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Day-to-Day Practices to Reduce the Carbon Footprint of Asphalt

NATIONAL ACADEMIES Sciences Engineering Medicine

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Day-to-Day Practices to Reduce the Carbon Footprint of Asphalt

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Introduction

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Tim Aschenbrener
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Like other industries, the asphalt industry is seeking and implementing techniques to reduce its overall carbon footprint. The United States government launched the Federal Sustainability Plan in December 2021 with goals of reducing Federal Operations emissions 65% by 2030 and achieving net-zero emissions by 2050 (1). In February 2022, the National Asphalt Pavement Association (NAPA) issued The Road Forward, its vision on sustainability with a net-zero carbon emissions goal by 2050 as well (2).

For more than a decade the Federal Highway Administration (FHWA) Sustainable Pavements Technical Working Group (SPTWG) has been supporting the development of resources and tools that state departments of transportation (DOTs) can use to help reduce the carbon footprint of their pavements and quantify the environmental impacts of pavement construction via life-cycle assessment (LCA) (3).

All these asphalt pavement stakeholders are working toward a common goal of net-zero emissions by 2050 and the use of technologies and tools to rationally quantify the environmental impacts of asphalt pavement materials and construction alternatives. Achieving the common net-zero goal will require incremental improvements over time. In the short term, some agencies and industry leaders are already planning for changes and implementing tools to contribute to the net-zero goal. Others are critically thinking about impediments that currently exist, or may exist in the future, and how to overcome them.

Session 3016, “Day-to-Day Practices to Reduce the Carbon Footprint of Asphalt,” was held at the 103rd Annual Meeting of the Transportation Research Board (TRB) in January 2024. The objective of this session was to organize, document, and communicate techniques to reduce the asphalt pavement carbon footprint. It offered an opportunity for representatives from a state DOT, an asphalt plant manufacturer, and an asphalt mixture producer and contractor to share current, day-to-day practices to reduce the carbon footprint. From the information presented in this session, technical experts can estimate the magnitude of the carbon footprint reduction associated with various activities, and plan accordingly for implementation and adoption to reduce the carbon footprint of asphalt.

The first speaker was Ben Bowers of Auburn University who provided a brief introduction of sustainability, life-cycle assessment and environmental product documents (EPDs). The next speaker, Greg Renegar of Astec Industries, presented an overview of the carbon footprint at the asphalt plant and various technologies that could be adopted to reduce the carbon footprint. This was followed by a presentation by Cheng Ling of Pike Industries discussing different drivers and improvement opportunities from an asphalt mixture producer and contractor's perspective. The final presentation of the session was by Brian Diefenderfer of the Virginia DOT offering an agency's perspective on reducing environmental impacts of pavement rehabilitation.

This E-Circular provides a synopsis of the session by including key figures along with a synthesis of the points delivered by each of the four presenters. The material provides a helpful reference and a reminder that there is value in understanding how we can get started today to reduce the carbon footprint and where we need to go in the future.

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Acknowledgments

The committee thanks Ben Bowers, Brian Diefenderfer, Cheng Ling, and Greg Renegar for presenting and all participants at the session for sharing their valuable insight, experience, and knowledge.

The following TRB Standing Committees were cosponsors of the workshop, and their contribution has been key to the event's success.

- Standing Committee on Asphalt Materials Selection and Mix Design (AKM30)

A special recognition goes to the people that planned and organized the workshop and prepared this document.

- Tim Aschenbrener, FHWA, AKC60 Committee Member
- Ben Bowers, Auburn University, AKM30 Committee Member
- Ben Cox, U.S. Army Corps of Engineers, AKC60 Committee Member
- Brian Diefenderfer, Virginia Transportation Research Council (VTRC), AKC60 Committee Member
- Adam Hand, University of Nevada, Reno, AKC60 Committee Chair
- Dave Johnson, Asphalt Institute, AKC60 Committee Friend
- Cheng Ling, Pike Industries, AKM20 Committee Member; and
- Greg Renegar, Astec Industries, AKC60 Committee Friend

