown machine. During hot weather the roller would normally have to wait until the mixes made at 275° - 300°F cooled before rolling could begin. Hecht's results also showed significantly less asphalt hardening at the lower mixing temperature. For the projects studied, about 0.5 gallon of fuel oil per ton of aggregate dried was saved.

In the limited use of lower mixing temperatures in Virginia over the past three construction seasons no serious problems have been encountered. However, since the reduction of the mixing temperature is optional with the contractors, most have continued to use the usual mixing temperature of around 300°F. This reluctance to change is most likely indicative of the feeling that lower mixing temperatures might require changes in techniques for placing and compacting mixtures, changes that would decrease the efficiency of work crews with a resulting overall increase in costs to the contractor. That is, the reduced cost of fuel for heating would be more than offset by a reduction in production. Whether or not this is true is a matter that needs further study.

Protection of Stockpiles to Eliminate Moisture

Since the vaporization of water requires a significant input of energy, a significant amount of construction energy can be saved by utilizing dry aggregate from the stockpile. A reduction in stockpile moisture of 3% theoretically saves energy equivalent to about 2/3 gallon of gasoline for each ton of mix. A reduction in moisture content of 5% saves energy equivalent to more than 1 gallon of gasoline per ton. As the cost of fuel for dryers increases, the capital investment needed to provide cover for stockpiles will become more attractive and this possibility should not be overlooked.

Improved Control of Airflow and Exhaust Temperatures on the Aggregate Dryer

The proper operation of the hot mix plant is the responsibility of the contractor. In times of relatively inexpensive fuel oil and adequate supplies, adjustments such as the damper-setting to control air flow through the dryer and exhaust temperatures were not generally considered critical. However the publication "Theoretical Computations of the Fuel Used and Exhaust Produced in Drying Aggregates" (Information Series 61)[11] shows that a significant saving in fuel and a significant increase in production can be attained by proper plant adjustments. The report shows that a 4% saving in fuel and a 24% increase in production can be attained by reducing exhaust temperatures 125°F. Damper adjustments were shown to result in a reduction in fuel of about 8%.

The optimum adjustment of a plant will depend on a number of factors and will vary with each plant. Overall savings will result from a combination of adjustments and cannot be completely predicted from the theoretical computations given in the referenced NAPA report,[(11)] but the data given clearly indicate that development of an awareness of the need for proper adjustments by plant operators can provide a significant fuel economy and reduction in production costs.

Rigid Pavement Construction

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 of cement manufactured.[(12)] 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. Japan also has an efficient industry — showing the use of 3.9 million Btu/ton.[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.[13]

This workshop explored a large number of possibilities for energy conservation in areas relating to the manufacture and use of cements in concrete applications.

All of the possibilities discussed do not affect concrete construction relating to highway facilities, but many have a 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.[(14)] 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. Her 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).[(15)]

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.

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.

ENERGY CONSIDERATION IN USE OF WASTE MATERIALS AND INDUSTRIAL BY-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. However, the added advantages of eliminating a source of environmental pollution and the conservation of higher quality conventional materials often make the use of the waste material advantageous to the community.

Fly Ash and Bottom Ash

To the power plant manager, both fly ash and bottom ash are nuisance waste materials that must be disposed of, but to the highway engineer these materials have a significant potential for applications in highways. 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.(16) 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 —

1. lime- or cement-fly ash-aggregate pavements;
2. stabilized fly ash pavements (lime-fly ash aggregate or cement-fly ash aggregates);
3. soil stabilizers and soil modifiers (lime-fly ash or cement-fly ash);
4. fly ash-soil bases and subbases;
5. fly ash embankments;
6. structural backfill; and
7. 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 recently compiled a summary of the amounts of fly ash, bottom ash, and boiler slag collected and used in the United States in 1977. This summary is given ible 6 in Table 6. 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 which 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.[16] 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.[17]

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 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.[18]

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 a year.[19]

Steel slags are also useful, but they require more care in their selection and use because of their potential for expansion.

