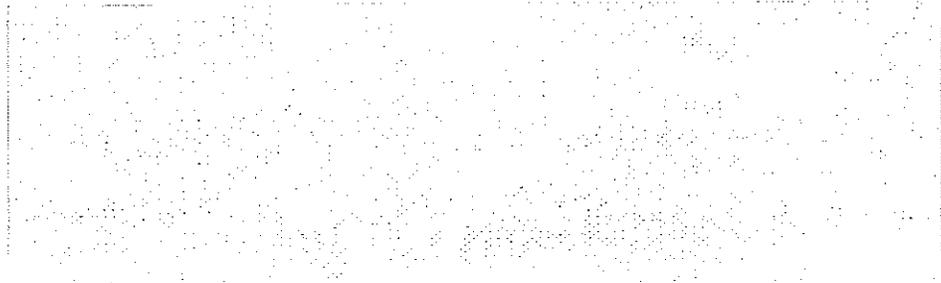


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**COST AND ENERGY CONSIDERATIONS INVOLVED IN THE
RECYCLING OF PORTLAND CEMENT CONCRETE**



MATERIALS and TECHNOLOGY DIVISION



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RECYCLING OF PORTLAND CEMENT CONCRETE

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Research Laboratory Section
Materials and Technology Division
Research Project 78 B-99
Research Report No. R-1257

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Summary

If a decision is made to reconstruct a rigid pavement, both money and energy can be saved by recycling. Amounts of savings depend primarily on costs of aggregates delivered to the job site and difficulty in disposing of the old concrete. Both are increasingly related to haul distances and urbanization. Costs for recycling concrete vary considerably due in large part to the inexperience of both the contractor and the contracting agency. Concrete recycling may well offer the most cost-effective means of rehabilitating the miles of roadway that lie begging for treatment.

Introduction

This report is based upon a paper presented at the National Seminar on Portland Cement Concrete Pavement Recycling and Rehabilitation, St. Louis, Missouri, in 1981, and is based upon our experience to that date. It should be borne in mind that cost data are based upon 1981 figures.

Because of all the variables involved in costs and energy consumption between one construction project and another, a report such as this must simply present some widely applicable general considerations—illustrated with specific examples—that should be modified in evaluating an individual job.

As shown herein, concrete recycling, even using current methods, will save money and energy and as we improve through experience even greater savings will ensue.

COST CONSIDERATIONS

Removal of Existing Pavement

Once the decision to replace an existing pavement has been made, the cost of breaking out and loading the old concrete is about the same regardless of whether the material is to be wasted or reused. In Michigan, the cost for breaking out reinforced concrete pavement, 9 in. thick, is about \$1.75/sq yd for breaking out and \$0.75/sq yd for loading. Minnesota paid about \$1.75 for breaking and loading non-reinforced pavement.

Hauling and Disposal

The first opportunity for saving by recycling is through eliminating haul and disposal costs. The cost of hauling has escalated, paralleling increasing fuel prices, and disposal sites are becoming more difficult to find (especially in urban areas). It is unlikely that the old concrete could be disposed of very near the job site, and it will be shown subsequently that even if a disposal site were immediately adjacent to the crusher, it would still be more economical to recycle.

Because of bulking, 1 sq yd of 9-in. pavement has been found to take about 1 cu yd of hauling space. Using that relationship, the following hauling costs are somewhat typical in Michigan.

Hauling Distances, miles	Hauling Cost Per Sq Yd, 9-in. pavement
8 to 10	\$1.50
10 to 15	\$1.75
15 to 20	\$2.00

Dumping, or disposal charges, of \$2.00 to 2.50/cu yd (sq yd of pavement) are conservative for urban areas. There are concrete crushing businesses in some Michigan cities that would accept surplus concrete and eliminate dumping costs, but hauling costs would still be significant.

In the recent past, waste concrete has been coveted by crusher businesses. At least in Michigan, demand for crushed concrete base material has exceeded supply. Even with the razing of 485 acres in Detroit to accommodate a new General Motors plant, concrete crushing operators in the area said they will continue to take all the good rubble available. This demand exists even though crushed concrete has not been sold in Michigan as aggregate for fresh concrete or asphalt mix.

Production of Recycled Aggregate

A contractor would have to first decide whether to process the salvage pavement through a stationary or portable crushing plant. The cost for moving in and setting-up a portable plant has been found to be about \$5,000 in Michigan, a small cost in comparison to hauling off-site. A portable plant would probably not handle pieces quite as large as some stationary crushers; that would be a consideration in the breaking and removal operation.

