COST AND ENERGY CONSIDERATIONS IN PROJECT SELECTION FOR RECYCLING ASPHALT PAVEMENTS

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This report discusses the costs and energy factors involved in various recycling techniques and compares such costs and energy use with those involved in conventional procedures using all new materials for the rehabilitation of asphalt pavements. It is emphasized that the relative amounts of transportation and construction energy consumed in alternative procedures are of primary concern in highway construction and maintenance, and that this factor controls to a considerable extent the relative costs of different alternatives. The energy savings and cost reductions reported for the recycling projects included as a part of Federal Highway Administration Demonstration Project 39 are summarized. Differences in theoretical transportation and construction energy requirements for usual overlays and for hot recycling through a central mixing plant are also shown. The general conclusions drawn are that a number of recycling techniques offer means for conserving significant amounts of energy and reducing costs over traditional ways of rehabilitation. The amount of energy saved and the reduction in costs will depend on the conditions of each project. On-site cold recycling offers the greatest potential for direct energy conservation, but more information is needed on the durability of recycled components before the lifetime cost and energy effectiveness can be known.

Most reports concerning the feasibility of recycling asphalt pavements point out that the individual factors surrounding each project determine whether or not such recycling is economical or conserves energy. Where central plant mixing is involved the various factors interact in different ways depending on the distance between the source of new materials and the mixing plant or the distance from the job site to the mixing plant. Relative time and traffic delays are also factors in urban and congested areas. Traditionally, the cost-effectiveness has been recognized as the most desirable criterion by which to judge the selection of alternatives. More recently, some engineers and administrators have suggested that energy-effectiveness might be a better alternative. Under normal circumstances, however, the two alternatives will lead to the same conclusions.

There is a close relationship between overall energy requirements and costs. In particular, the recent very large increase in cost for construction of asphaltic highways is related to the increase in the cost of petroleum based fuels and asphalt, a derivative of petroleum. While it is not difficult to judge the amount and cost of energy consumed in the operation of equipment, some of the indirect energy balances are very difficult to determine and there has not been universal agreement on the energy factors involved in a number of operations. Additionally, the relative cost-effectiveness of two alternative materials or construction procedures for highways may not always be easy to determine, since the years of adequate performance that will be provided by each alternative cannot be precisely predicted. When dealing with recycling concepts, the economic value of conserving raw materials and the value of eliminating potential environmental problems are also somewhat intangible but must be considered in determining overall cost-effectiveness.

Although other factors may influence the final decision, the first factor to be considered in deciding whether or not a given recycling alternative is desirable is its cost relative to those of established rehabilitation procedures. The various reports prepared as a part of Demonstration Project No. 39 conducted by the Federal Highway Administration (FHWA) in cooperation with a number of states contain cost and energy use comparisons for a number of alternatives.(11) Although the comparisons within the various projects are not always made on the same basis, they generally show recycling to cost less and to use less energy than other available alternatives. While the final evaluation of cost-effectiveness must await information on how long the recycled pavements provide adequate service, these reports strongly support the feasibility of the recycling option in a number of different situations. However, much remains to be done to establish recycling as an alternative that is automatically considered in all situations. In a discussion at the FHWA Research Project Review in Williamsburg, Dr. Richard Smith stated:

"The technology to recycle reclaimed asphalt pavement materials has been developed, but little use is being made of it. The principal reason is seen to be a lack of economic motivation as the cost savings to be gained by recycling remain obscure to highway administrators and asphalt contractors alike." (2)

In the same presentation Dr. Smith pointed out the increasing value of salvageable material. In particular, recycling operations that reduce the need for new asphaltic binder are becoming increasingly attractive as the price of asphalt increases. When asphalt sold for $33 a tonne ($30 a ton) a 4% reduction in the amount of asphalt needed for a new mix amounted to $1.33 a tonne ($1.20 per ton); but at $165 a tonne ($150 a ton) for asphalt, a 4% reduction is equivalent to $6.61 per tonne ($6.00 per ton), a significant difference.

Energy Classification

In considering the energy used for any project, there is a need to include more than the total energy expressed as Btu's or an equivalent number of gallons of diesel fuel or gasoline.