Table 6

Ash Collection and Utilization — 1977

(Million Tons)

	Fly Ash Tons x 10⁶	Bottom Ash Tons x 10⁶	Boiler Slag (if separated from Bottom Ash Tons x 10⁶
1. TOTAL ASH COLLECTED	48.5	14.1	5.2
2. ASH UTILIZED	6.3	4.6	3.1
3. UTILIZATION PERCENTAGE			
A. COMMERCIAL UTILIZATION			
a. Mixed with raw material before forming cement clinker	7	—	3
b. Mixed with cement clinker or mixed with cement (Type 1-P cement)	5	2	—
c. Partial replacement of cement in concrete and blocks	25	—	—
d. Lightweight aggregate	2	3	—
e. Fill material for roads, construction sites, land reclamation, ecology dikes, etc.	20	20	8
f. Stabilizer for road bases, parking areas, etc.	3	5	2
g. Filler in asphalt mix	2	—	—
h. Ice control	—	22	13
i. Blast grit and roofing granules	—	—	48
j. Miscellaneous	3	9	22
B. ASH REMOVED FROM PLANT SITES AT NO COST TO UTILITY	7	17	4
C. ASH UTILIZED FROM DISPOSAL SITES AFTER DISPOSAL COSTS	26	22	—
	100	100	100

COMPARATIVE RESULTS

ASH COLLECTED	1966*	1974	1975	1976	1977
Fly Ash	17.1	40.4	42.3	42.8	48.5
Bottom Ash	8.1	14.3	13.1	14.3	14.1
Boiler Slag		4.8	4.6	4.8	5.2
TOTAL ASH COLLECTED-TONSx10⁶	25.2	59.5	60.0	61.9	67.8
ASH UTILIZED					
Fly Ash	1.4	3.4	4.5	5.7	6.3
Bottom Ash	1.7	2.9	3.5	4.5	4.6
Boiler Slag		2.4	1.8	2.2	3.1
TOTAL ASH UTILIZED-TONSx10⁶	3.1	8.7	9.8	12.4	14.0
PERCENT OF ASH UTILIZED					
% Fly Ash	7.9	8.4	10.6	13.3	13.0
% Bottom Ash	21.0	20.3	26.7	31.5	32.6
% Boiler Slag		50.0	40.0	45.8	60.0
PERCENT OF TOTAL ASH UTILIZED	12.1	14.6	16.4	20.0	20.7

*First year that data was taken
**1967-1973 data omitted from tabulation because of space limitation.

Compiled by the National Ash Association and Edison Electric Institute.

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 manufactured and relatively little energy is needed for processing.

ENERGY CONSIDERATIONS IN RECYCLING

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 courses or pavements. 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.[20,21,22,23] 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.[24] 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.[(25)] In a report on the rehabilitation of a runway at the Jacksonville International Airport,[(20)] 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.

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"[(26)] and a "State of the Art: Hot Recycling." The latter report is vol. 1, no. 1 of a planned series titled "Recycling Report."[(27)] It 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 building on the metal surfaces of the equipment and the smoke generated when heating the reclaimed material.

The synthesis report (No. 54) on recycling materials for highways published by the TRB provides a comprehensive discussion of various types of asphalt recycling techniques.[25]

Considerable additional work is being done by a number of transportation departments to determine the benefits of recycling and to develop 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 the judging.

ENERGY CONSIDERATIONS 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 viewpoint 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.[28] 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.

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 states. 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.[25] 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 energy conservation. Transportation departments should review their maintenance procedures to determine if a greater potential exists for saving materials and energy than is now being realized.

Minimization of On-site Repair Time

The need to develop maintenance and repair techniques that minimize disruption to traffic already have been discussed to some extent. 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.

CONCLUSIONS

This general review of the considerations relating to the use of energy in highway construction and maintenance leads to the following conclusions.

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. However, an understanding of potential energy problems must be developed in all activities relating to highway construction and maintenance.
2. The increasing national interest in utilizing industrial wastes is based on conserving supplies

of natural aggregates, conserving energy, and economically disposing of materials that might be harmful to the environment. The materials having the best potential for use in highways are mining wastes and fly ash and bottom ash from coal burning plants.

3. 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 by a number of states. Traditionally, the concern has been to reduce costs, but inasmuch as cost reduction stems mostly from the 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, the 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-effective 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.

4. At the present time the energy saved in recycling pavements is usually incidental to the desire to reduce costs and the need to conserve supplies of high quality aggregates or to avoid the accumulation of solid waste. There is a need to establish procedures for accurately estimating energy and cost advantages for different recycling techniques.