Asphalt Sustainability

An Introduction

BENJAMIN F. BOWERS

Auburn University

What is sustainability? This is a simple question that garners many different responses. Many people consider sustainability as being “green” or “environmentally conscious.” However, sustainability is much more than this. The Federal Highway Administration defines sustainable pavements as having the ability to:

- “Achieve the engineering goals for which it was constructed
- Preserve and restore surrounding ecosystems
- Use financial, human, and environmental resources economically
- Meet basic human needs such as health, safety, equity, employment, comfort, and happiness.” (1)

This is best summarized by the “triple bottom line” of sustainability where planet, profit, and people are considered. However, it is at the nexus of all three of these pillars that sustainability exists, as shown in Figure 1. Each of these pillars asks a different question:

- Profit—Are we maintaining and growing the economy?
- People—Are we caring for all people?
- Planet—Are we taking care of our environment?

Each of these elements has an important role in sustainability, and all of them ultimately rely on performance. Profit relates to making money and maintaining a healthy economy. If a business is producing a product that is environmentally or socially conscious but is not making money, then the business model is not sustainable, and it will ultimately close. If people are getting sick due to exposure to fumes during production of a product, then it will be challenging to find people to hire and thus the product production is not socially sustainable. If all the natural resources in the environment are expended or the environment is rendered unlivable, then there will no longer be any raw materials to build with or environment in which to inhabit. This would not be environmentally sustainable.

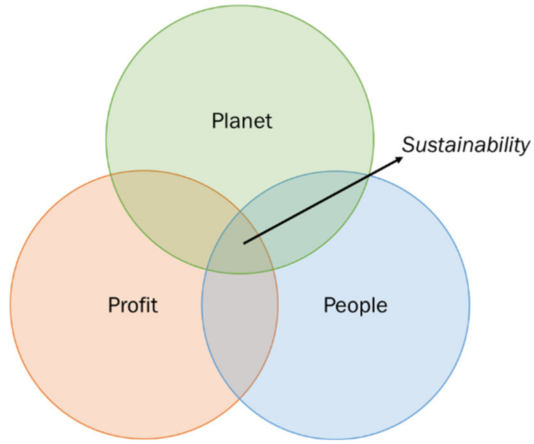

FIGURE 1 The triple bottom line.

Understanding that sustainability requires meeting requirements in each part of the triple bottom line while maintaining performance, one might ask: Well, how do I measure my sustainability?

Green Rating Systems, such as FHWA's Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), the Greenroads Rating System from the Sustainable Transport Council, or Envision from the Institute for Sustainable Infrastructure, among others, consider social impacts. Greenroads, for example, provides 10 credits and up to 21 points for "Access and Livability" (2). Envision assigns 14 credits and up to 200 points to assessing the quality-of-life contributions of a project (3). Examples from the Envision framework for quality of life include enhancing public health and safety, minimizing noise and vibration as well as light pollution, encouraging sustainable transportation, and preserving historic and cultural resources.

Life-cycle cost analysis (LCCA) is a common way to measure the profit—or financial—element of sustainability in transportation engineering and decision-making. The steps of an LCCA are described by the FHWA (4) as:

1. Establish alternative design strategies.
2. Determine activity timing.
3. Estimate agency costs.
4. Estimate user costs.
5. Determine life-cycle costs.

An LCCA considers the costs of the entire life of the asset, not just the initial costs.

LCA is the "eco-accounting" process used to quantify the environmental element of sustainability. LCA is a systematic analysis of the potential environmental impacts of products during their life cycle, as shown in Figure 2 for asphalt mixtures, including but not limited to greenhouse gas emissions, eutrophication, acidification, ozone depletion, non-renewable depletion, water consumption, smog formation, and waste generation.

Greenhouse gas emissions are often reported in the form of global warming potential (GWP) or carbon dioxide equivalents (CO2eq). Each greenhouse gas, such as methane, has its impact on global warming based on how much energy it will absorb over time and thus not release into earth's atmosphere. An easy way to think about this is we are "normalizing" any greenhouse gas to how much CO2 it would be equivalent to.

