Technical Paper PE-101

PROCESSING RAP

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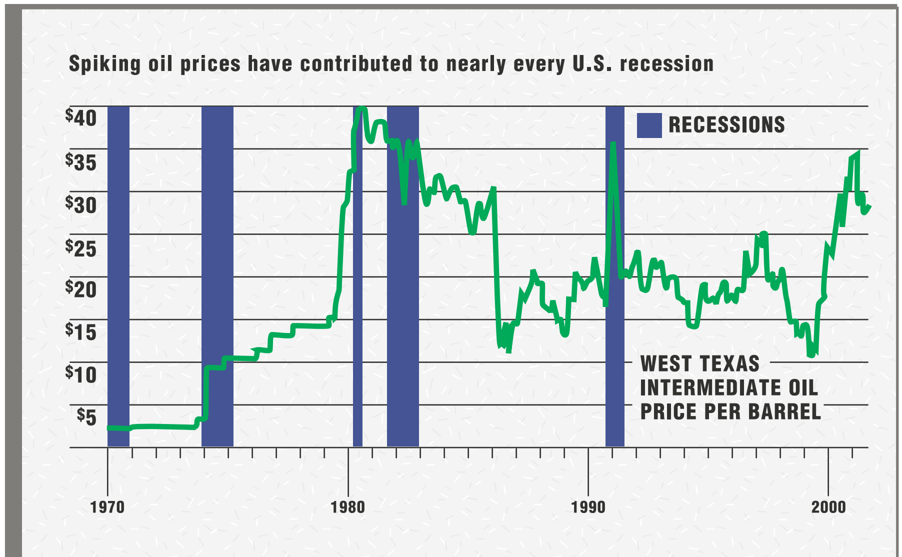


CRUDE OIL PRICES F1

Asphalt mixes first appeared in the United States in the late 1800's. Natural asphalt from Trinidad Lake was placed in drums and imported into the United States where drums were heated and the asphalt melted to be mixed with combinations of aggregate of various sizes to produce a smooth quiet road. Professor Alonzo Barber of the Harvard college obtained a franchise from the British Government to bring Trinidad Lake asphalt into the United States and distribute it. From these early beginnings, asphalt roads have grown to become the major pavement of choice with approximately 94% of the roads in America being surfaced with asphalt. In the early 1900's due to high cost of the Trinidad Lake material, recycling of old pavements was common. During the 1920's with more and more automobiles coming available the demand for roads increased. Concurrent with this was the need for more fuel and as oil was discovered in Pennsylvania and California, Trinidad Lake asphalt was replaced by a less expensive product, the residue from the refining process (the bottom of the barrel) and the roads were made from asphalt being derived from the oil refining process. Due to the fact that liquid asphalt was difficult to handle, sticky, and at low temperatures a rubbery-like substance, oil refineries just wanted to be free of the material and basically gave it away initially. Due to the abundance of crude oil in Texas and other areas of the United States, asphalt and oil remained relatively cheap through the 50's, 60's and into the early 70's.

During the 1950's and 60's, liquid asphalt sold for approximately $20.00/ton. Since an average of 5% asphalt was used to glue the aggregate together to form a road, the glue or asphalt only costs approximately $1.00/ton and aggregate was approximately $1.00/ton leading to a virgin material costs of the hot mix asphalt of approximately $2.00/ton. By the early 70's, liquid asphalt had increased to approximately $30.00/ton, with the asphalt or glue at $1.50/ton and aggregate to about $1.50/ton resulting in material costs of $3.00/ton.

In 1973, **Figure 1**, crude oil prices escalated due to the first oil embargo in the United States and liquid asphalt prices escalated to $80.00/ton in a very short time period. As a "rule of thumb" asphalt prices per ton are usually 6 times the price of a barrel of crude oil, i.e. 6 x $30.00/ barrel equals $180.00/ton liquid asphalt. This also resulted in higher aggregate prices (due to higher fuel prices) and liquid asphalt prices of approximately $4.00/ton of mix (5% of $80.00/ton). And thus resulting in a total virgin material cost of $6.00-$7.00/ton.

Again in 1979, **Figure 1,** crude climbed to $30.00/barrel and liquid asphalt prices escalated to $180.00/ton with the second oil embargo.

MILLING MACHINE F2

RUTTED HIGHWAY F3

CITY STREET DRAINAGE F4

This resulted in material costs for the asphalt portion of hot mix at $9.00/ton and aggregate costs had escalated to approximately $4.00-$5.00/ton resulting in a total virgin material costs of $13.00/ton.