5. Because asphalt cutbacks are not only wasteful of energy but also pollutive, continuing efforts are needed to minimize and eventually phase out their use in highway construction and maintenance. Efforts to improve emulsions and to develop improved construction techniques with such materials should continue.

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

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Appendix A

Useful Energy Factors Relating to Highway Construction
(Except as noted, factors shown are based on Reference 29.)

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.

Appendix B

Basis for Calculations of Energy Used for Various Type Bases
(Factors used shown in Appendix A)

CRUSHED STONE AGGREGATE: Table 1

Embodied energy = 35,700 Btu/ton

Aggregate is hauled in 3 axle rigs at 8,540 Btu/ton-mile

Aggregate contains 5% moisture when hauled

Energy for loading — 4,400 Btu/ton

Energy for spreading, compacting — 17,000 Btu/ton

Assume base compacted to 135 pcf

Equivalent to 712.4 tons per inch thickness in 1 mile pavement — 24 ft. wide.

For short-haul situation, aggregate is moved 20 miles.

For long-haul situation, aggregate is moved 130 miles.

Calculations:

Calculate total Btu's for 1 mile of base course — 24 ft. wide, 1 inch thick. — Convert to equivalent gallons of gasoline by dividing by 125,000 (Btu/gal).

(C) Loading — 4,400

(c) Spreading, compacting — 17,000

21,400 Btu/ton construction energy

21,400 x (1.05 x 712.4) ÷ 125,000 = 128 gal. (eq. gasoline)

Transport Energy

(T) Short haul - (1.05 x 712.4) x 8,540 ÷ 125,000 = 1,022 gal.

(T) Long haul - (1.05 x 712.4) x 8,540 ÷ 125,000 = 6,644 gal.

Embodied Energy

(E) 712.4 x 35,700 ÷ 125,000 = 203 gal.

EMULSION TREATED AGGREGATE BASE: Table 2

Assume natural local aggregate used at 15,000 Btu/ton embodied energy

Aggregate is hauled in 3 axle rigs at 8,540 Btu/ton-mile

Emulsion is hauled in 4 axle rigs at 10,080 Btu/ton-mile

Assume emulsion content 8 percent — plant mix

Assume emulsion contains 10 percent distillate, 65 percent asphalt

Energy for loading aggregate — 4,400 Btu/ton

Energy for plant operations — 6,630 Btu/ton

Assume base compacted to 140 pcf

Equivalent to 739.2 tons per inch thickness in 1 mile

Assume aggregate hauled to plant at 5 percent moisture

For short-haul situation, emulsion is hauled 50 miles to plant, aggregate is hauled 10 miles

For long-haul situation, emulsion is hauled 150 miles to plant, aggregate is hauled 100 miles to plant, and mix hauled 30 miles to job site.

Calculations:

Calculate total Btu's for 1 mile of base course, 24 ft. wide — 1 inch thick. Convert to equivalent gallons of gasoline by dividing by 125,000 (Btu/gal)

(T) Loading aggregate - 4,400 x 1.05 x .92 x 739.2 ÷ 125,000 = 25.1 gal.

(T) Hauling aggregate (short haul)
1.05 x .92 x 739.2 x 8,540 x 10 ÷ 125,000 = 488 gal.

(T) Hauling aggregate (long haul)
1.05 x .92 x 739.2 x 8,540 x 100 ÷ 125,000 = 4,880 gal.

(T) Hauling emulsion (short haul)
.08 x 10,080 x 50 x 739.2 ÷ 125,000 = 238 gal.

(T) Hauling emulsion (long haul)
.08 x 10,080 x 150 x 739.2 ÷ 125,000 = 714 gal.

(C) Mixing aggregate and emulsion
739.2 x 6,630 ÷ 125,000 = 39.2 gal.

(C) Hauling mix to job site (short haul)
739.2 x 8,540 x 10 ÷ 125,000 = 505 gal.

(C) Hauling mix to job site (long haul)
739.2 x 8,540 x 30 ÷ 125,000 = 1,515 gal.

(C) Laydown, compaction
739.2 x 17,000 ÷ 125,000 = 100 gal.