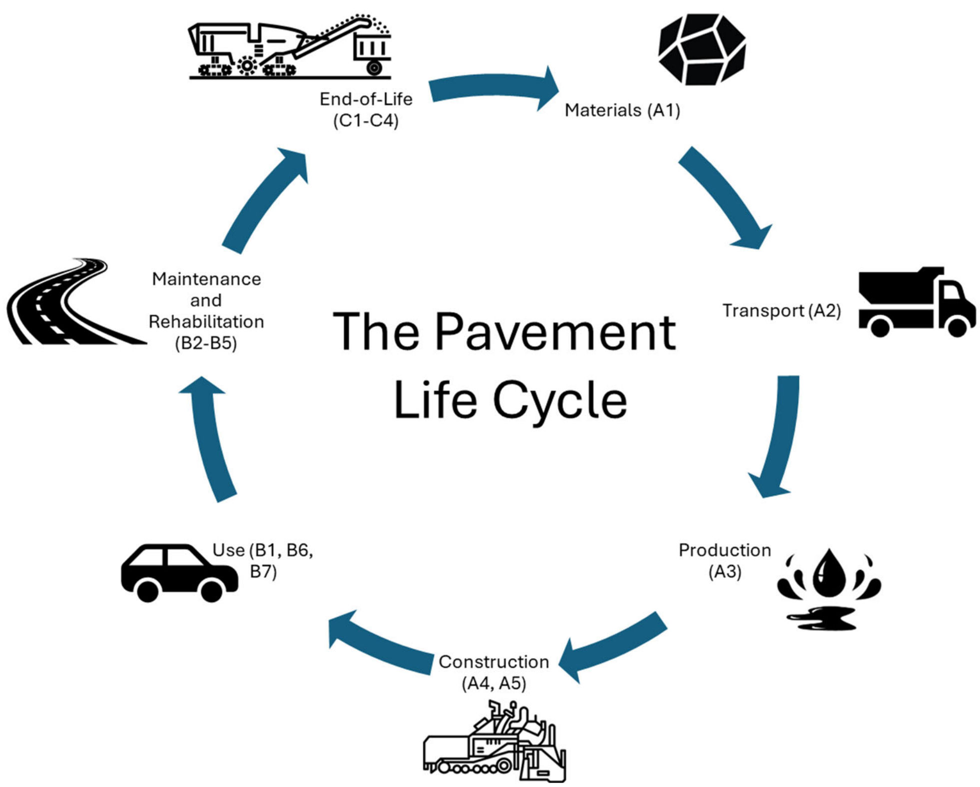

FIGURE 2 Life cycle of asphalt mixtures.

For example, methane (CH_4) has a GWP of 27–30, meaning that 1 ton of methane released into the atmosphere has the equivalent energy absorption to that of 27—30 tons of CO2 (5). By making all greenhouse gas emissions equivalent to the amount of CO2 released you can account for all of them in a single number, making it easier to understand the impacts of a single product or series of products.

So then, what is an environmental product declaration or EPD? An EPD is a cradle-to-gate LCA for a product. In pavements, EPDs would account for the materials (A1), transport (A2), and production (A3) portion of an asphalt mixture. It would account for the environmental impacts, through an LCA, of the raw materials (e.g., aggregate, asphalt binder, additives), their transport to the asphalt plant, and the actual production of the mixture (e.g., burner fuel consumed, stack emissions) all the way until the mixture is loaded into the truck. Once the truck is loaded and pulls forward it officially enters the next phase of the LCA and is no longer considered in the EPD for the asphalt mixture product.

Not just anyone can create an EPD. In order to become an EPD, a Product Category Rule PCR), which is developed in conformance with International Standards Organization (ISO) 14025 “Environmental labels and declarations” and in the case of asphalt mixtures ISO 21930 “Sustainability in building and civil engineering works.” Meijer et al. (6) define a PCR as:

> *“…industry consensus standards and guidelines that are used in developing and reporting Environmental Product Declarations (EPDs), which are transparent, verified reports used to communicate environmental impact of a specific material or product.”*

A third-party verifier is used to validate the EPD. In the case of asphalt mixtures, the NAPA has an EPD tool called Emerald Eco-Label that contractors can use to produce third-party verified EPDs (7). This helps to prevent competition from “gaming” the system and producing EPDs for mixtures that intentionally make them appear better environmentally than they are.