The early concern about noise and dust problems when crushing concrete in urban areas has apparently been exaggerated. At last report, the crushing plant set up in an urban area of Chicago had caused little problem except for the noise from back-up warning horns on loaders. This spring, a crusher was set up on a busy urban street in a suburb of Grand Rapids, Michigan and no complaints have been received about either dust or noise from the plant.

Therefore, because of the high costs of hauling, the relatively modest move-in expense, and manageable environmental problems with an on-site plant, it is very likely that a contractor would choose the portable.

Uses for the Aggregate

Coarse Aggregate - The coarse fraction of crushed material can be used as aggregate for making concrete, or aggregate for an open graded

base course. Studies in Michigan have shown open graded bases to be a major factor in keeping the underside of a slab dry. Hence, concrete deterioration near transverse joints and subsequent D-cracking is minimized. For that reason, Michigan is designing open graded bases for new concrete Interstate pavements. To provide high stability, coarse open graded base material must consist either largely of crushed materials, or a stabilizer must be added. On a project near Flint, Michigan that was recently planned and estimated for recycling, crushed coarse base material was found to be considerably more expensive than coarse aggregate for making concrete. That was because there is no requirement for a minimum proportion of crushed material in coarse aggregate for concrete. In that case, it was decided that if there was insufficient coarse aggregate for both base and concrete, base would get first priority and additional coarse aggregate would be purchased for making the concrete.

Fine Aggregate - The fine aggregate fraction can be used for making concrete, in a dense graded base, or as backfill. If salvaged fines are used for making concrete, a majority of virgin sand will be needed so the mix will be workable (1). Through an efficient pavement removal and crushing operation, the largest proportion of recycled material will be the coarse rather than fine fraction. Therefore, additional sand for making concrete will probably be necessary anyway.

Sizing of Aggregates

When crushing concrete, there are several reasons why it is profitable to obtain maximum production of the coarse aggregate fraction. First, in Michigan, coarse aggregate for concrete costs about \$5.00 to 6.00/ton at the pit; about twice the cost of fine. Second, some Michigan aggregate producers insist that buyers of coarse aggregate purchase a proportional amount of fine aggregate; producers have accumulated huge quantities of fine material and are running out of coarse. Further, fine aggregate is produced at more sites and is, therefore, more likely to be available nearer a paving project. Thus, hauling costs would be minimized if only fine aggregate must be purchased off the job site.

How can we obtain maximum production of coarse aggregate from crushed concrete? If the old pavement has shown no great propensity for D-cracking, a top size of 1-1/2 in. might be permitted for the recycled coarse aggregate. Crushing to smaller top sizes, although sometimes necessary to limit D-cracking, results in a higher fraction of fine material.

Coarse aggregate production can be further maximized by balancing the crushers. The primary crusher should be set to reduce material to the largest size that will fit the secondary without requiring tertiary crushing.

Costs of Crushing

In Michigan, a contractor's ownership charges for crushing pavement

containing reinforcing mesh have been stated by one producer to be about \$1.45 to 1.70/ton. Adding to that his operating and maintenance charges of \$2.00 to 2.40/ton means total crushing costs to the purchaser of \$3.45 to 4.10/ton. Those charges would be applied only to the coarse aggregate produced and if the producer maximized the fraction of coarse aggregate.

Costs for crushing unreinforced pavement would be slightly lower. There would probably be no difference in the number of personnel required since the one required to pick steel from reinforced concrete would be needed for odd jobs around the plant even when crushing unreinforced concrete. However, production rates have been lower with reinforced concrete because of the tendency of the steel to 'ball up' and jam crushers. Salvaged steel can be sold for scrap, at this time, for about \$40.00/ton and this pays for loading and hauling it away.

A comparison of crushing costs in Minnesota, Iowa, and Michigan is as follows:

	Cost of Pavement Removal and Crushing (\$/sq yd)	Type of Reinforcement
Minnesota (2)	2.60	Plain concrete
Iowa (1)	3.30	Edge bars and tie bars
Michigan	4.25 - 4.55	Mesh and dowels

In 1980, Minnesota paid \$2.60/sq yd for breaking out and crushing a plain concrete pavement of 9-7-9 in. cross-section. On their project, about 16 miles long, Minnesota estimated a total savings of more than \$600,000 by recycling instead of using virgin coarse aggregate.