As has been pointed out, "All Btu's were not created equal". It can also be added that "all Btu's are not interchangeable". (3) Someone has calculated that the American public carries around 1 billion kg (2.3 billion lb.) of excess weight. The extra food calories and the energy required to produce that food are sufficient to operate 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. Such calculations supply interesting trivia for conversation but they have no true bearing on energy conservation. There is no way that Btu's saved by a reduction in the human intake of food calories can be economically converted to either vehicle fuel or electricity.

In evaluating the energy impact of highway construction four categories of energy should be considered. These have been defined as follows:

1. Embodied Energy: The amount of energy that has been used to manufacture or process a material up to the point it is to be used for a project.
2. Transport Energy: 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.
3. Construction Energy: The energy needed to process the material, move it to the job site, and complete the project. For asphalt used in highway construction this category 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.
4. Indirect Energy: The energy used by the work force in getting to and from the job site, the increased energy expended by users of the highway because of construction related delays, the energy involved in manufacturing equipment, etc. (3)

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. Conservation in these categories has a direct bearing on reducing the costs of highway construction or minimizing increases in costs. In considering recycling and alternative rehabilitative procedures, the differences in energy use in these categories will likely be one of the major considerations in determining relative costs.

For manufactured products such as metal components, the relative amount of embodied energy will likely be reflected in costs. However, this may not be true for those natural resources such as aggregate and asphalt that are processed rather than manufactured. In particular, for the construction of asphaltic pavements the amount of this category of energy used depends on how embodied energy is defined.

Under one view 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; 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 as being stored in the highway. In another view high sulfur asphalt would be classed as a waste by-product of the refining process — in which case the embodied energy would include only the energy used in processing and storing asphalt cement for sale.

Under present circumstances the differences in these views may be of only academic interest to the highway builder, because engineering factors along with the availability and costs of materials form the basis of his decision as to whether asphalt or some suitable alternative will be used for a given project. However, if proposed revisions in FHWA regulations go into effect, the definition of embodied energy could become very important. The proposed changes would, in effect, require an evaluation of the energy impact as part of the environmental impact statement. It is possible that decisions concerning alternative types of construction could be affected by their relative energy efficiencies. As many realize, when the Btu's in the asphalt is considered to be embodied energy, asphalt paving becomes substantially more energy-intensive than portland cement concrete paving. When the Btu's in the asphalt are not included as embodied energy, asphalt construction is placed in a much more favorable light.

This difference in definitions should not be allowed to influence the selection of pavement type. It is important that the present practice of judging alternative types of construction on the basis of technological considerations, availability, and cost-effectiveness be continued. It is also important that changes in refining processes and techniques for burning residual petroleum fuel be monitored by the highway industry to assure that an adequate supply of asphalt for highway construction and maintenance is available. Under present circumstances, the generally large amount of residual fuel available and the difficulty of burning some residuals containing asphalt assure adequate supplies of asphalt for highway construction. However, future developments could change refining priorities in a way that would create shortages of asphalt in some locations.

Indirect energy has a bearing on overall land use and transportation planning, but for alternative types of highway construction the amounts required are substantially the same. Consequently, in this discussion, no further consideration will be given to indirect energy.

Recycling Options

The Texas Transportation Institute draft report on "Interim Guidelines for Recycling Pavement Materials" identifies 24 recycling alternatives.(4) Eight of these options involve maintenance and repair operations on pavement surfaces not often associated with recycling. Another 8 involve in-place recycling that results in minor or major structural improvements; they generally involve crushing, pulverizing, and replacing the old pavement with or without new asphalt or modifiers. The final 8 options involve central plant recycling. These may be either cold or hot mix operations with or without the addition of new binder. Obviously, the type of project involved, the location of the project (urban or rural), and the amount of traffic involved automatically rule out certain options for given projects. Because the many combinations of equipment and procedures and the rehabilitative techniques that are available do not provide the same level of performance or length of service before additional measures must be taken, estimates of energy or cost savings for various classes of recycling based on theoretical considerations are so dependent on the assumption made that they are of questionable value. After consideration of a number of these alternatives, it was decided that the information in the reports on work performed as part of FHWA Demonstration Project No. 39 provide the best evidence that recycling enables energy conservative and cost savings in many situations. A summary of the energy and cost analyses presented in the reports on this project is given in Table 1.(1)