Conclusion

With a better understanding of what sustainability truly is, accounting for all parts people, profit, and planet (environment), the question must be asked: How can we as members of agencies, industry, and policymakers become more sustainable with respect to asphalt pavements? The following chapters will shed an important light on how this can be achieved through asphalt mixture production, construction, and agency decision-making.

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Reducing Asphalt Carbon Footprint at Asphalt Plants

GREG RENEGAR
Astec Industries

There are those who not only believe in man-made global warming but also believe they have a moral duty to do everything possible to attempt to address this warming regardless of the cost or the likely effects. There are also those in this industry who believe that man-made global warming is either not true or the situation is not as dire as represented. And there are those that fall somewhere in between the extremes. Regardless of the truth, there is one thing for certain: The changes coming to this industry have the momentum of a freight train barreling down the tracks. The asphalt industry will be affected in significant ways.

As with all machines, asphalt plants have come a long way since 1912 (Figure 1). As with most products that advance through the years, every aspect that can possibly be measured has drastically improved. The photograph on the left is a Warren Brothers plant made in 1912. The middle photograph shows what a typical asphalt plant looks like in 2024 and has looked like for several years. What will the plant of the future

FIGURE 1 Asphalt plants.

be like? What will be different? What will the operational characteristics of the future asphalt plant be like?

The photograph of the 1970 vintage automobile compared to the modern version is an example of what asphalt plant innovation of the future could look like (Figure 2). Every aspect of performance, reliability, longevity, and efficiency on the new model is vastly superior, but the cars still strongly resemble each other. What made the difference? The application of new technology to the design, materials, and manufacturing. The asphalt plant of the future will likely strongly resemble current plants, but the performance, due to the application of technology, will be even cleaner and more energy efficient.

Economics (i.e., being able to process reclaimed asphalt pavement [RAP] well), industry changes such as changes in mix designs, regulations and specifications, and competition are the typical market forces that drive plant innovation (Figure 3). These forces are always present in varying degrees. These forces create a need. Available, proven technology is applied, and this results in innovation that satisfies the new needs. UBER is an example of this in the transportation industry. The old "recipe" for getting to and from many places was by using a taxi. The combination of three available technologies (GPS, smartphone, software) created a new recipe that tens of millions of people all over the world use every day instead of the old recipe.

Looks similar – Both instantly recognizable as a Mustang

Not similar performance due to technology

FIGURE 2 Innovation example.

As seen in the chart in Figure 4, 43% of the carbon footprint of asphalt mix production (material [A1], transportation [A2], production[A3]) comes from the asphalt plant. And 90% of that 43% carbon footprint comes from the drying process. This illustrates that improving the thermal efficiency of the drying process is an important aspect of carbon reduction.

The following facts are important in that a foundation of industry knowledge is required in order to make doable, impactful decisions regarding carbon reduction (Figure 5).

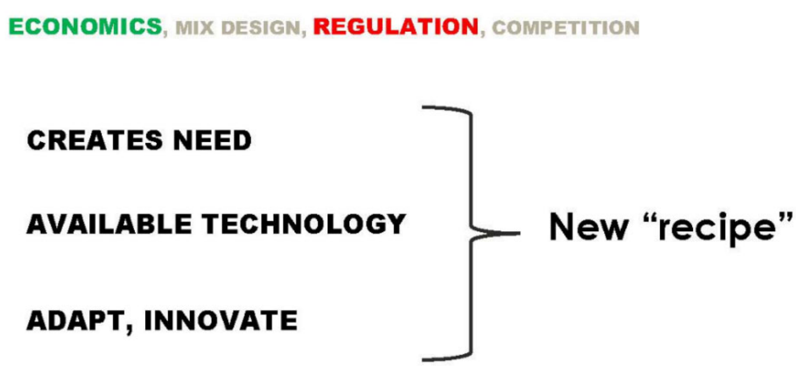


FIGURE 3 Innovation drivers.