In 1975, two things came together that made recycling again economically feasible. First, the prices of liquid asphalt and aggregate had escalated as mentioned above and secondly, a machine called a road planer or milling machine was developed **Figure 2**, that would remove as little as a 1/4” or as much as 6” of material from the roadway in one pass. This revolutionary new machine allowed numerous benefits to the road building industry. A few of them are as follows:

Rutted roads could be milled to a level surface resulting in a more uniform and higher quality pavement when placed over a flat surface, **Figure 3**.

Drainage could be maintained on city streets by milling the road surface prior to placement of another lift of mix eliminating stacking of layer on layer of resurfacing material, **Figure 4**.

Milling eliminated the raising of utilities and manholes and maintained proper drainage to the curb, **Figure 5**.

Milling eliminated the reduction in clearance under overpasses, **Figure 6**.

Milling eliminated the increase of weight on bridges caused by adding layer after layer.

While all of these advantages helped the public works designers to establish and maintain elevations, clearances, etc., it also generated an enormous amount of reclaimed pavement that could be recycled.

A second contribution of milling machines to the asphalt industry was the reduction in cost of obtaining recycled material versus complete pavement removal. Early milling costs were in the $4.00/ton range, but currently milling costs of $2.00-$3.00/ton, depending whether on highway or in city work, is normal. With the combination of higher virgin material costs and lower removal costs, hot mix asphalt has become the highest volume recycle product in the United States. The low cost of milling material versus the higher costs of virgin material produces a differential that gives recycle a tremendous economic advantage. Basically, recycling is worth what it replaces. **Figure 7** shows the economic benefit of adding recycle based on the various percentages used.

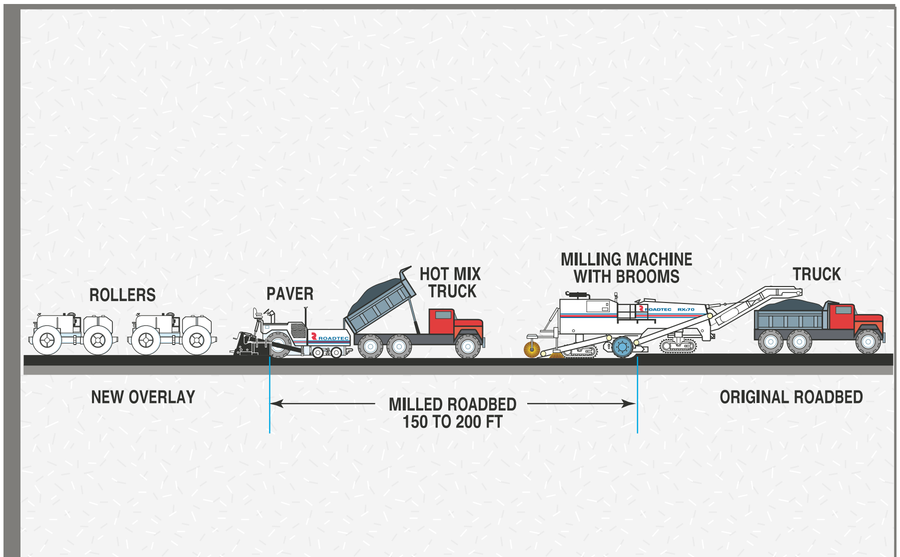
UTILITIES F5

MILLING ALLOWS CLEARANCES TO REMAIN CONSTANT F6

AGGREGATE	$ 5.00 X 0.95 =	$ 4.75 / TON
ASPHALT	$ 1.80 X 0.50 =	9.00
		$ 13.75
MILL RECYCLE		
(MILLING 3.00 - TRUCKING 2.00)		$ 5.00
		$ 8.75

% RECYCLE	SAVINGS / TON OF MIX
10%	0.87
20%	1.74
30%	2.62
40%	3.58

ECONOMICS OF RECYCLE F7



INLAID PAVING WITH MILLING MACHINE & PAVER F8

VOLUME OF RAP % F9

While recycling is often looked at in many industries as an inferior product to new materials, in hot mix asphalt it is often found to be a superior product since the liquid asphalt available today is often not of the same quality as it was a number of years ago. Current specifications allow the artificial softening of harder asphalts and lead to liquids with high percentages of volatiles and less binding strength than the original liquid. Even where current liquids are used today, the light oils are generally evaporated during mixing and placement and over a period of time resulting in purer asphalt occurring in the recycled product.