In 1977, Iowa paid \$3.30/sq yd for removing and crushing on Route 2. There were both transverse and longitudinal edge and centerline reinforcing bars in the slab. The pavement was of 10-7-10 in. thickness and had been resurfaced with 3 in. of asphalt. The asphalt was removed prior to removing the concrete. On this 15-mile project, Iowa estimated a total savings of more than \$115,000 by recycling instead of using virgin aggregate.

In Michigan, we have estimated removal and crushing costs of about \$4.25 to 4.55/sq yd for a 9 or 10-in. thick slab with reinforcing steel mesh and load transfer dowels. The disparity in pavement removal and crushing costs between states might be due to a combination of unfamiliarity with the process, differences in quantities and types of reinforcement, and differing slab thicknesses. Moreover, Michigan's estimated cost of crushing is based upon the quantity of coarse aggregate produced.

Using Michigan's estimated costs for removal and crushing of concrete, how does the cost of recycled aggregate compare with virgin aggregate? Since the cost of removal of old pavement (\$2.50/sq yd) must be paid for both replacement or recycling, it can be neglected in the comparison.

As stated earlier, the cost per ton of the recycled coarse aggregate would be about \$3.45 to 4.10/ton. Fine aggregate would be incidental.

Virgin coarse aggregate costs \$5.00 to 6.00/ton at the pit and averages \$10.00 to 11.00/ton including delivery costs to the job site. That is more than double the cost of the recycled material. Adding to the expense of the option to use virgin material are costs of \$1.50/sq yd, or even more, for disposal of the old concrete, and the possibility of damaging haul roads during aggregate delivery or waste concrete disposal. Another factor that would decrease the cost of using recycled concrete is the likelihood of producing a greater quantity of valuable aggregate than is needed to replace the original pavement section. Therefore, the use of recycled aggregates becomes an overwhelming economic choice.

Other Costs

Iowa (3) estimated \$27,000 in haul road savings by deleting disposal and choosing recycling. Variable haul road savings could be realized but in many cases hauling trucks would simply run on what was left of the pavement being broken out, and only short haul roads would be needed; that is our past practice in Michigan.

Another value that should be assessed is that of aggregate in excess of that needed for producing fresh concrete. Assuming 20 percent waste, a figure later proven much too high, and using the value of 76 percent of all the crushed material retained on the No. 4 sieve (1), computations show that 46 percent more coarse aggregate can be produced than is needed to replace a section equal to that broken out (Appendix A). As noted earlier, coarse aggregate costs \$5.00 to 6.00/ton at the pit and 100 percent crushed material is even more expensive. Therefore, the value of that surplus material should be considered in any cost comparison. Because of unfamiliarity with the process, and differences in materials, it may now be difficult to accurately estimate quantities, but they should be planned for. As a comparison, asphalt recycling has become so common in Michigan that at least one contractor has offered to buy good salvaged asphalt mix for \$9.00/ton. Existing asphalt roads are considered to be 'money in the bank' instead of a liability and in the future, concrete roads should be regarded similarly.

It is generally agreed that the angularity of sand from crushed concrete causes a fresh mix to be somewhat harsh. Engineers are faced with the choice of either adding natural sand and maintaining the normal water-cement ratio or a combination of adding smaller quantities of natural sand in combination with more water and cement and/or using a water reducer. The choice should be based upon the cost of natural sand and the possibilities for alternate uses of crushed concrete sand on the job site. Since general concrete quality decreases with increased water-cement ratio, additional water should be used sparingly and with judgment.