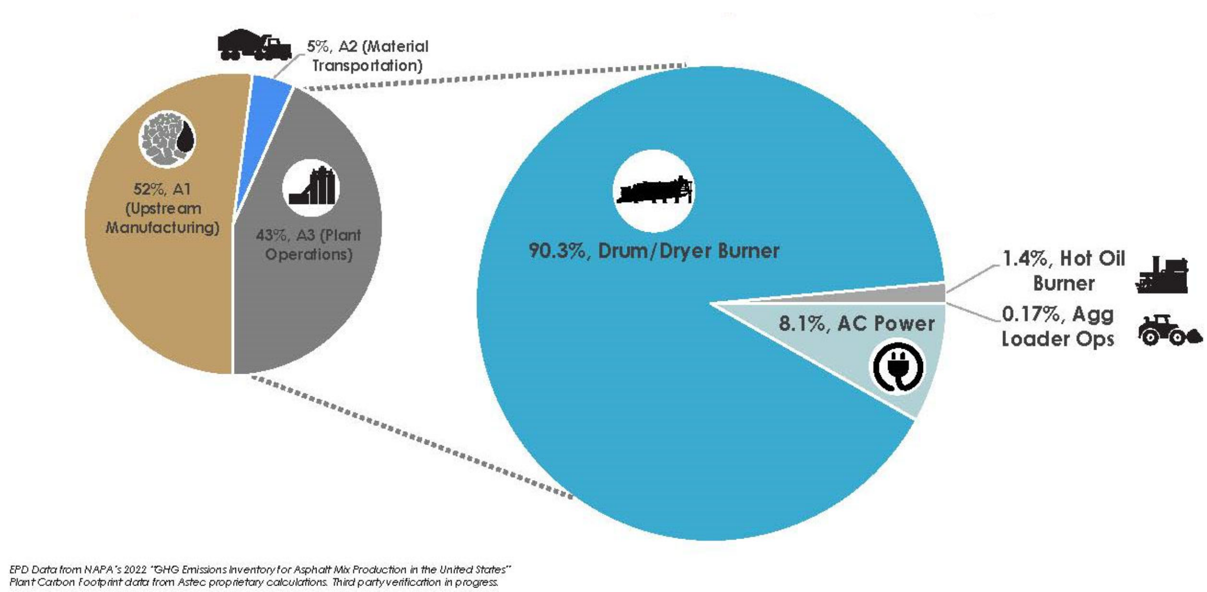


FIGURE 4 Asphalt plant carbon footprint.

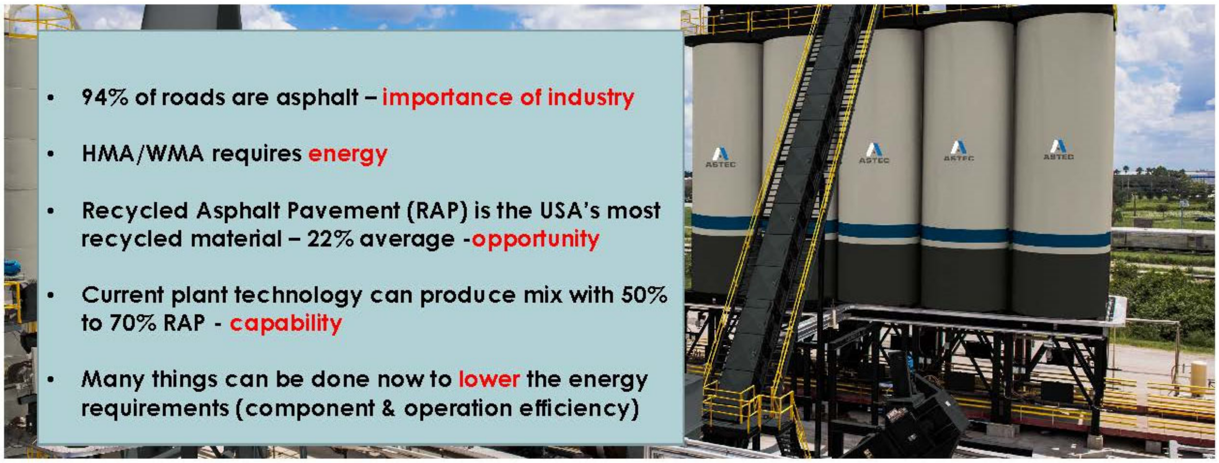


FIGURE 5 Facts to consider.