The recycling procedures demonstrated varied widely and were undertaken to solve different problems. Also, for different situations essentially the same recycling alternative may be compared to different rehabilitative procedures. In almost all cases, however, the reported savings by recycling are significant. Of the 21 projects reporting energy and cost analyses, only 2 reported negligible savings in energy and 5 reported negligible savings or increased costs for the recycled material; and in each of these cases, special circumstances appear to have influenced the reported cost comparisons. Reported figures for energy conservation, expressed as equivalent gallons of diesel fuel saved for each lane-mile of recycled pavement, varied from a low of 390 gal. to a high of 7,730 (equivalent to a low of 920 ℓ/km to a high of 18,260 ℓ/km). The 70-gal. per lane mile saving in report DP-39-4 was excluded because it represented the removal and reuse of material originally used as a temporary detour rather than a rehabilitation of an old pavement.

The reasons for the very wide spread reported were not completely analyzed, but differences relate primarily to the recycling sequence, the extent to which hot materials were used, and the percentage of recycled materials in the rehabilitated pavement. Cost reductions are not always proportional to energy saved; they are also influenced by the bases of comparisons. In general, the highest reduction of cost is estimated when actual costs for cold, in-place recycling projects are compared to estimates for replacing bases with hot black base and asphalt concrete overlays. Although quantitative estimates of energy and money to be saved by specific procedures cannot be derived from Table 1, it can be concluded that in almost any type of situation recycling will require the consumption of less direct energy in the project and also provide a savings in costs. Whether or not a project is cost-effective or energy-effective cannot be judged from the figures in Table 1, since the level and length of service to be obtained from the recycled material has not been established.

The potential advantages of in-place recycling techniques in several situations where costs must be kept low have been recognized for some time and such techniques are used to a considerable extent. However, until recently, recycling on heavily travelled roadways as an alternative to the usual practice of applying an overlay of all new material has not been considered to a large extent. Consequently, it is important to examine some of the theoretical aspects and basic principles involved in central plant, hot mix recycling and to compare the amount of energy it requires with the energy required in normal overlay procedures.

Figure 1 is a block diagram of the various operations for conventional overlays and for central plant, hot mix recycling. The energy used in each of these operations varies from project to project but factors based on reasonable assumptions are available, and, based on theoretical factors, the relative differences in the amounts of energy consumed can be estimated.

Blocks A-1 and S-1 represent embodied energy — that is, energy already consumed when the highway engineer becomes involved. The level of this energy does not enter directly into the amount of fuel required to build a highway and, since the method of calculating this energy is in question, it will not be further considered in this discussion.

Blocks S2 and R2 are key units, since the distances the materials must be moved are important in establishing potential energy conservation. Energy must also be expended to crush the old pavement and stockpile the crushed material at the dryer. Differences in energy consumption between the overlay and recycled mix will occur from different moisture contents. From this point, the amounts of energy consumed in mixing and hauling the material from the plant to the job site and in compaction are essentially the same for the new overlay and the recycled mix.

To illustrate the effects of the distances that the aggregate must be hauled to the job site and the distances the old pavements must be moved to the plant and returned, calculations of energy used in hauling (transport energy) and energy used in construction (construction energy), were made for several sets of assumed conditions.

All calculations were made using the factors published in "Energy Requirements for Roadway Pavements",(5) with the following assumptions.

Composition of overlay:

Asphalt — 6%, aggregate basis
Aggregate — 85% crushed stone
15% sand

Composition of new mix added with recycled material:

Same as for overlay

For recycled material, add 2% asphalt
Asphalt is hauled 50 miles in 4-axle rigs
Aggregate, reclaimed material, and new mix hauled in 3-axle rigs
New aggregate contains 5% moisture
Reclaimed mix contains 2% moisture
Aggregate and reclaimed mix enters drier at 21°C (70°F)
Final mix heated to 149°C (300°F)

Table 1. Summary of cost and energy savings given in FHWA demonstration project 39 reports.