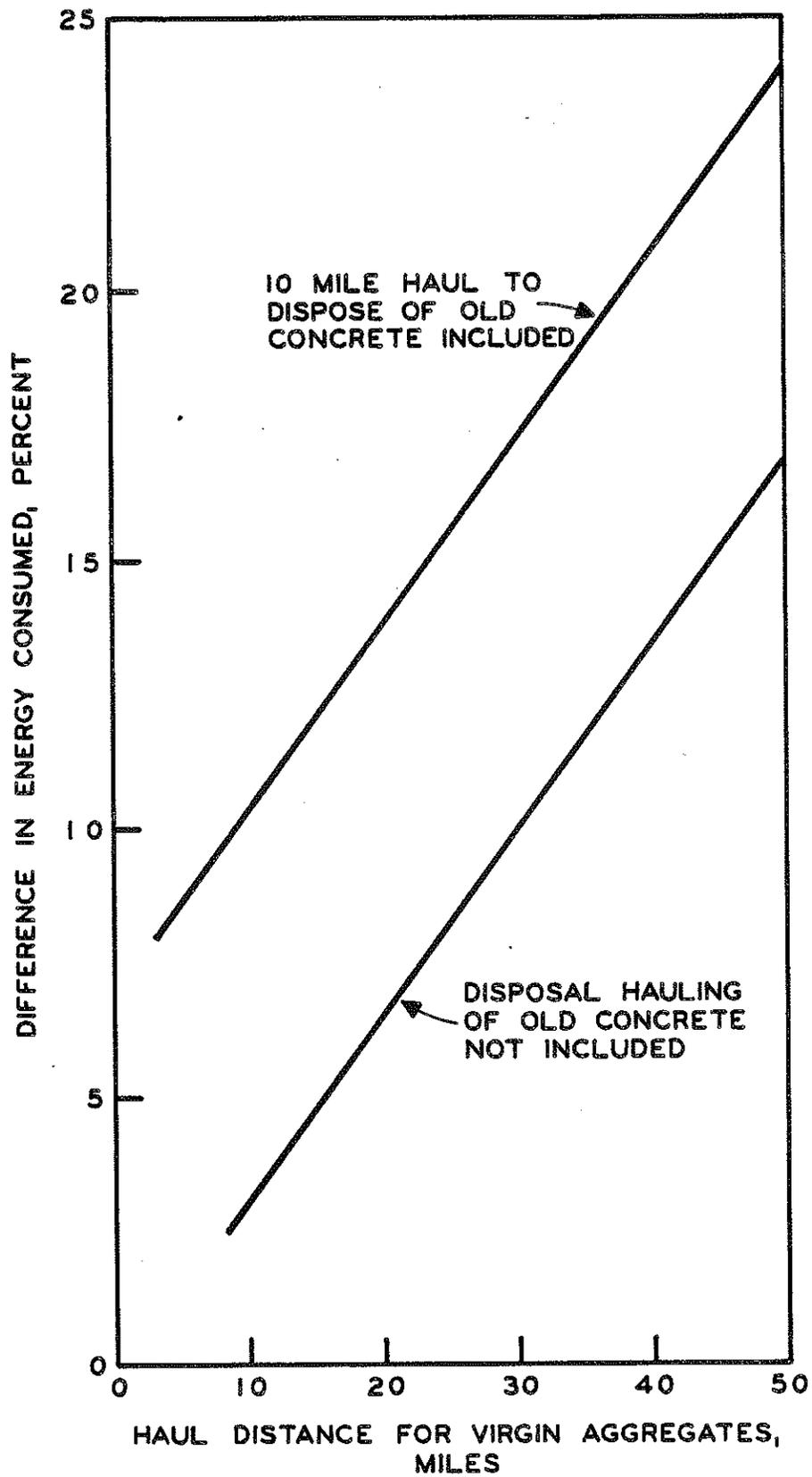


Figure 1. Energy savings (percent) of recycled as compared to conventional concrete.

ENERGY CONSIDERATIONS

Although cost is still the prime factor in choosing among different construction alternatives, energy is taking an increasingly larger share of the construction dollar. Thus, finding ways to save energy means saving money today and saving even more in the future.

In estimating energy savings by recycling, it is impossible to make a realistic general quantitative estimate; there are simply too many variables in each construction project. However, if a concrete pavement is to be replaced, it is almost certain that some amount of energy will be saved by recycling.

If an energy comparison is made, operations and materials can be divided into those that are, and those that are not dependent upon the choice to recycle.

Common Energy Requirements

Breaking out and loading old pavement,
Producing and hauling cement to the site,
Mixing, hauling, and placing the concrete,
Producing, hauling, and installing reinforcing steel
and load transfer devices,
Sawing joints, and
Producing and transporting and installing joint sealer.

Unique Energy Requirements

1. Conventional mix

Hauling and disposing of old concrete,
Producing virgin aggregates: crushed stone, bank
run or crushed gravel, and sand, and
Hauling virgin aggregates.

2. Recycled mix

Moving crusher to job site,
Crushing concrete, and
Transporting concrete to crusher and from crusher
to plant if machines are at different sites.

