ΘPORTUNITIES FOR CONSERVING ENERGY IN ASPHALT PAVING PROCESSES

by

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

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

Charlottesville, Virginia

October 1978
VHTRC 79-R19

ENERGY TASK GROUP

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PREFACE

This report constitutes a reassessment of information relating to asphalt paving processes that is contained in two previously prepared reports involving energy conservation in all areas of highway construction and maintenance. The two reports are "Energy Use and Conservation in Highway Construction and Maintenance", (VHTRC 78-R42), prepared by the Virginia Highway and Transportation Research Council in cooperation with the U. S. Department of Transportation, Federal Highway Administration, and "Ideas for Energy and Material Conservation in Highway Construction",(FHWA-TS-78-237), prepared by the Texas Transportation Institute for the U. S. Department of Transportation, Federal Highway Administration (Contract).

The implications of considering the total energy concerned from the standpoint of four categories of energy — transport energy, construction energy, embodied energy, and indirect energy — discussed in this report were not included in the original presentations.

ABSTRACT

This report discusses the potential for energy conservation in a number of activities related to the use of asphalt materials in highway construction. It is pointed out that not only should the total energy be considered, but also the category of the energy involved. The categories suggested are (1) embodied energy, (2) transport energy, (3) construction energy, and (4) indirect energy. Transport energy and construction energy have a major direct impact on highway contractors, since such energy consists primarily of the fuel to operate hauling and construction equipment. The indirect and embodied energy categories are important from a national viewpoint, but with respect to highway construction are of concern only to the extent that they affect the cost and availability of materials.

Included are discussions of asphalt supply and costs; effects of substituting emulsions for cutbacks; the potential for energy conservation with drum mixing; the potential for conservation with conventional asphalt mixing plants; energy saving through the use of asphalt stabilized aggregates; and energy considerations in recycling asphalt pavements.

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INTRODUCTION

The discussions presented here are based partly on the report entitled "Energy Use and Conservation in Highway Construction and Maintenance",[1] and partly on a Texas Transportation Institute study for the Federal Highway Administration entitled "Ideas for Energy and Material Conservation in Highway Construction".[2]

Highway construction is estimated to consume about 2.5 quadrillion (10 to the 15th power) Btu's per year, which is equivalent to the energy in 24 billion gallons of petroleum. But even this huge quantity represents only about 3% of the national annual consumption of energy. Thus, even a large reduction in the energy used in highway construction is not going to result in a very large reduction in the total energy used nationally and the nation's energy supply problem obviously will not be solved by modifying activities in this technical area. 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.

(3%)

To be realistic, one must also recognize that most decisions on what type of highway facility is to be built will continue to be based primarily on fulfilling the needs and on overall cost-effectiveness rather than energy considerations. Nevertheless, an understanding of the current energy situation is important because it may indicate future cost trends as well as potential shortages.

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, if the concern is with the national energy picture, it is also necessary to consider the source of the energy. When dealing with energy derived from solar sources, dollar costs are the major consideration; once a solar facility is built and becomes operative, the energy utilized does not deplete natural resources that would otherwise be utilized. On the other hand, Btu's derived from petroleum are of major concern. However, decisions regarding alternative sources of energy are not likely to be a concern of the highway engineer and contractor. They will look at what's available and how much it costs and be guided accordingly.

To get a more 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.

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 report and no consideration will be given to it here.

The discussions presented here are concerned both with the opportunities for conserving energy in asphalt processes and the possible effects of changes in energy costs and availability on asphalt construction. The discussions encompass the following subjects:

1. Asphalt supply and costs
2. Substitution of emulsions for cutbacks
3. Increased use of drum mixing
4. Improved efficiency in the operation of conventional asphalt mixing plants
5. Use of asphalt stabilization techniques to upgrade local aggregates for use in base courses
6. Recycling of asphalt pavements.

ASPHALT SUPPLY AND COSTS

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 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".(3)

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."

