



U.S. Department of Transportation
Federal Highway Administration

IN-PLACE AND CENTRAL-PLANT RECYCLING OF ASPHALT PAVEMENTS IN VIRGINIA

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Like many other highway agencies, the Virginia Department of Transportation (VDOT) is facing the challenge of providing long-lasting and cost-effective pavement rehabilitation solutions in an era of limited resources and increased construction costs. To meet this challenge, VDOT demonstrated the use of in-place recycling and central-plant recycling methods for rehabilitating two Interstate highway projects.

WHAT WAS THE MOTIVATION?

A heavily traveled section of pavement on I-81 near Staunton, Virginia exhibited recurring structural-related distresses (fatigue cracking and rutting) that called for more extensive rehabilitation measures beyond periodic patching and mill and inlay solutions. The original aggregate base and subgrade had weakened considerably and were no longer capable of providing support to the surfacing layers. VDOT performed a complete project-level investigation of the I-81 project and confirmed that it was a candidate for reconstruction.



WHAT WAS DONE?

In the reconstruction of the I-81 project, VDOT employed full-depth reclamation (FDR), cold central-plant recycling (CCPR), and cold in-place (CIR) techniques to help reduce overall costs and make use of the materials in the existing pavement. Each process was selected to best address the existing distresses in each lane. A unique traffic management plan was developed to provide greater access for the contractor while reducing disruptions on the heavily traveled roadway. Based on the success of the I-81 project, in 2018 VDOT used CCPR and FDR techniques on a second larger Interstate project on a segment of I-64 near Williamsburg. Design and construction details for each of these Interstate projects are provided in the following sections.

PROJECT NO. 1: I-81 NEAR STAUNTON, VIRGINIA

During the 2011 construction season, VDOT rehabilitated a 3.66-mi pavement section of southbound I-81 near Staunton. This was the first time in the United State that FDR, CCPR, and CIR techniques were used together on an Interstate project (traffic volumes of 28,000 vehicles per day with 25 percent trucks). Critical to the project's success, VDOT followed a collaborative process in developing materials and testing specifications for the materials and providing inspector training. VDOT personnel and contractors worked together to ensure appropriate material selection and good quality of construction is achieved (see call-out). The cost of the rehabilitation project was \$7.64 million and was completed within 8 months.

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The project was constructed in two phases, with work first being done on the right lane and then work proceeding on the left lane. The completed cross section for each lane was different (see figure 1 [Diefenderfer and Apeagyei 2014]) since the level of deterioration differed between lanes (Diefenderfer, Bowers, and Apeagyei 2015). Furthermore, for the right lane, the first 2,150 ft of the project was constructed in accordance with the thicknesses shown in the center cross section of figure 1 but construction concerns resulted in a later modification changing the design for the remainder of the project to the thicknesses shown in the right cross section.

SN = 5.68	SN = 9.89	SN = 9.89
4-inch New AC	4-inch New AC	6-inch New AC
5-inch CIR	8-inch CCPR	6-inch CCPR
Existing AC		
Existing Aggregate	12-inch FDR	12-inch FDR
Subgrade	Subgrade	Subgrade
Left Lane	Right Lane (first 2150 ft of project)	Right Lane (remainder of project)

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Figure 1. Pavement cross sections on I-81.

The structural capacity of both lanes was determined following the guidelines from the 1993 AASHTO Guide (AASHTO 1993) and using the results of Falling Weight Deflectometer (FWD) testing. The structural layer coefficient for the CIR layer was calculated to be 0.39 whereas the structural layer coefficient for the CCPR layer was found to be between 0.37 and 0.44 (Diefenderfer, Bowers, and Apeagyei 2015).

The CCPR and CIR materials were produced with a cement content of 1 percent and a foamed asphalt content of 2 percent. The FDR was stabilized using a 3 percent combination of cement and a proprietary lime kiln dust product.