Report No.	Classification of Pavement Recycled	General Description of Recycling Process	Energy Saved in Equiv. Gal. Diesel Fuel(a)		Estimated Dollar Saving(b)		Remarks
			Total	Per Lane Mile	Total	Per Lane Mile(c)	
1	Rural	Cold. Total pavement ripped, pulverized CMS emulsion added; relaid as 4-in. mat.	11,900	4,000	26,600	6,700	
2	Urban (curb-gutter)	Cold. Top 1 in. heater scarified, old material blended with new a.c. in repaver, HVMS emulsion added as needed, relaid as surface.	0.06 per s.y. -in.	420	Nil	Nil	Cost compared with average bid price of conventional overlay.
3	Interstate	Hot. Top 0.15 ft. milled, material mixed in pugmill with rejuvenators and new mix relaid. Friction course added.	76,200	4,760	320,700	20,000	
4	Material from Detour	Hot. Old material blended with new at hot plant. Laid as 6 in. mat on secondary road.	1,100	70	59,400	4,950	
5	State Road	Cold. Heater scarified, rejuvenator added, compacted. Overlaid with 1 1/2 in. mat.	32,400	1,120	408,300	14,080	Compared with removing pavement, replacing with 2 in. hot mix.
6	State Road	Hot. Top 3 in. cold milled, stockpiled, blended with new material in hot plant, relaid as surface.	9,100	810	Not Reported		
7	U.S.-Secondary	Cold. Top 1 3/4 in. milled, replaced on shoulder.	246,600	5,000	737,600	15,000	Compared with hot mix overlay.
8	Rural	Cold. Top 3 in. scarified, SA-1, and new asphalt added, road mixed, compacted as new base. Overlaid.	Not Reported			23,260	Compared with hot mix base.
9	Interstate	Hot. Total 4 1/2 in. cold milled, blended with new material in hot plant, relaid as surface.	27,200	450	146,000	2,430	
10	Rural	Hot. Pavement scarified, crushed, blended with new material in hot plant, relaid as surface.	154,500	7,730	138,400	6,920	
11	Interstate	Hot. Pavement scarified, crushed, blended with new material in hot plant, relaid as base. Overlaid.	0.21 gal./ton		Not Reported		
12	U.S.-Secondary	Cold. Top 1 1/2 in. heater scarified, new material added, compacted. Open graded surface applied.	113,000	5,280	232,000	10,841	Compared with hot mix overlay.

13	Rural	Cold. Total pavement pulverized, mixed, relaid as base. Two inch overlay applied.	0.48 gal/ ton		None		Recycled base cost more per ton.
14	U.S.-Primary	Hot. Overlay over P.C.C. removed, crushed, blended with new material in hot plant, relaid as surface.	Nil		None		Long haul to crusher and high capital costs for equipment.
16	Interstate	Hot. Total 4 1/2 in. pavement broken up, crushed, remixed at hot plant, relaid as surface.	Nil		Nil		
17	U.S.-Primary	Hot. Total pavement cold milled, blended with new material at hot plant, relaid as surface.	52,200	1,070	Nil		
19	Material from Runway	Hot. Old material stockpiled, crushed, blended with new material at hot plant, relaid as base. Overlaid.	10,700	1,690	59,600	9,370	
20	U.S.-Secondary	Cold. Top 4 in. pulverized, CMS2 added, mixed, relaid as surface.	0.67 gal/ s.y.	4,720	2.21/s.y.	15,560	Compared with new base and overlay.
21	State Road	Cold. Surface heater scarified, compacted, rejuvenator added. New 1 in. overlay applied.	Not Reported		Not Reported		
22	State Road	Cold. SS-1 applied prior to recycling top 1 in. with repaver. Friction course added.	19,200	1,330	85,350	5,930	
23	Urban	Hot. Top 1 in. to 3.5 in. milled, blended with new at hot plant, relaid as leveling course. Overlaid.	5,130	390	26,800	2,040	
24	3-Projects: Interstate, Rural, Secondary	Cold. Pavement ripped, pulverized, aggregate added, relaid as base. Overlaid.	Not Reported		Not Reported		
25	Rural	Cold. Pavement ripped, pulverized, new aggregate added, road-mixed with SS-1h, compacted. Chip seal added.	11,880	2,700	54,000	12,270	Compared with new 4 in. mat.

(a) 1 gal. = 3.78 litres
1 gal/lane mile = 2.36 litres/lane kilometre

(b) Costs of recycled techniques compared with costs of usual rehabilitation procedure.