In addition, aggregates that tend to be absorptive, only absorb the liquid asphalt one time. The recycled product, when combined with new aggregate, often will have a thicker film due to the fact that absorption does not occur but once in the RAP portion of the mix. Perhaps the best description of recycling could be summed up by the words of a Japanese customer (who was the first to recycle in Japan) when asked what he told his customers concerning recycle, he said “its all the same age”.

AVAILABILITY OF RECYCLED ASPHALT PRODUCTS (RAP)

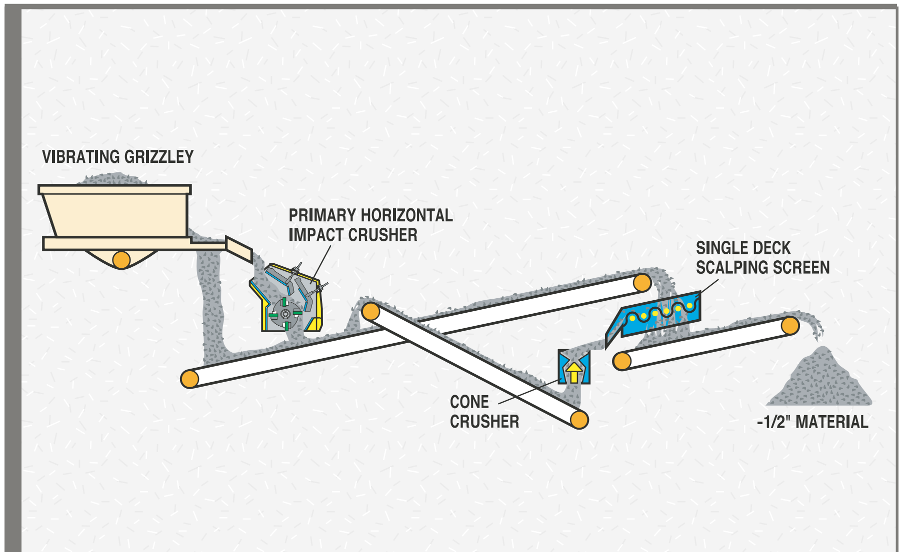
Due to the benefits of milling in cities and on highways, more recycle is becoming available. Inlays are becoming commonplace in most states where 1-1/2” to 2” of material is milled and a new surface is installed in the removed area without increasing the elevation of the road. This type of construction is very beneficial since the inlay area allows containment of the new mix on each side resulting in superior joints and it permits construction to be done at night with minimum disruption to the traveling public, **Figure 8**. This type of construction results in enough material being available to produce 100% recycle mix and although this is not practical, it results in increasing quantities of RAP.

In addition, with rebuilding of sewers, electrical lines, and other utilities below the roadway, numerous amounts of ripped up material is available. Milling on parking lots is often done versus complete removal since material can be milled to an exact elevation and the price of milling is much less than total excavation and re-grading prior to placing a new surface. This also results in a large quantity of material being available. With the passage of each year, it is our opinion that the amount of recycle available will increase steadily and more efforts must be made to increase the quality of recycle placed into hot mix asphalt without sacrificing quality.

RAP CRUSHING **F10**

PROCESSING RAP MATERIAL

Hot Mix Asphalt producers generally have two types of recycle asphalt that is available; ripped up material being brought in by customers and secondly, mill material from highway projects, parking lots, city streets, etc. Typically, mill material is placed in recycle bins and the oversized mill material passes over a single or multiple deck screen. The bulk of the material is fed directly to the plant without processing. When RAP is screened over 1-1/2" to 2" screens, unless the asphalt plant has a long mixing time, the RAP cannot be totally melted and homogeneously mixed with the new virgin aggregate and asphalt.



TWO-STAGE RAP CRUSHER CIRCUIT PRODUCING ONE PRODUCT **F11**

Some plants are equipped with closed circuit crushing systems that crush the oversized material that does not pass through the screen and returns it to the top of the screen as shown in **Figure 9**. Ripped up material has been crushed through various types of crushing plants **Figures 9 and 10**. For percentages of RAP of less than 15%-20% feeding one size of material is generally adequate, but as the percentage of recycle is increased, and the quality of mix is more scrutinized, it has become more obvious that multiple sizes of RAP will be required.