Virginia Construction Requirements

- **Material specifications.** VDOT allows up to 30 percent RAP in surface and intermediate asphalt mixtures and up to 100 percent RAP in CCPR and CIR (provided that volumetric and mixture design requirements are met).
- **Mixture designs.** VDOT requires contractors to develop a mixture design for each in-place recycled mixture, including stabilizing/recycling agents, dosage, additives (if used), moisture content, target gradation, and field density. Subgrade characteristics, including consistency properties and soil classification, are needed for FDR projects to select the stabilizing agent.
- **Performance testing.** Each in-place mixture design developed for FDR, CIR or CCPR was required to pass VDOT-specified stability and/or strength test criteria.
- **Test strip.** VDOT required the contractor to submit a quality control (QC) plan and complete a test strip.
- **Acceptance.** The acceptance criteria included density, depth, gradation, stabilizing/recycling agent dosage rate, stability/strength test results, and binder properties.
- **Weather.** Recycled layers should be constructed when ambient temperatures are above 50 °F and no freezing temperatures are forecasted within 48 hours of placement.
- **Curing.** Based on the recycled agent and recycled approach, the curing period should be observed before the road is open to traffic.

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A unique traffic management plan was set up to help maintain safe traffic flow through the work zone. This included a major public service announcement campaign, a detour route dedicated for passenger traffic, and the establishment of targeted lane reduction times tied to days of the week when lower traffic volumes were anticipated. Figure 2 shows a segment of I-81 illustrating traffic management on the project (Diefenderfer and Apeagyei 2014).



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Figure 2. Traffic management on I-81 project.

PROJECT NO. 2: I-64 NEAR WILLIAMSBURG, VIRGINIA

The good performance of CCPR over FDR on the I-81 project encouraged VDOT to employ this design technique for the widening and reconstruction of a portion of I-64 near Williamsburg in 2018. The project included three segments, with CCPR and FDR used on Segments 2 and 3 and a conventional construction approach (full-depth asphalt on a treated base) used on Segment 1. The construction of Segment 2 is anticipated to be completed in 2019, while work on Segment 3 is anticipated to be completed in 2021.

The I-64 project is scheduled to use similar recycling designs as used on I-81 to address the structural distresses in the existing lanes in the most cost-effective way. The improvements for Segments 2 and 3 include reconstructing the existing lanes and

adding an additional 12-ft wide travel lane and a 12-ft wide shoulder to the inside of the pavement in both directions. The traffic levels for I-64 are approximately 43,000 vehicles per day with about 9 percent heavy trucks.

Figure 3 shows the cross sections for the rehabilitation of the existing lanes and the new lane addition for Segment 2 (Diefenderfer 2018). The cross section for the reconstruction of the existing lanes was similar to that used on the I-81 project, except a 2-inch open-graded drainage layer (OGDL) was incorporated into the design for drainage. The FDR was stabilized with 5 percent cement. For the new lane addition, the aggregate base layer in the new lanes incorporated the existing pavement layers as recycled concrete aggregate (RCA) and reclaimed asphalt pavement (RAP) stabilized with 5 percent cement, and then topped with the same OGDL, CCPR, and AC layers. The CCPR mixture design consists of 85 percent RAP and 15 percent quarry by-products with top size passing No. 10 sieve stabilized with 2.5 percent foamed asphalt binder and 1 percent cement. Figure 4 shows an overview of a portion of the I-64 construction on Segment 2 (Diefenderfer 2018).

SN = 7.06	SN = 7.06
4-inch AC	4-inch AC
6-inch CCPR	6-inch CCPR
2-inch OGDL	2-inch OGDL
12-inch FDR	12-inch Cement-Treated Recycled Base (RAP & RCA)
Subgrade	Subgrade
Existing Lanes	New Lane

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Figure 3. Segment 2 cross sections on I-64 project.

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Figure 4. Overview of I-64 project during widening.

WHAT BENEFITS WERE ACHIEVED?