(c) 1 mile = 1.6 kilometres

Figure 1. Major steps in constructing overlays and in central plant, hot mix recycling.

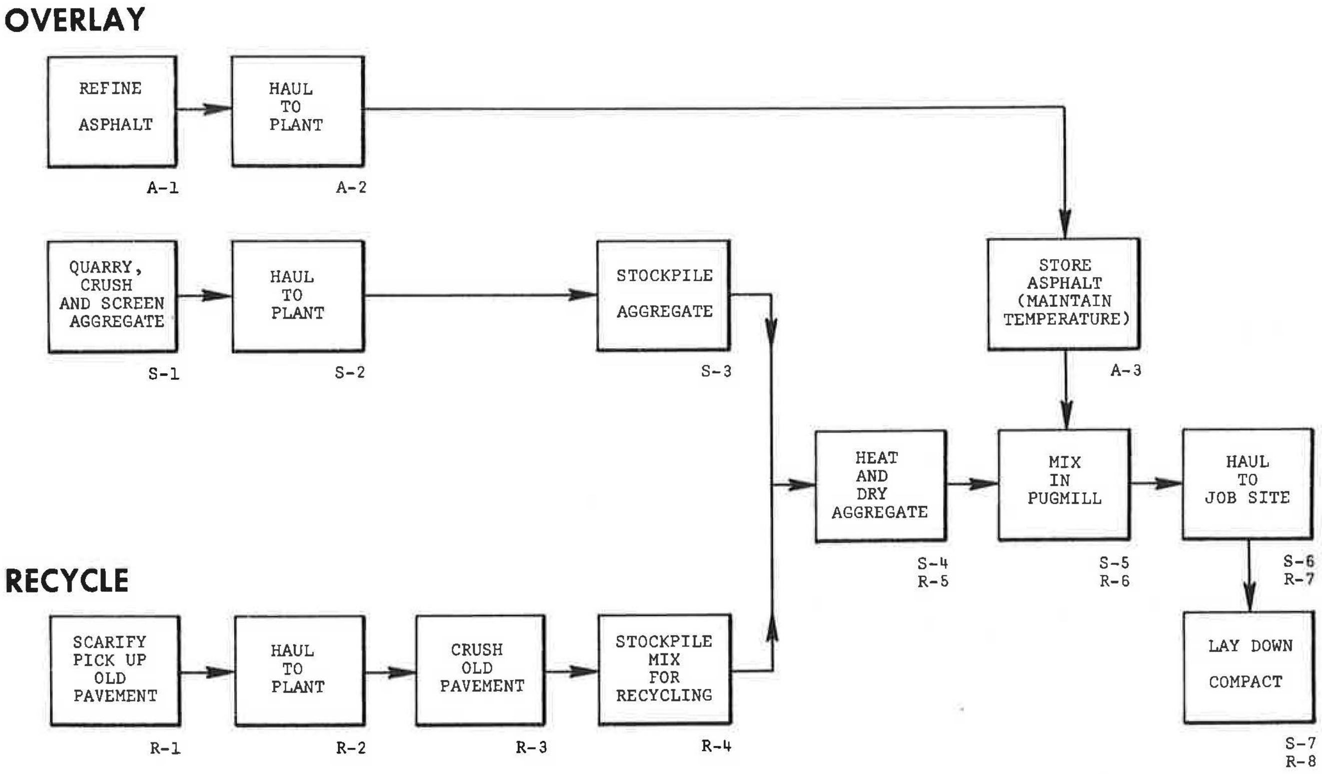


Figure 2 illustrates the combined transport and construction energy used for an overlay compared to that for recycling 50-50 and 80-20 blends of recycled and new material, where the job site is assumed to be an average of 16 km (10 mi.) from the plant and the aggregate must be hauled the distances indicated. This figure demonstrates the significant effect of the transport energy required to haul new aggregate. As the distance the new material must be hauled increases, the advantage of recycling significantly increases, as would be expected. Energy saved also increases as the proportion of recycled material in the final mix increases. For a haul of 96 km (60 mi.) for new aggregate, the energy saved by using a 50-50 blend of recycled and new materials amounts to about 4 ℓ. of diesel fuel per tonne of mix placed (1 gal. per ton). If an 80-20 blend can be used, about 7 ℓ. of diesel fuel per ton of mix placed can be saved (1.7 gal. per ton).