After separating materials and operations, average energy consumption values can be assigned to each unit of material or unit distance transported. Computations for an example energy comparison are shown in Appendix B and results are plotted in Figure 1. Unit energy consumption values were taken from the Asphalt Institute (4). Further energy savings might be realized if recycled sand were used as a part of the fine aggregate. However, savings are realized even when virgin aggregates must be hauled only 10 miles, and as haul distances increase, so do savings (Fig. 1). Since

less energy is needed to produce crushed gravel than crushed stone, a smaller savings would have been found if the former were chosen in the example.

REFERENCES

1. Bergren, J. V. and Britson, R. A., "Portland Cement Concrete Utilizing Recycled Pavement," Iowa Department of Transportation, January 1977.
2. Preliminary information from the Minnesota Department of Transportation.
3. Arn, Jerry, Letter to James E. Klein, Iowa Department of Transportation, January 19, 1978.
4. "Energy Requirements for Roadway Pavements," The Asphalt Institute, November 1979.

APPENDIX A

A COMPARISON OF CRUSHED CONCRETE QUANTITIES WITH THOSE NEEDED FOR REPLACEMENT (9-in. pavement, 24-ft wide)

Coarse Aggregate Available

Weight of pavement = $9/12 \times 24 \times 100 \times 150 = 270,000$ lb/Sta.
Assume 20 percent waste, weight of material available = 216,000 lb/Sta.
Assume 76 percent* retained on No. 4 sieve, weight of coarse aggregate available = 164,000 lb/Sta.

Coarse Aggregate Required

Volume of pavement = $9/12 \times 24 \times 100 = 1,800$ cu ft/Sta.
Assume 40 percent by volume is coarse aggregate, then volume of coarse aggregate in pavement = 720 cu ft/Sta.
Assume specific gravity of crushed concrete = 2.5*
Weight of crushed aggregate = $720 \times 2.5 \times 62.4 = 112,320$ lb/Sta.

We should, therefore, have 164,000 lb available, less 112,000 lb required, giving us 52,000 lb/Sta. surplus, or 46 percent more coarse aggregate by weight than needed for a replacement concrete mix.

*See Ref. 1 in the text (Bergren and Britson).

TABLE 1
SAMPLE CALCULATIONS FOR DETERMINING THE ENERGY SAVED BY RECYCLING CONCRETE

Materials	10 Mile Haul		20 Mile Haul		30 Mile Haul		50 Mile Haul	
	Recycled	Virgin	Recycled	Virgin	Recycled	Virgin	Recycled	Conventional
Portland Cement								
Produce	7,110,000 BTU/ton							
Haul 50 miles x 2 @ 5,040 BTU per ton-mile	504,000 BTU/ton							
Total to Produce and Haul	7,614,000 BTU/ton							
Aggregate								
Produce								
Crushed stone @ 56,000 BTU/ton (2/3 of total aggregate)	37,330 BTU/ton							
Crushed concrete @ 56,000 BTU/ton (2/3 of total aggregate)	37,330 BTU/ton							
Sand @ 15,000 BTU/ton (1/3 of total aggregate)	5,000 BTU/ton							
Total to Produce	42,330 BTU/ton							
Haul								
Crushed stone: number of miles x 2 @ 4,270 BTU/ton-mile x 1.05 x 0.67	18,024 BTU/ton							
Crushed concrete: 3 miles x 2 @ 4,270 x 1.05 x 0.67	29,591 BTU/ton							
Sand: number of miles x 2 @ 4,270 x 1.05 x 0.33	47,615 BTU/ton							
Total to Haul	89,945 BTU/ton							
Total to Produce and Haul	2,147,148 BTU/cy							
Mix Composition for One Cubic Yard								
Portland cement: 7,614,000 BTU/ton, 564 lb/cy (2.89 cu ft), 2,147,148 BTU/cy								
Water: 352 lb (4.52 cu ft)								
Air: 6 percent (1.62 cu ft)								
Crushed stone: 2,000 lb (12.69 cu ft) } 2,886 lb/cy =								
Sand: conventional mix, 886 lb } 1.49 tons/cy								
with recycled coarse aggregate, 949 lb (6.7 cu ft) } 2,878 lb/cy =								
Crushed concrete: 1,827 (12.4 cu ft) } 1.44 tons/cy								
Total for One Cubic Yard	2,276,469 BTU/cy	2,344,224 BTU/cy	2,319,041 BTU/cy	2,478,100 BTU/cy	2,301,691 BTU/cy	2,478,100 BTU/cy	2,611,045 BTU/cy	2,876,261 BTU/cy
Plant Operation								
Handling Aggregate								
Conventional: 2,966 lb x 1.05 x 4,640 BTU/ton								
Recycled: 2,878 lb x 1.05 x 4,640 BTU/ton								
Mixing								
Total Plant	7,006 BTU/cy							
Haul and Place								
Haul 3 miles x 2 @ 4,270 BTU/ton-mile								
Conventional: 3,632 x 3 x 2 x 4,270								
Recycled: 2,000 x 3 x 2 x 4,270								
Placing								
Total Hauling and Placing	47,679 BTU/cy							
Total Energy per Cubic Yard	2,359,979 BTU/cy	2,409,391 BTU/cy	2,382,631 BTU/cy	2,543,247 BTU/cy	2,345,381 BTU/cy	2,476,212 BTU/cy	2,510,663 BTU/cy	2,943,428 BTU/cy
Savings by Recycling, Percent								17.2%