- Over 94% of the roads in the United States are asphalt. This shows the importance of the asphalt industry to our nation.
- A given amount of energy (heat) is required to make HMA (hot mix asphalt) and WMA (warm mix asphalt). There is no "free lunch" when it comes to producing asphalt mix.
- Good performing, high-RAP-percentage roads have been designed, produced, and placed for the last 40 years. The current RAP usage in the United States is 21%. Asphalt plant technology is able to produce from 50% to 70% RAP. Therefore, there is a huge opportunity to increase the percentage of RAP in roads.
- Using more RAP means less blasting, crushing, transporting of virgin aggregates. In some places, the best source of aggregate is not a local quarry but the roads (RAP) getting ready to be replaced.

The good news is that many things can be done now to reduce the energy required per ton of asphalt.

Innovation is sometimes driven by regulation. California is an example of how more restrictive emission (NOx) regulations have driven plant innovation, specifically burner technology (Figure 6). Regulation must be practicable to execute and achieve the objective without unintended consequences. Even though regulation may seem "fair" in that all producers must comply, regulation comes at a cost. Many regulations, as they attempt to do something good, raise the cost of asphalt, and raise the cost for entry into the industry.

In the past, fuel selection has typically been based on availability and cost per Btu. In the future, it could be mandated outright, or indirectly mandated by reducing emission limits. Fuel selection can make a significant difference in carbon emissions and other emissions such as NOx (Figure 7). Although hydrogen might sound attractive as a burner fuel in that the products of combustion are heat and water, currently there are significant cost and technical barriers to hydrogen's practical, widespread use to heat aggregate by using existing technology. Blending hydrogen with natural gas is a feasible "baby step" as the economics and other technical issues are being resolved through innovation.

FIGURE 6 Asphalt plant current technology.

FIGURE 7 Existing technology: burners.

Since 43% of HMA carbon comes from the plant process (A3), and 90% of the plant process carbon comes from the aggregate dryer, the thermal efficiency of the aggregate dryer is very important. The red arrows shown in the aggregate dryer cut-away illustration show where burner energy (heat) goes. Most of the heat goes into the aggregate. Some heat goes into the equipment itself, and some escapes through the gases that exit the drum (Figure 8).

Everything that gets hot on an asphalt plant besides the aggregate is a waste of energy. In a perfect world, nothing but the aggregate would get hot. In the world we live in, it is impossible for parts of the plant to not be hot. In fact, it is absolutely necessary for some plant equipment to be hot. In this aggregate dryer cut-away, the narrow red arrow exiting the dryer represents minimizing the amount of heat (energy) that bypasses the aggregate in the form of hot gases (Figure 9). Technology exists that allows the plant control system to optimize the aggregate dryer thermal efficiency (how much heat goes into the aggregate versus heat that does not go into the aggregate). In effect, it allows the plant to produce HMS/WMA with the minimum amount of fuel thus minimizing carbon emissions.