Total Transport Energy (Short)	= -	488	+	25	+	238	=	751	gal
Total Transport Energy (Long)	=	4,800	+	25	+	714	=	5,619	gal
Total Construction Energy(Short)	= +	39	+	505	+	100	=	644	gal
Total Construction Energy (Long)	= -	39	+	1,515	+	100	=	1,654	gal

Embodied Energy in Emulsion

10 percent distillate at 135,000 Btu/gal and 241 gal/ton equivalent to 26 gal. gasoline/ton emulsion.

26 x 739.2 x .08 ÷ 125,000 = 1,538 gal. equivalent in distillate

65 percent asphalt at 587,500 (Caloric Energy not included)
.65 x 587,000 x 739.2 x .08 ÷ 125,000 = 181 gal. equivalent from asphalt

65 percent asphalt at 37,130,000 Btu/ton =
.65 x 739.2 x 37,130,000 x .08 ÷ 125,000 = 11,417

Energy for manufacturing emulsion
2,000 Btu/gal x 241 gal/ton x 739.2 x .08 ÷ 125,000 = 228 gal.

Mix is 92% aggregate
.92 x 739.2 x 115,000 ÷ 125,000 = 82 gal. equivalent from aggregate

Total embodied energy when caloric energy in asphalt cement not included =
1,538 + 181 + 228 + 82 = 2,029 gal. (E_1)

Total embodied energy when caloric energy in asphalt cement is included =
1,538 + 11,417 + 228 + 82 = 13,265 (E_2)

HOT MIX ASPHALT (BLACK BASE): Table 3

Assume all crushed stone used at 35,700 Btu/ton embodied energy

Assume 4.5 percent asphalt content (typical for Virginia highway construction)

Energy for loading aggregate — 4,400 Btu/ton

Aggregate hauled to plant with 5 percent moisture

Aggregate hauled in 3-axle rigs at 8,540 Btu/ton-mile

Asphalt hauled to plant in 4-axle rigs at 10,080 Btu/ton-mile

Energy for drying aggregate (% moisture x 28,000 Btu/ton-aggregate)

Energy to heat aggregate to 300°F (230 x 470 Btu/°F ton)

Energy for other plant operations — 19,800 Btu/ton

Energy for spreading and compacting mix — 16,700 Btu/ton

Assume base compacted to 145 pcf

Equivalent to 766 tons per inch thickness in 1 mile.

For short-haul situation asphalt is hauled 50 miles to plant, aggregate is hauled 10 miles to plant, and mix is hauled 10 miles to job site.

For long-haul situation asphalt is hauled 150 miles to plant, aggregate is hauled 100 miles to plant, and mix is hauled 30 miles to job site.

Calculations:

Calculate total Btu's for 1 mile, Black Base, 24 ft. wide - 1 inch thick. Convert to equivalent gallons of gasoline by dividing by 125,000 (Btu/gal)

(T) Loading aggregate: 4,400 x 1.05 x .955 x 766 - 125,000 = 27 gal.

Hauling Aggregate:

(T) Short: 1.05 x .955 x 766 x 8,540 x 10 ÷ 125,000 = 525 gal.

Long: 1.05 x .955 x 655 x 8,540 x 100 ÷ 125,000 = 5,250 gal.

Hauling Asphalt:

(T) Short: .045 x 10,080 x 50 x 766 ÷ 125,000 = 139 gal.
Long: .045 x 10,080 x 150 x 766 ÷ 125,000 = 417 gal.

(C) Drying aggregate: 766 x 5 x 28,000 ÷ 125,000 = 858 gal.

(C) Heating Aggregate: 766 x 230 x 470 ÷ 125,000 = 662 gal.

(C) Other plant operation: 766 x 19,800 ÷ 125,000 = 121 gal.

Haul Mix to Job Site

(C) Short: 766 x 8,540 x 10 ÷ 125,000 = 523 gal.
Long: 766 x 8,540 x 30 ÷ 125,000 = 1,569 gal.

(C) Laydown compaction: 766 x 16,700 ÷ 125,000 = 102 gal.

Total transport energy (short) = 27 + 525 + 139 = 691 gal.

Total transport energy (long) = 27 + 5,250 + 417 =5,694 gal.

Total construction energy (short) = 858 - 662 + 121 + 523 + 102 = 2,266 gal.