APPENDIX B

SAMPLE CALCULATIONS FOR DETERMINING THE ENERGY SAVED BY RECYCLING CONCRETE

This Appendix describes computations of energy consumed for production and placing 1 cu yd of concrete on two hypothetical construction projects. In one case, conventional construction techniques are used, the old pavement is hauled away and disposed of. In the second case, the old pavement is recycled into coarse aggregate for concrete in the new pavement.

Table 1 shows the steps used in developing comparisons of energy used in the two situations. Table 2 tabulates results of energy use comparisons and includes energy used to haul the old pavement to a disposal site; a necessary operation for conventional construction.

TABLE 2
SUMMARY COMPARISON OF ENERGY SAVED
IN RECYCLING CONCRETE PAVEMENTS

Haul Distance for Virgin Aggregates, miles	Disposal of Old Concrete Not Included			Disposal of Old Concrete Included; 10-Mile Haul to Disposal Site		
	Energy Consumed in Producing and Placing 1 cu yd of Concrete, BTUs		Energy Savings, percent	Energy Consumed in Producing and Placing 1 cu yd of Concrete, BTUs		Energy Savings, percent
	Recycled Mix	Conventional Mix		Recycled Mix	Conventional Mix	
10	2,340,000	2,409,000	3.0	2,340,000	2,580,000	10.3
20	2,383,000	2,543,000	6.7	2,383,000	2,714,000	13.9
30	2,425,000	2,676,000	10.4	2,425,000	2,847,000	17.4
50	2,511,000	2,943,000	17.2	2,511,000	3,114,000	24.0

Situation

1. Six sack mix for recycled and conventional mixes.
2. Water-cement ratios for both mixes are 0.5.
3. Both conventional mix and recycled are 67 percent coarse aggregate, 33 percent fine aggregate.
4. Moisture content is 5 percent for coarse aggregate, fine aggregate, and crushed concrete.
5. Haul distances are: three miles from pavement to crusher and plant; varies as shown for virgin aggregates; 50 miles from source of cement to plant.

6. Cement is hauled in four-axle rigs (Michigan haulers are often 9 to 11-axle rigs).

7. Aggregate and concrete are hauled in three axle rigs (Michigan gravel haulers for long distance are usually 11-axle rigs).

8. Specific gravities are: 2.5 for crushed concrete coarse aggregate; 2.65 crushed stone; and, 2.68 sand.

9. Coarse aggregate to fine aggregate ratio is 2 to 1.

10. Crusher and plant are at same site.

11. Recycled concrete is used only as coarse aggregate for new mix.

12. Hauling of old concrete to disposal site in the conventional mix alternate has not been included.

Energy Consumed in Hauling Old Concrete to Disposal Site

1. Distance to disposal site = 10 miles.

2. Weight of concrete to be disposed of = 4,000 lb/cu yd
= 2 ton/cu yd.

3. Haul in three axle truck: energy used = 4,270 BTU/ton-mile.

In order to place 1 cu yd of new mix, 1 cu yd of old concrete must be disposed of. Therefore, the energy consumed by disposing of 1 cu yd of old concrete must be added to the energy consumed in producing and placing 1 cu yd of new conventional mix.

Energy consumed by hauling = 10 miles x 2 @ 4,270 BTU/ton-mile
x 2 tons/cu yd
= 170,800 BTU/cu yd