For Figure 3, calculations were made assuming new aggregate was available 16 km (10 mi.) from the plant in one case and 64 km (40 mi.) in a second case. The transport and construction energies were calculated and plotted for various distances from the job to the plant.

As can be seen, the energy advantage of recycling is lost if new aggregate is available near the plant and the material for recycling must be hauled an appreciably greater distance. As shown in Figure 3,when the aggregate must be hauled 16 km (10 mi.) to the plant any haul distance from the plant to the job site that exceeds 35 km (22 mi.) results in a use of more transport and construction energy for recycling than for an all new overlay. When the aggregate is hauled 64 km (40 mi.), recycling retains its advantage until the distance between the job site and the plant exceeds 96 km (50 mi.)

Another significant conclusion to be drawn from these calculations is that a large proportion of the energy used is needed for heating and drying the aggregate or recycled mix. Consequently, if this step can be eliminated, a significant amount of energy could be saved. For the situation in which the aggregate is hauled 16 km (10 mi.) to the plant, and the job site also averages 16 km (10 mi.), the construction energy used for heating and drying the aggregate or mix for a 50-50 blend is 59% of the total. For a 64-km (40-mi.) aggregate haul, this energy amounts to 50% of the total. The use of asphalt rejuvenators in cold procedures offers a means of saving a significant proportion of this energy. On-site preparation also is advantageous because these is no requirement for transport energy.

It thus appears that efforts to improve cold-milling and on-site "repaving" equipment should be continued so as to take maximum advantage of the potential for reducing costs and conserving energy.

Major Consideration for Various Classes of Roadways

The interim guidelines prepared by the Texas Transportation Institute lists four broad classes of roadways.(4) These are:

1. Interstate and urban freeway.
2. Rural primary (U.S. and state signed routes).
3. Rural secondary (farm to market roads, park roads, etc.).
4. Urban streets (arterial collector, local).

Figure 2. Effect of the distance new aggregate must be hauled to plant on energy consumption in central plant recycling.