There is a strong possibility, however, that the price of asphalt paving will increase more than would be indicated by normal inflation because asphalt cement prices will rise in proportion to the increase in the price of petroleum. In addition, the cost of fuel and other energy used in the manufacture of asphalt paving mixtures will increase accordingly. The National Asphalt Pavement Association (NAPA) estimates that by 1980 the average cost of asphalt cement will be $120 per ton.(4) 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 a little over $23.00 in 1980. Increases beyond 1980 may be proportionally greater if the world price of petroleum continues to rise sharply.

At present there seems to be considerable difference of opinion among the experts as to how much petroleum is left in the world and as to when a crunch other than that attributable to inflation will occur — the pessimistic view typified by Schlesinger and the Department of Energy is that a severe shortage will occur by 1980. The optimistic view is that petroleum shortages won't develop until after 2000, and possibly as late as 2050. Ultimately, however, in view of the almost certain depletion of petroleum, the supply of asphalt will diminish and a new binder or extenders to be used in conjunction with asphalt will be needed. Judging from the recent reports it appears that there will continue to be enough asphalt for at least the rest of the century, but its competitive position with portland cement concrete is likely to be less favorable.

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 to an attitude of "I'll use cutbacks as long as I can get them". The producer, on the other hand, has 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 accounts for 2.3% of the estimated national hydrocarbon emissions, and in some states cutback emissions were as high as 15% of the hydrocarbon emissions.(5) 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.

As is well known, 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.

In September 1974, 42 states permitted emulsions to be substituted for cutbacks and probably a greater number now have such a provision. However, the extent to which this shift has been made is not known. Action by the EPA to curtail the use of cutbacks except under special circumstances requiring permits is now being considered; so it is likely that more shifts will soon be made.

Some dissatisfaction with emulsions has been reported by some personnel of states that have made the decision to use emulsions in lieu of cutbacks; other states apparently have no difficulty. It is extremely important that personnel using emulsions be trained in their use and understand their characteristics. The type of aggregate used and even the weather can have a greater effect on construction with emulsions than with cutbacks. Agencies whose highway construction and maintenance personnel are generally unfamiliar with emulsions should make use of the technical assistance usually available from the emulsion supplier.

The advantages and disadvantages of using emulsions in lieu of cutbacks are summarized below.

Advantages

Energy Conservation

In general terms, the saving by substituting emulsions for cutbacks on a one-to-one basis represents about 1/3 gallon of gasoline for each gallon of emulsion used. Nationwide the total elimination of cutbacks would save energy equivalent to 300-400 million gallons of gasoline per year.

Other examples of potential energy conservation are as follows:

1. For applications such as fog seals or tack coats which require about 0.1 gallon per square yard, the saving in distillate amounts to an energy equivalent of about 470 gallons of gasoline for each mile of pavement.

2. The potential saving is much more substantial for multiple surface treatments requiring a total of about 0.9 gallon per square yard. The potential saving is equivalent to 4,200 gallons of gasoline for each mile of pavement.

3. Although, as stated, some difficulties still exist in the use of emulsions in the construction of dense-graded base courses, substantial energy saving is possible. For an 8-inch thick base containing 8% liquid asphalt, energy equivalent to 26,000 gallons of gasoline per mile can be saved, even if the emulsion used contains 10% distillate. If an all-water based emulsion were used, energy equivalent to 38,000 gallons of gasoline per mile might be saved.

It should be noted that all of this potential saving of energy would be a reduction of embodied energy in the materials being used by the highway engineer. These energy equivalents of thousands of gallons of gasoline don't actually reduce the gasoline or diesel oil the highway contractor must buy to operate his equipment. Thus, the only incentive to him in making such a change is the cost differential that may exist.

Reduction in Pollution

A large proportion of the distillate contained in the cutback evaporates into the air and creates pollution. As stated, the EPA estimates that on a national basis evaporation of distillates from cutbacks accounted for 2.3% of the hydrocarbon emissions found in the air. However, in some states the distillates from cutbacks represent as much as 15% of the hydrocarbon pollution. The danger is further increased by the fact that most cutbacks are used in the summer when air stagnation problems are at their worst and photochemical synthesis occurs most readily.

The use of emulsions with no distillate eliminates this problem. Where some distillate must be used in the emulsion, the problem is reduced but is not entirely eliminated.