PERFORMANCE

I-81, Staunton

Annual measurements of roughness and rut depth for the I-81 project are shown in figure 5. The left and right lanes do not exhibit any significant changes in smoothness over the 6-year period, with the International Roughness Index (IRI) values remaining between 42 and 56 inches/mi. The average rut depths for both lanes are nominally 0.10 inches after 6 years of service. To date, observations suggest that the performance of the CCPR and FDR sections, when properly designed and constructed, are similar to that of conventional asphalt pavements and can be used for heavy traffic volume loads.

I-64, Williamsburg

The I-64 project remains under construction and thus no performance data are available.

COSTS

On both projects, significant cost reductions were realized through the use of recycled products, proper structural design leading to reduced new asphalt

layer thicknesses, replacement of hot-mix asphalt with CCPR mixtures, and replacement of natural aggregates base layers with in-place recycled and treated layers.

I-81, Staunton

The estimated cost savings for this project ranged from a few percentages of the \$7.9 million contract price to more than \$70 million, depending on the rehabilitation alternative used for comparison (Diefenderfer and Apeageyi 2014). It is estimated that the use of in-place recycling techniques on the I-81 project reduced the construction time from 2 years (using conventional pavement reconstruction methods)

to 3 or 4 months (FCP 2011), which could translate into significant agency and user cost savings.

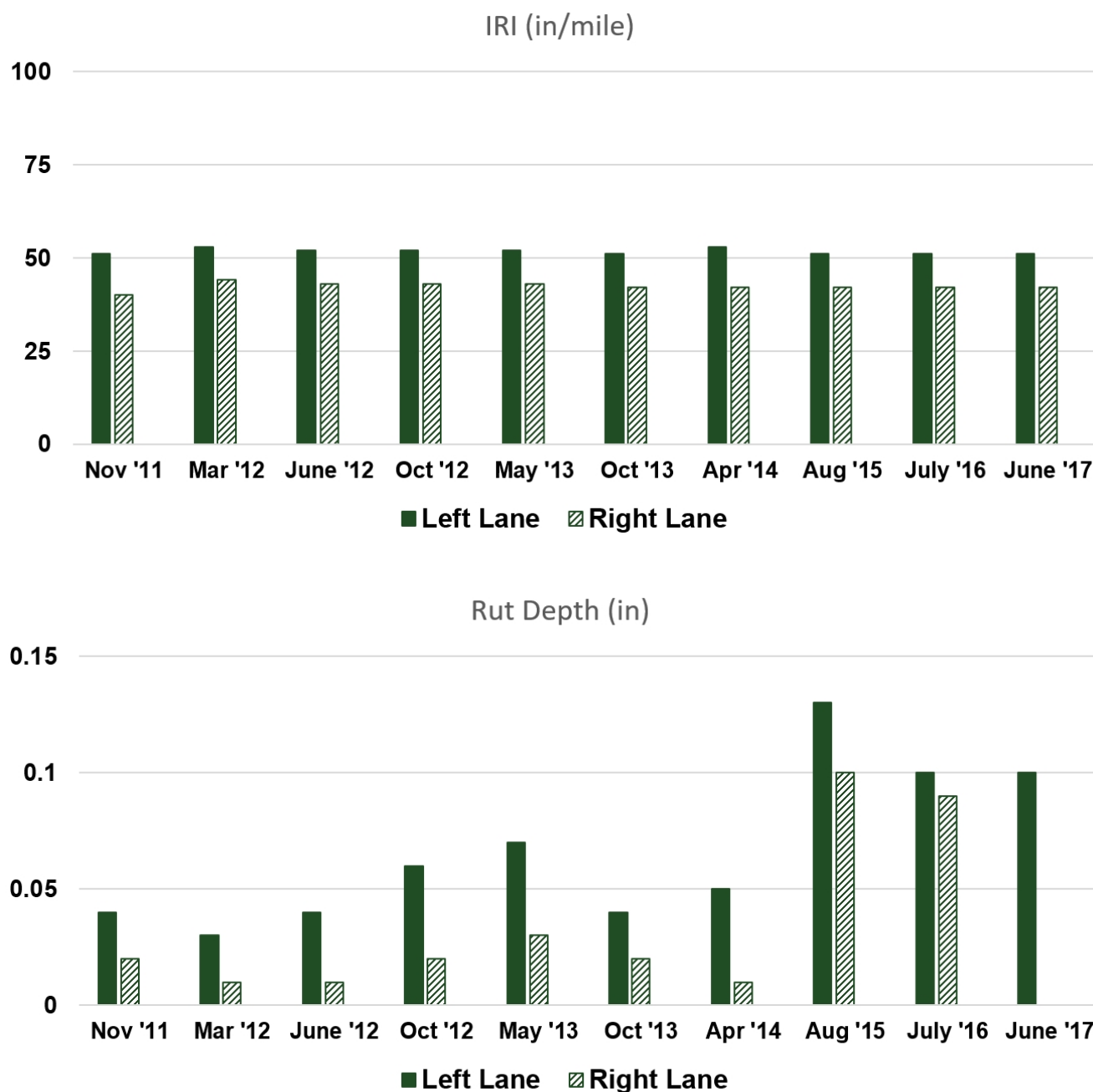
VDOT has found pavement recycling to be a series of cost-effective and environmentally conscientious methods for pavement rehabilitation. The agency continues to look for projects where these innovative technologies can be implemented through collaborative relationships with contractors.