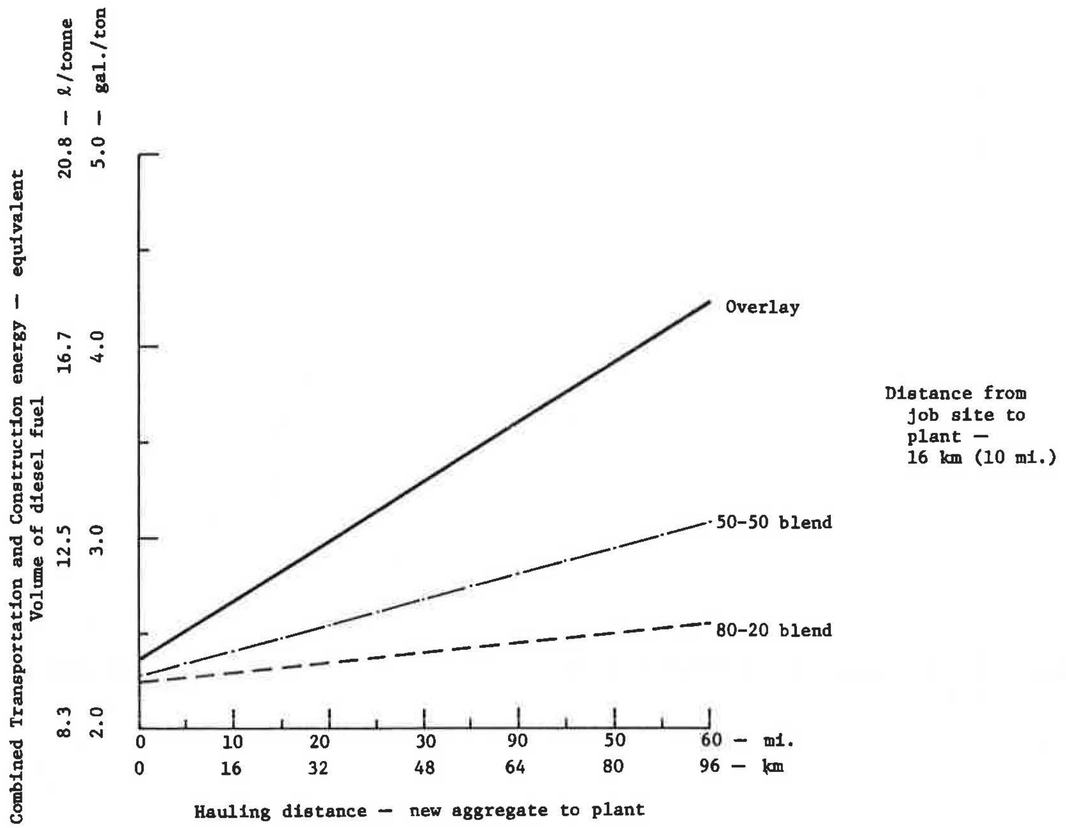
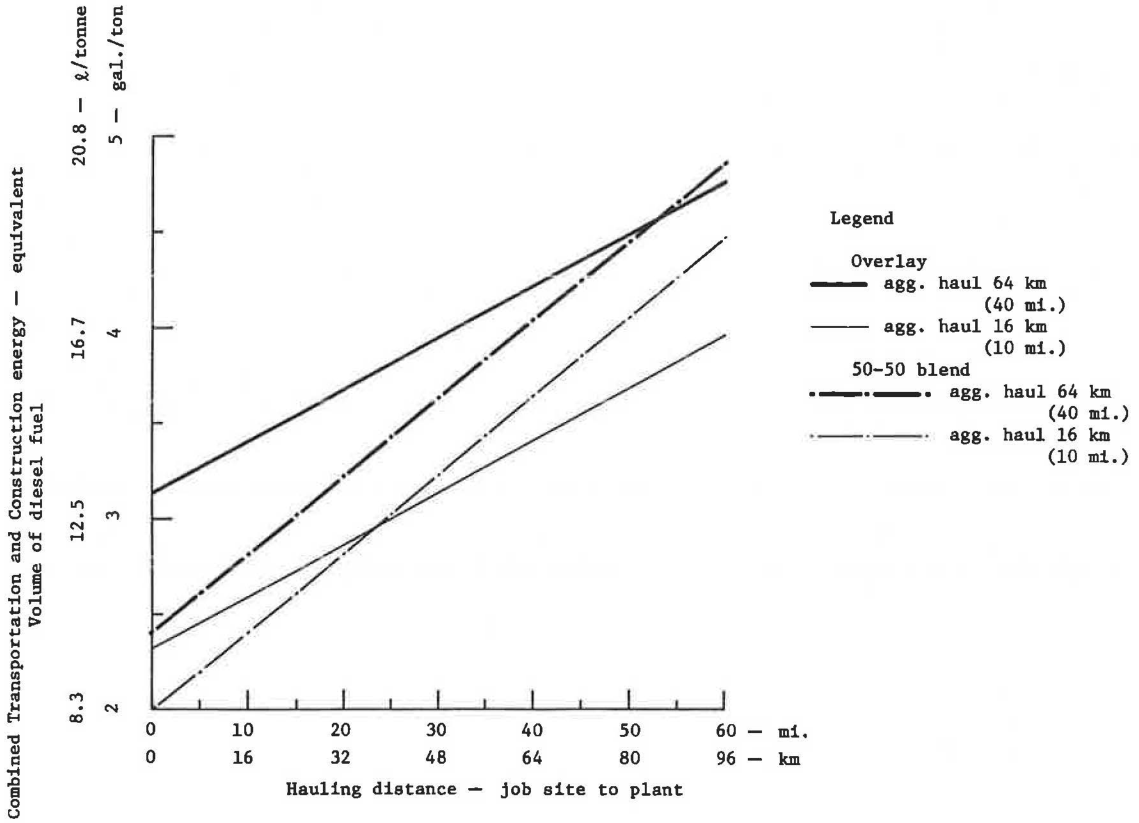


Figure 3. Effect of hauling distance from job site to plant on energy consumption in central plant recycling.