Economy

The economy that can be achieved from a shift to the use of emulsions depends upon geographic location. In some areas of the country emulsions are equal in costs to cutbacks. However, in other areas emulsions are less expensive. As old refineries yielding distillates that must be further refined for use as fuel are taken out of service, the source of less expensive distillates will disappear from the market and cutbacks will most likely become more expensive.

Greater use of emulsions will also tend to hold down their costs. Since, as previously mentioned, the energy saved in the shift to emulsions is embodied energy, there is little incentive for the contractor to use emulsions when the choice of materials is left to him, unless there is a cost advantage.

Disadvantages

Emulsions Must be Matched to the Aggregate Being Used

The choice of the emulsion to use for a given purpose will vary with the characteristics of the available aggregate. Thus, a single type and grade of emulsion cannot be substituted for a single type and grade of cutback. Consequently, special training and knowledge are needed to properly use emulsions. Such training and assistance is offered by the major emulsion manufacturers and guidelines are under development by the FHWA in cooperation with the American Emulsion Manufacturers Association and the Asphalt Institute.

Limited Penetration of Emulsion into Base When Used as Prime

Emulsions do not perform as well as cutbacks when used as primes for dense-graded bases. The emulsions do not penetrate into the base as well. Research is under way to develop improved emulsions for this purpose and some success has been achieved by using emulsions containing distillates. The amount of distillate so used is less than that in cutbacks so that some conservation is still possible.

Difficult to Coat Dense-Graded Aggregates

Emulsions work well in open-graded mixtures used as bases or surface courses but are more difficult to use in dense-graded mixtures. Generally, distillates are needed in the emulsions to obtain adequate mixing and aeration is needed prior to compaction so that proper stability is attained. One principal supplier of emulsifiers reports the development of emulsifiers for making emulsions without added distillates suitable for dense mixes.[6] Emulsions of this type are apparently being used with good results for on-site mixing operations.

Need to Aerate

Aeration must be adequate prior to compaction of dense mixtures because water and petroleum distillate are very difficult to remove after compaction. Such aeration requires time and is costly in energy and man-power because of the need to operate additional equipment. Since the extra energy used is construction energy, it directly affects the highway contractor in an adverse manner. Research to solve this problem centers around equipment and materials that reduce the amount of liquid (water and distillate) required during the mixing process.

THE INCREASED USE OF 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.[7] 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 conditions is shown in Table 1, which is reproduced from reference 2.

Table 1

Equivalent Gal/Ton of Gasoline
Required to Mix at Different Temperatures
and Remove Different Percentages of Water
for Drum Mixing and Pug Mill Mixing
(From reference 2)

Percent Water Removed	Aggregated heated to —					
	210°F		260°F		320°F	
	Drum	Pugmill	Drum	Pugmill	Drum	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

1 gal/ton = 4.172 l/metric ton.

Table 1 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 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 in Virginia, 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 that 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 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%.[8] 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% 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.

Better 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)[9] 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,[9] but the data given clearly indicate that development of an awareness of the need for proper adjustments by plant operators can provide significant fuel economy and a reduction in production costs.

ENERGY SAVING BY ASPHALT 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, for equal performance where different volumes of material must be moved, stabilization may prove to be the most energy-conservative approach in the long term. Whether or not this is true depends greatly on the distances involved and the 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 report; 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 where materials and energy are still available at reasonable prices, 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 2, 3, and 4 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. Details of how each value was calculated are given in the Appendix. The energy factors used for the calculations are those given in "Energy Requirements for Roadway Pavements",(10) except as noted below. For the energy to manufacture (embodied energy) crushed stone, a factor of 35,700 Btu/ton was used rather than 70,000 Btu/ton, since the lower figure represents information gathered by the National Crushed Stone Association subsequent to the publication of reference 10. In Table 3 it has been assumed that the emulsion used contains 10% distillate and the energy represented by this distillate is included as embodied energy. Calculations for including the caloric energy in the asphalt cement as embodied energy as well as calculations excluding caloric energy are also included in Tables 3 and 4.

The significance of transport energy for crushed stone base is clearly illustrated by Table 2. 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 energy required for the same thickness and same hauling situation by the different types of construction in Tables 2, 3 and 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 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 total of transport and construction energy represents the areas where 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 3 and 4 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.