—Brian Diefenderfer, Virginia

I-64, Williamsburg

VDOT saved about \$10 million (about 7 percent of the \$139 million contract) on the mainline initial construction cost of Segment 2 on the I-64 project. Total savings are expected to be greater since similar recycling treatments are used for the full-width shoulders in lieu of conventional asphalt (see table 1). For both Segment 1 and 2, VDOT has realized savings of \$15 million by employing pavement recycling technologies on the project (Lombardo 2018), approximately a 6 percent savings on the combined (Segment 1 and 2) project cost of \$261 million.

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Both graphs: © 2019 Virginia DOT

Figure 5. IRI and rut depth measurements on I-81 (note: spike in 2015 readings are the result of an equipment change).

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Table 1. Breakdown of mainline pavement construction costs of the I-64 project Segment 2 compared with a conventional full-depth asphalt alternative.

Layer	Conventional Design Layers Specs	Conventional Design Cost All Lanes (\$/yd ²)	Recycled Alternative Layer Specs	Recycled Alternative New Lane (\$/yd ²)	Recycled Alternative Existing Lanes (\$/yd ²)
Treated Base	8-inch treated base	\$20.25	12-inch treated base ²	\$27.34	–
Open Graded Drainage Layer	2-inch OGD	\$6.75	2-inch OGD	\$4.05	\$4.05
Full-Depth	–	–	12-inch FDR	–	\$6.00
Cold Central-Plant Recycling	–	–	6-inch CCPR	\$14.58	\$14.58
Asphalt Concrete	12-inch AC ¹	\$55.68	4-inch AC ³	\$14.90	\$14.90
Total Cost per yd²	–	\$82.68	–	\$60.87	\$39.53
Total Cost per project⁴	–	\$12,363,107	–	\$3,033,769	\$3,940,479

1 Total asphalt cost of an 8-inch base course (1-inch nominal maximum aggregate size, NMAS), a 2-inch SMA (0.75-inch NMAS), and a 2-inch SMA (0.5-inch NMAS)

2 Cement-treated base layer was constructed using 100 percent recycled concrete

3 Total asphalt cost of a 2-inch SMA (0.75-inch NMAS) and a 2-inch SMA (0.5-inch NMAS)

4 Total mainline pavement areas are 149,530 yd² (99,686 yd² existing and 49,843 yd² new for widening the pavement)

– No data or n/a

ENVIRONMENTAL IMPACTS

As a member of the [Under2 Coalition](#) of regional and subnational governments, environmental considerations are important to the State of Virginia as it works to drive climate action. Although the potential environmental impacts for these projects were not computed prior to construction to inform decision making, a limited life-cycle assessment (LCA) was performed independently after construction to demonstrate how the recycled designs could contribute to the State's environmental goals.