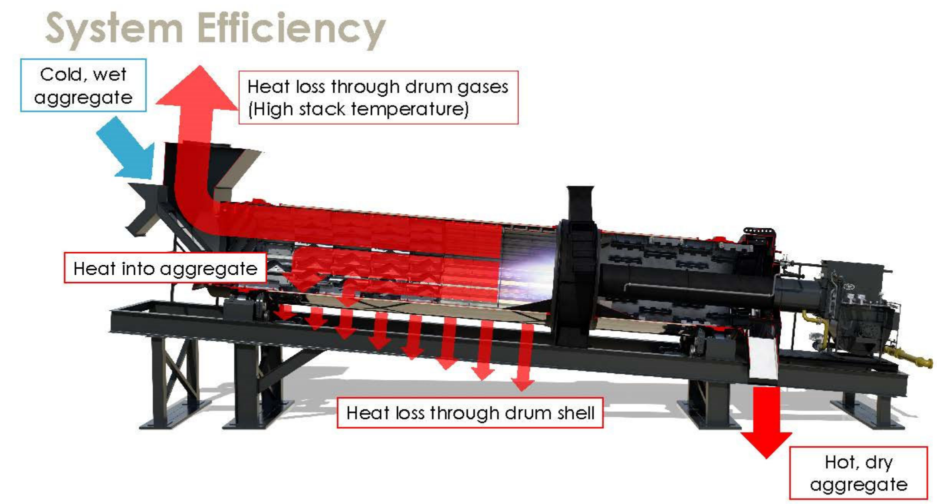


FIGURE 8 Most heat going into aggregate.

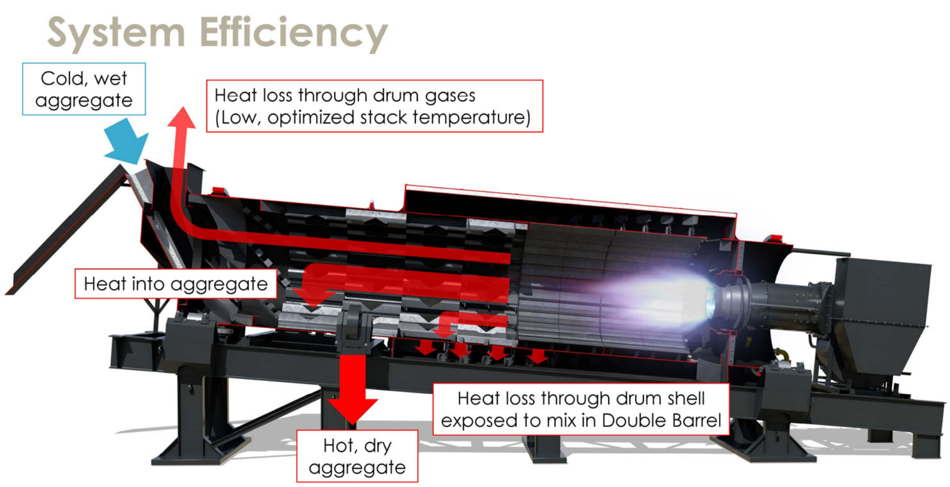


FIGURE 9 Minimizing heat that bypasses aggregate.

An asphalt plant aggregate dryer has several heat transfer challenges. Some combinations of aggregates have more surface area than others. Since heat transfer occurs through surface area, the mixes with less surface area make heat transfer much more difficult. In fact, the heat from the burner will bypass low surface area aggregates and exit the plant in the form of hot stack gases. When this happens dryer efficiency suffers and the carbon emissions per ton of asphalt increase.

Another challenge occurs when the showering flights inside the dryer are not as full due to either a lower production rate, or a higher percentage of RAP being used. The higher the percentage of RAP, the less virgin aggregate there is inside the aggregate dryer (Figure 10). Also, when running RAP, all of the energy is transferred to the virgin aggregate, and this extra energy is shared with the RAP later in the plant process. In the past, the only way to improve dryer efficiency for these challenging conditions was to physically go inside the dryer and modify the internals. Success was often marginal, and even when one mix got the desired effect, another mix might be adversely affected.

Variable frequency drive (VFD) Technology is now used to slow down or speed up electric motors Figure 10). With a rotary aggregate dryer, a higher rotational speed allows more heat to go into the challenging combinations of aggregates, and a lower rotational speed will allow more heat to bypass the aggregate which is needed with some high surface area mixes.

By combining optimized aggregate veiling flight geometry, VFD technology, and plant controls, it is possible to optimize the thermal efficiency of each mix or combination of aggregates.

For every 60°F change in the temperature of the gases exiting the drum, commonly called the “stack temperature,” the maximum production rate will be affected by approximately 10%, and the fuel will be affected by 4% (Figure 11). If the stack temperature is 60°F hotter than necessary, the plant production will decrease by 10 % and the fuel required will increase by 4%. Neither is very “green.” But alternatively, if VFD technology is used to decrease the “stack temperature,” the plant can produce more mix in a day, and each ton of mix will require 4% less fuel. VFD technology can be used to significantly reduce the carbon emissions of an asphalt plant.