1/4" x 0" RAP (left), 1/2" + (right) F12

1/2" x 1/4" RAP F13

FOLD 'N GO F14

Logic dictates that RAP should be treated like any other aggregate, sized, and fed to the plant in multiple sizes, if the quality of the final product is to be insured. On most mixes designed in the United States in the last 50 years, a film thickness of 9 to 10 microns has been commonplace. By sizing the material into specific size ranges, the amount of liquid asphalt in each of these materials is much more consistent. Trying to produce a product using 30, 40 or 50% RAP with one size results in segregation of the material and wide variations in liquid asphalt content, making it very difficult for the plant to produce a high quality mix.

The most economical way of processing the RAP into multiple sizes is to screen it first. Since most of the mill material is surface mix, it is 1/2 inch or 12.5 mm minus material. With mill material, 70%-80% of the material will pass a 1/2 inch screen and if sized into two sizes, a 1/4” x 0” **Figure 12**, and 1/2” x 1/4” **Figure 13**, the consistency and the percentage of RAP that can be used increases significantly. **Figure 14** shows a portable, high-frequency screen. It is self-contained with its own engine and hydraulic drives that allow prescreening of RAP into three sizes, one oversized and two finish products. Since 70%-80% of the material will pass 1/2” minus opening, only 20%-25% of the oversized material requires crushing. A highly mobile unit such as this can be moved quickly between multiple plants sizing the material and reducing the amount of material required to be crushed.

It is estimated that pre-screening the material, as shown here in **Figure 14**, can be done for $.50 to $.75 per ton therefore, reducing the cost of crushing significantly, since only 20%-25% of the material will be required to be crushed. A crusher, as shown in **Figure 16**, can then be used to feed the material directly into a prescreening unit, again sizing the material into two different sizes.

ECONOMICS

By processing the material into two different sizes, higher percentage of RAP can be accurately blended producing not only additional savings but also resulting in a higher quality, more consistent mix and elimination of penalties. With the more restrictive gradation requirements of the SuperPave mix design procedure, producers often find it difficult to insert more than 10% RAP when using only a single size. By separating the RAP into two sizes, producers are successfully increasing RAP quantities to as high as 40% while also improving the quality of the mix. **Figure 17** shows a 12.5 mm Superpave mix with 15% recycle.

- **DEPRECIATION**
  (Based upon 5 yr. depreciation $150,000 costs; 200,000 TPY)....................0.15
- **MAINTENANCE**
  (Including Screen Cloth)..0.15
- **LOADER & LABOR**
  ($70,000/yr.)..0.35

0.65 / TON

COST OF SCREENING F15

CRUSHER AND 5030 SCREENING PLANT F16

SIEVE SIZE IN	SIEVE SIZE mm	12.5 mm SUPERPAVE MIX WITH 15% RAP	12.5 mm SUPERPAVE MIX WITH 40% FRACTIONATED RAP
3/4	19.00	100.0	100.0
1/2	12.50	96.7	95.2
3/8	9.50	86.1	78.2
4	4.75	65.0	57.3
8	2.36	45.9	44.9
16	1.18	33.4	35.2
30	0.60	24.5	26.9
50	0.30	15.0	16.7
100	0.15	8.2	8.8
200	0.075	5.2	5.4

COMBINED GRADATION 12.5 mm SUPERPAVE MIX F17

INGREDIENT	$ / TON	APPROVED DESIGN		DESIGN WITH FRACTIONATED RAP	
		% USED	$ / TON	% USED	$ / TON
RAP (5.7% AC)	3.00	15	0.45		
PLUS #4 RAP (3.7% AC)	3.65			14	0.52
MINUS #4 RAP (7.0% AC)	3.65			26	
NEW AGGREGATE	8.00	85	6.80	60	4.80
OPTIMUM AC (%)		5.7		5.7	
AC FROM RAP		0.86		2.34	
NEW AC	175.00	4.84	8.47	3.36	5.88
MIX COSTS			15.27		12.15
GAIN BY USING FRACTIONATED RAP					3.57

12.5 mm SUPERPAVE MIX **F18**

SIEVE SIZE		12.5 mm SUPERPAVE MIX WITH 10% RAP	12.5 mm SUPERPAVE MIX WITH 35% FRACTIONATED RAP
IN	mm		
3/4	19.00	100.0	100.0
1/2	12.50	95.9	94.2
3/8	9.50	88.6	80.0
4	4.75	61.4	57.2
8	2.36	41.4	41.8
16	1.18	28.9	31.7
30	0.60	21.6	24.3
50	0.30	13.5	14.0
100	0.15	7.8	7.7
200	0.075	5.2	5.0