The analysis compared the actual recycled designs constructed on I-81 and I-64 to one lane of a fictitious conventional reconstruction strategy and included materials and initial construction stages to quantify potential reductions in energy and global warming potential (GWP) VDOT realized towards its goal. It is important to note that, in order for those reductions

to be achieved, the long-term performance of the recycled sections has to be similar to or better than that of the (fictitious) conventional pavement design.

I-81, Staunton

Figure 6 (top) shows the environmental performance of the three recycled sections on the I-81 project compared to a fictitious conventional design (14-inch asphalt on an 18-inch aggregate base). Both total primary energy demand (approximate 50 to 70 percent reductions) and GWP (approximate 40 to 70 percent reduction) are considerably less for the recycled sections compared to the conventional pavement. The left lane of the project, which featured a 4-inch asphalt on a 5-inch, resulted in lower energy consumption and GWP, both of which contribute positively to the State's drive for climate action.

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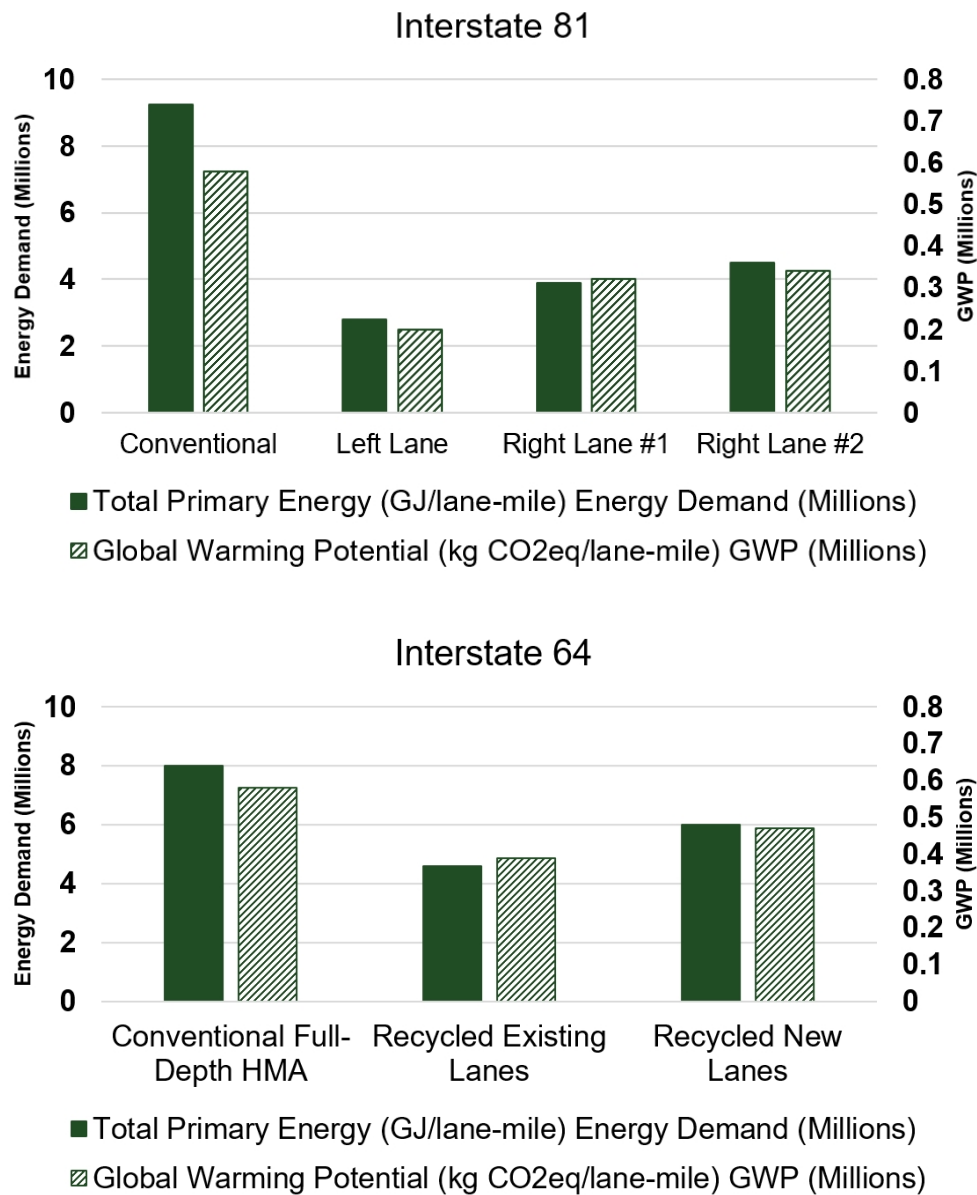