As illustrated by the brief description in Table 1 of the various recycling projects constructed in Demonstration Project 39, there are numerous combinations of treatments for recycling road material and the most desirable process for a given project does not necessarily depend upon the class of roadway. Consequently, it is not possible to pinpoint the specific energy and cost factors that must be considered for each class. However, general statements of the conditions most likely to apply for different classes of roadways may be of some significance.

1. Interstate and Urban Freeway

The usual rehabilitation procedure for this type of highway would be either an overlay after correcting localized base problems or surface unevenness, or complete rebuilding of the roadway where serious base failure has occurred. The most likely recycling technique is to remove all or part of the old pavement and to reuse the removed material as a portion of the new hot mix. The new mix may be applied as a base or surface.

The primary energy and cost consideration is the relationship between the distance from the project to the asphalt plant and the distance that new aggregate must be hauled to the plant. As has been shown, as the distance the aggregate must be hauled becomes progressively greater than the distance between the mixing plant and the job site, the saving in energy and cost for recycling increases significantly. Conversely, when a source of new aggregate is at or near the asphalt plant, the advantages of recycling decrease significantly as the distance between the plant and job site increases. Under conditions favorable to recycling, the higher the percentage of recycled material in the new mix, the greater the savings in energy and costs. However, problems in controlling pollution and the probable lesser performance capabilities of the recycled mix are negative factors. The amount of new asphalt or rejuvenators to be used is also an important consideration.

2. Rural Primary (U.S. and State Signed Routes)

Table 1 indicates that surface recycling is often used for this class of roadway. The more significant energy savings and cost reductions occur when the surface material is milled or heater scarified and reworked on-site with the addition of a rejuvenator or asphalt emulsion. Sometimes, aggregate is also added. Processing through a road mix machine in this application provides through mixing. Hot mixing of the removed material with new aggregate and asphalt at a central plant is also sometimes employed with a lesser conservation of energy because of the fuel needed to heat the material. However, for heavy traffic conditions, the use of the additional energy may be cost-effective and a better blended and more uniform product is obtained.

3. Rural Secondary (Farm to Market Roads, Park Roads)

Recycling of this type pavement often consists of reworking the total pavement and base into a new base with a surface treatment. The significant cost and energy savings in these situations results from the elimination of the need to purchase large quantities of aggregate and transport them to the job site. Obviously, savings increase significantly as the distance the new aggregate must be hauled increases. In-place mixing with road machines or manipulation with graders are most often used on this class of roadway. The use of emulsified asphalt in lieu of cutback asphalts or hot plant mix is the most energy efficient procedure.

4. Urban Streets

Surface recycling with hot plant mixing is likely to be required for urban streets. One significant advantage to recycling in this situation is the elimination of the need for raising levels of manhole covers or correcting the heights of curbs and drains as would be necessary for an overlay. One alternative that may be considered for this class of roadway is to remove and stockpile old surface material for use elsewhere in a less demanding situation as part of a base or surface course. In this situation, the savings in energy and costs are not in the initial project but are realized by salvaging the economic value of the removed material on another project.

Conclusions

The conclusions to be drawn from the information presented in this discussion as well as from indications from other sources, are as follows:

1. Various recycling techniques can be used to save energy and reduce costs in rehabilitating pavements. For each project, the amount of energy saved or the reduction in cost will depend on the prevailing conditions.
2. For highway reconstruction and rehabilitation procedures, the more important energy considerations are the amounts of transport and construction energies used. These are likely to have the more significant effect on costs.
3. On-site cold recycling offers the greatest potential for energy conservation. However, the performance potential of the recycled pavement is an important consideration in considering the lifetime cost-effectiveness or lifetime energy-effectiveness. More information concerning the performance of recycled mixes is needed for judging the lifetime effectiveness of different recycling options.
4. The cost and energy advantages for hot mix, central plant recycling depend greatly on the distances materials must be moved. As the distance the new aggregate must be hauled becomes increasingly greater than the distance between the asphalt plant and the job site, the advantages of recycling increase significantly. Conversely, as the distance between the job site and the asphalt plant become increasingly greater than the distance from the plant source of new aggregate, the cost and energy advantages of recycling reduce significantly. When asphalt plants are located at or very near the source of aggregate, and the job site is an appreciable distance from the plant recycling could require more energy and cost more than other alternatives.

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