Table 2

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

Table 3

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.

Table 4

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.

The advantage of being able to utilize local materials through stabilization with emulsions is shown by comparisons from Tables 2 and 3. 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 made based on the actual conditions for the project and the hauling distances involved. However, the approximations given in Tables 2, 3, and 4 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.

RECYCLING OF ASPHALT PAVEMENTS

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 and the transport energy that would have to be expended to bring in all new materials and dispose of the old pavement.

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 will 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"(11) and a "State of the Art: Hot Recycling."(12) These reports describe several techniques for using conventional pug mill 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 a specialized plant is available. This is the FHWA Implementation Package 75-5 on "Recycled Asphalt Concrete."(13) A later report describing some additional plant improvements has been published in an AAPT Proceedings.(14) A more comprehensive state of the art report prepared as a part of NCHRP synthesis project 20-5 is also available.(15)

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;(16) Welsch discussed the experience in Texas;(17) Ingberg discussed Minnesota's experience;(18) McGhee and Judd discussed Arizona's efforts;(19) and Brown covered Iowa's experience.(20)

In general, all of the TRB presentations confirmed the difficulties with respect to controlling emissions indicated by the earlier report. Different approaches were taken to solve problems encountered, and each had reasonable success. Equipment manufacturers and contractors are still experimenting, and further improvements are being made as experience is gained. In general, the technology of recycling asphalt is developing rapidly. One problem still needing study is how to determine the actual condition of the binder in the recycled pavement. Extraction of the binder from mixes by the use of solvents and recovery of the binder results in complete and uniform blending of all old and new asphalt or added softening agents, a condition that is seldom (if ever) achieved for a field installation. It is also necessary to obtain more information on the durability of recycled pavements in comparison with new pavements. A significant reduction in the life of the recycled pavement could result in a total life-cycle use of energy greater than that required for new asphalt pavements.

CONCLUSIONS

1. In assessing the direct impact of energy factors on all types of highway construction, consideration must be given to the breakdown of the total energy involved into several categories. The categories to be considered are embodied energy, transport energy, construction energy, and indirect energy. Of these, transport energy and construction energy have a direct bearing on fuel use by the highway contractor and are the categories of major concern to the highway builder. Indirect energy is difficult to assess and does not significantly influence decisions in highway construction. Consequently, it is generally not considered in relation to highway energy problems. Embodied energy represents energy already spent by others outside the highway construction field and thus does not affect direct energy use by highway contractors, but may be a significant factor in assessing the total energy requirements over the life-cycle of specific types of construction.

2. The supply of asphalt products for use in highways could ultimately be affected by changes in the availability of petroleum and refining techniques, but under present conditions appears adequate for the foreseeable future. The relative competitive position of asphalt with portland cement concrete may deteriorate.

3. The substitution of emulsion for cutbacks represents important savings of embodied energy and, in some areas, monetary savings. However, the greatest benefit of such substitution is the reduction of air pollution that would normally result from the evaporation of hydrocarbons into the air when cutbacks are used.

4. The present trends towards higher mixing temperatures for drum mixing and lower mixing temperatures for pug mill mixing tend to eliminate the advantages of drum mixing compared to conventional pug mill mixing. Additional research is needed to fully assess the benefit of conducting drum mixing at as low a temperature as possible consistent with the need for proper compaction.

5. All stabilization techniques have a potential to save overall energy if their use results in significant reductions in the distances which high quality aggregate would have to be hauled.

6. Recycling and rebuilding of old pavements is a means of conserving the supply of good highway aggregates. Whether or not the total process conserves energy depends greatly on the transport energy used. If the material to be recycled must be moved to a central mixing plant and returned, much of the energy saving potential will be negated by the additional transport energy required. Any significant decrease in the service life of the recycled pavement compared to a new pavement may also result in greater life-cycle energy costs for recycling.

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APPENDIX

BASIS FOR CALCULATIONS OF ENERGY USED FOR VARIOUS TYPE BASES

CRUSHED STONE AGGREGATE: (Table 2)

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 3)

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

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 4

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.

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