COMBINED GRADATION 12.5 mm RAP MIX **F19**

INGREDIENT	$ / TON	APPROVED DESIGN		FRACTIONATED RAP	
		% USED	$ / TON	% USED	$ / TON
RAP (5.7% AC)	3.00	10	0.30		
PLUS #4 RAP (3.7% AC)	3.65			15	0.55
MINUS #4 RAP (7.0% AC)	3.65			20	0.73
NEW AGGREGATE	8.00	90	7.20	65	5.20
OPTIMUM AC (%)		5.83		5.83	
AC FROM RAP		0.57		1.96	
NEW AC	175.00	5.26	9.21	3.87	6.77
6.55					
MIX COSTS			16.71		13.25
GAIN BY USING FRACTIONATED RAP					3.46

12.5 mm SUPERPAVE MIX **F20**

By fractionating the RAP, the percentage of recycle can be increased to 40%. The savings through increased recycle is shown in **Figure 18**. **Figure 19** shows a mix with RAP increased from 10% to 35%. **Figure 20** shows the savings by increasing the RAP percentages from 10% to 35% and **Figure 22** shows a 9.5 mm mix with RAP increased from 15% to 40%.

Innovative operators have used the pre-screening plants for producing a large number of multiple sizes. Where SMA mixes are required, minus 16 mesh RAP can be processed, producing a minus 16 mesh product and feeding it directly into the asphalt plant while also producing two additional sizes of product that can be used in mixes at a later date. By using the minus 16 mesh or minus 4 mesh product to replace mineral filler and a portion of the polymerized asphalt, the cost of mix can be reduced significantly.

Figure 23 shows the gradations and asphalt content of the two RAP's. **Figure 24** shows the savings that result.

SIEVE SIZE		9.5 mm SUPERPAVE MIX	9.5 mm SUPERPAVE MIX
IN	mm	WITH 15% RAP	WITH 40% FRACTIONATED RAP
3/4	19.00	100.0	100.0
1/2	12.50	100.0	100.0
3/8	9.50	98.5	97.8
4	4.75	72.6	77.2
8	2.36	44.1	44.9
16	1.18	33.2	35.1
30	0.60	24.2	26.5
50	0.30	12.7	12.4
100	0.15	8.0	8.2
200	0.075	6.2	6.3

COMBINED GRADATION 9.5 mm SUPERPAVE MIX F21

INGREDIENT	$ / TON	APPROVED DESIGN		DESIGN WITH FRACTIONATED RAP	
		% USED	$ / TON	% USED	$ / TON
RAP (5.7% AC)	3.00	15	0.45		
PLUS #4 RAP (3.7% AC)	3.65			20	0.73
MINUS #4 RAP (7.0% AC)	3.65			20	0.73
NEW AGGREGATE	8.00	85	6.80	60	4.80
OPTIMUM AC (%)		5.4		5.4	
AC FROM RAP		0.86		2.14	
NEW AC	175.00	4.54	7.95	3.26	5.71
MIX COSTS			15.20		11.97
GAIN BY USING FRACTIONATED RAP					3.23

9.5 mm SUPERPAVE MIX F22

SIEVE SIZE	#4 RAP	#16 RAP	POND SAND
1	100	100	100
3/4	100	100	100
1/2	98	100	100
3/8	97	100	100
4	84	100	100
8	68	100	100
16	56	92	100
30	45	71	99
50	33	49	97
100	21	31	62
200	13	21	42
AC CONTENT	7.9%	8.9%	