Figure 6. Comparative environmental impact analysis of sections constructed on I-81 and I-64 projects (made from environmental inventory data from Illinois Tollway [Al-Qadi et al. 2015] and FHWA [Al-Qadi et al. 2017]).

I-64, Williamsburg

The bottom chart of figure 6 shows the total primary energy and GWP for the two recycled sections on I-64 compared to a fictitious conventional HMA pavement (12 inches [305 mm] of HMA on an 8-inch [203-mm] treated base). The energy reductions achieved by the recycled designs range from about

25 to 45 percent, while the GWP reductions range from about 15 to 40 percent. The environmental reductions were less on the I-64 project than on the I-81 project due to a higher percentage of stabilizing agent use and a greater expected hauling distance.

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On Segment 2 of the I-64 project, VDOT estimates that it will reuse more than 180,000 tons of existing milled pavement; this translates into the elimination of more than 4500 tons of new asphalt binder (Canty 2017). This not only saves cost but also conserves resources.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

These two construction projects demonstrate that it is possible to engineer the design of high-volume pavements utilizing in-place recycling techniques to achieve cost and environmental benefits (in terms of reduction in energy consumption and GWP). The following represent some of the key outcomes from the two projects:

- Pavements incorporating CIR, FDR, and CCPR technologies can be designed for high structural capacities and used on high-volume roadways.
- On the I-81 project, the traffic management plan—a combination of a public awareness campaign, dedicated detour route for passenger traffic, and targeted lane reduction times tied to days of the week with anticipated lower traffic volumes—played a key role in its safe and successful construction.
- It is estimated that the use of in-place recycling techniques on the I-81 project reduced the construction time from 2 years (using conventional pavement reconstruction methods) to 3 or 4 months (FCP 2011).
- The estimated cost savings for the I-81 project ranged from a few percentages of the \$7.9 million contract price to more than \$70 million, depending on the assumed rehabilitation alternative (Diefenderfer and Apeageyi 2014).
- The three recycled sections on the I-81 project showed 50 to 70 percent energy reductions and 40 to 70 percent GWP reductions when compared to a fictitious conventional pavement.
- On the I-64 project, VDOT saved about \$10 million (about 7 percent of the \$139 million contract) on the mainline initial construction cost of Segment 2 on the I-64 project. For both Segment 1 and 2, VDOT has realized savings of \$15 million (about 6 percent of the \$261 million contract).
- The two recycled sections on I-64 showed 25 to 45 percent energy reductions and 15 to 40 percent GWP reductions when compared to a fictitious conventional asphalt pavement. The type of stabilizing agent and the associated hauling distances can reduce the potential environmental benefits.
- Both projects contributed positively to the State in making progress towards their climate action goals.
- For both projects, additional cost savings were also realized as a result of the reduced construction times associated with the recycling alternatives (e.g., reduced user delay costs, reduced traffic control costs), but these costs were not quantified.
- In VDOT's experience, a collaborative process between the agency and the contractors helped ensure appropriate material selection and that good quality construction is achieved.
- The success of pavement recycling projects depends on several key items, including material specifications and mix designs, performance testing, quality control, acceptance criteria, and construction practices.

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