Total construction energy (long) = 858 - 662 + 121 + 1,568 + 102 = 3,312 gal.

Embodied Energy:

Asphalt (Caloric Energy not counted)
= .045 x 766 x 587,500 ÷ 125,000 = 162 gal.

(Caloric Energy Counted)
= .045 x 766 x 37,130,000 ÷ 125,000 = 10,239 gal.

Aggregate
.955 x 766 x 35,700 ÷ 125,000 = 209 gal.

Total Caloric Energy not counted (E_1) = 371 gal.

Total Caloric Energy counted = (E_2) = 10,448 gal.

LEAN CONCRETE BASE (ECONOCRETE): Table 4

Assume local aggregate (or crushed concrete) used:

Embodied energy = 15,000 Btu/ton

Aggregate is hauled in 3-axle rigs at 8,540 Btu/ton-mile

Aggregate contains 5% moisture when hauled

Cement is hauled in 4-axle rigs at 10,080 Btu/ton-mile

Energy for loading aggregate = 4,400 Btu/ton

Energy for handling aggregate at plant = 4,650 Btu/ton

Energy for mixing = 3,580 Btu/cu.yd. = 1,665 Btu/ton

Energy for placing = 2,437 Btu/ton

Calculations:

Calculate total Btu's for 1 mile of base course - 24 ft. wide, 1 in. thick.

Convert to equivalent gallons of gasoline by dividing by 125,000 (Btu/gal.)

Assume 250 lbs cement per cu. yd. concrete at a water/cement ratio of 0.5

1 cu. yd. concrete contains - 250/196 = 1.28 cu. ft. cement

125/196 = 2.00 cu. ft. water

by difference= 23.72 cu. ft. aggregate

Therefore,

1 cu. yd. = .125 tons cement

= .062 tons water

=1.957 tons aggregate

Total 2.15 tons per cu. yd.

at 2.15 tons/cu.yd.

1 mile = 14,080 sq. yd. $\times \frac{1}{36}$ (for 1 in. thickness) = 391 cu.yd./mile

Embodied energy:

1 ton concrete contains .058 tons cement

.058 x 6,340,000 Btu/ton = 367,710 Btu (cement)

1 ton concrete contains .91 tons aggregate =

.91 x 15,000 Btu/ton = 13,650 Btu (aggregate)

Total embodied energy = 381,370 Btu/ton

381,370 ÷ 125,000 = 3.05 equivalent gallons of gasoline per ton.

841 tons/mile x 3.05 gal/ton = 2,565 equivalent gallon per mile per inch.

Transport energy:

Loading = 4,400 Btu's/ton ÷ 125,000 = .035 gal/ton

Short haul:

Aggregate = .91 x 1.05 (5% water) x 10 miles x 8,540 ÷ 125,000 = .653

Cement = .058 x 50 miles x 10,080 ÷ 125,000 = .234

Total = .035 + .653 + .234 = .922 gal/ton

841 tons x .922 gal/ton = 775 gal/in. thickness

Long haul:

Loading = .035 gal/ton

Aggregate = .91 x 1.05 x 100 x 8,540 ÷ 125,000 = 6.53 gal/ton

Cement = .058 x 150 x 10,080 ÷ 125,000 = .702

Total = .035 + 6.53 + .702 = 7.267 gal/ton

841 tons x 7.267 gal/ton = 6,112 gal/in. thickness

Construction energy:

Handling =	4,650 Btu/ton
Mixing =	1,665 Btu/ton
Placing =	2,437 Btu/ton
Total =	8,752 Btu/ton ÷ 125,000 = .07 equivalent gal/ton
841 x .07 =	58.87 gal. per mile per inch thickness (say 59)

Summary of assumptions relating to short- and long-haul situations (Assume asphalt mixing plants between aggregate source and job site.)

	Short haul	Long haul
Miles aggregate for graded base hauled to job site	20	130
Miles asphalt and emulsion hauled to plant	50	150
Miles hot mix agg. hauled to plant	10	100
Miles cold mix agg. hauled to plant	10	100
Miles hot mix hauled to job site	10	30
Miles cold mix hauled to job site	10	30

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
°Centigrade = (° Fahrenheit - 32) x 5/9