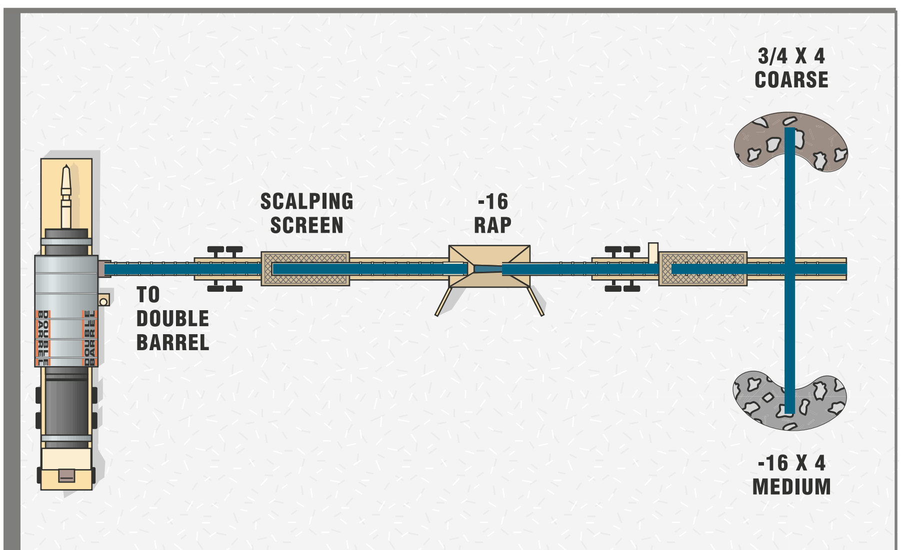
GRADATION OF RAP F23

INGREDIENT	$ / TON	APPROVED DESIGN		#4 RAP		#16 RAP	
		% USED	$ TON	% USED	$ TON	% USED	$ TON
# 4 RAP (7.9% AC)	3.65			15	0.55		
#16 RAP (8.9% AC)	3.65					15	0.55
NEW AGGREGATE	8.00	91	7.28	81	6.48	81	6.48
MINERAL FILLER	30.00	9	2.70	4	1.20	4	1.20
FIBER STABILIZER	400.00	0.35	1.40	0.35	1.40	0.35	1.40
OPTIMUM AC (%)		5.9		6.3		6.3	
AC FROM RAP				1.19		1.34	
NEW PMAC	275.00	5.90	16.23	5.11	14.05	4.96	13.64
MIX COSTS			27.61		23.00		23.27
GAIN BY USING REFRACTIONATED RAP					3.93		4.34

12.5 mm SMA VIRGIN MIX COMPARED TO MIXES USING VARIOUS RAP F24

INGREDIENT	VIRGIN MIX	#4 RAP	#16 RAP
# 4 RAP (7.9% AC)		15	
# 16 RAP (8.9% AC)			15
NEW AGGREGATE	91	81	81
MINERAL FILLER	9	4	4
FIBER STABILIZER	0.35	0.35	0.35
AIR VOIDS IN BEAMS %	7.5	6.0	5.9
RUT DEPTH IN THE ASPHALT PAVEMENT ANALYZER (mm)	7.8	5.0	5.7
50 BLOW MARSHALL MIX DESIGN PROPERTIES			
OPTIMUM AC %	5.9	6.3	6.3
AIR VOIDS %	3.5	4.3	4.0
VMA %	79.5	70.9	72.7
SALVAGED MATERIAL USED			
FINES FROM RAP %	0.0	15	15
ASPHALT FROM RAP %	0.0	1.19	1.34

12.5mm SMA MIXTURES WITH RAP AND PG 64-22 BINDER F25



EXAMPLE LAYOUT F26

Figure 25 shows how the RAP actually improves the rutting performance.

When using minus 16 mesh RAP, the material should be fed directly from the screen to the RAP feeder on the asphalt plant due to its high asphalt content. **Figure 26** shows a screening plant feeding directly to a RAP bin. The other two sizes are stockpiled for future use.

Since the percentage of liquid varies with the size of RAP, 1/4” x 0” RAP may have as high as 7% liquid while 1/2” x 1/4” may have less than 4% liquid. Some states place limits on the percentage of RAP before the grade of liquid is changed. Using finer RAP allows a significant reduction of new liquid without exceeding the percentage of RAP required.

Most important when considering the use of multiple sizes of RAP is the improvement in quality. One producer, using 3/4” minus RAP, was limited to 20% and continuously experienced penalties for quality. By sizing the RAP, the percentage has increased to 40% and penalties have disappeared.

CONCLUSION

With each passing year, the amount of recycle materials available continually increases. The economic benefits of adding recycle are obvious. An increase of 10% recycle can be shown to reduce the cost (based on the economics in **Figure 7**). This significant savings certainly justifies processing the RAP and treating it like any other material. High-frequency screening plants can reduce the cost of processing RAP significantly. These highly portable plants make multiple sizes of recycle available to allow the production of high quality mixes. The savings can result in pay backs in just a few months on the screening plant while improving the quality of the finished product and resulting in better, smoother, higher quality roads for the traveling public to use.

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