The equations known as the “fan laws” mathematically describe how much the flowrate, static pressure, and power required changes as the speed (rpm) of a centrifugal fan changes. Basically, the fan output (cubic feet per minute) changes linearly with the fan speed (rpm), the pressure changes as the square of the fan speed, and the power changes as the cube of the fan speed.

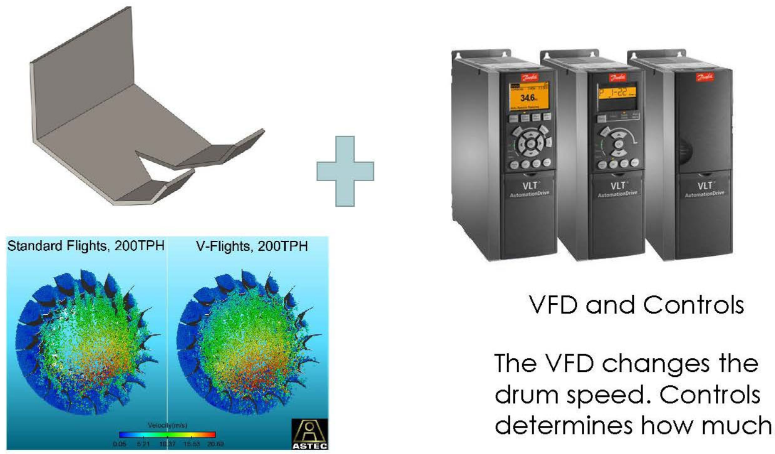


FIGURE 10 Stack temperature control.

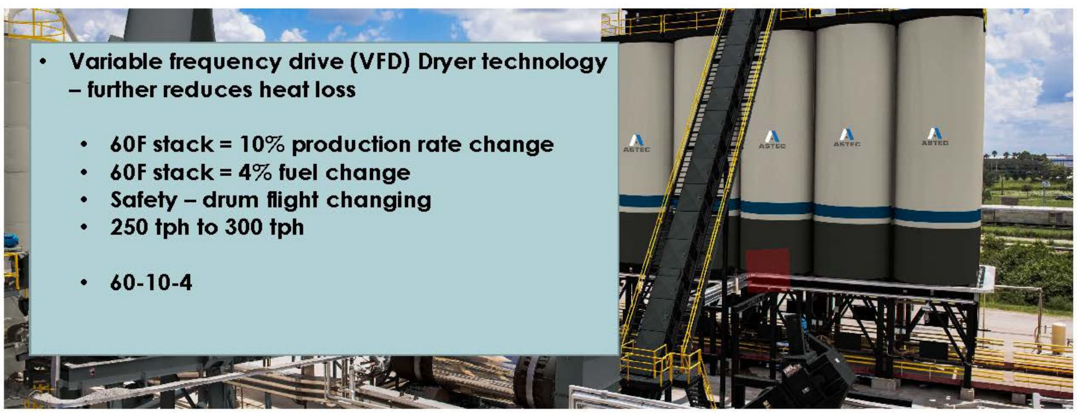


FIGURE 11 Asphalt plant current technology.

For example, if a centrifugal fan is running at 80% output because that is all that the process requires, the power consumption is reduced 50%. This is a common occurrence on a baghouse exhaust fan, and burner fan (Figure 12).

If the fan speed is reduced to 50% of the maximum design speed, the power consumption is only 12.5% of that required at full fan speed. This is also a common occurrence when producing at lower production rates or with low material moisture.

There are also several other benefits of using VFD technology to modulate fan output instead of using an outlet damper.

Depending on how utility-supplied electricity is generated (natural gas, nuclear, coal, wind, solar, hydro) many plant components can use electric heat instead of hot oil to reduce the carbon footprint. The illustration lists plant components that are currently available with electric heat (Figure 13). If the electricity is produced from "clean" sources, there will be an actual reduction in the carbon footprint. If the utility electricity is produced from coal or another hydrocarbon, the carbon footprint hasn't really been reduced, it has just been moved to another location.

There are many places on a typical asphalt plant that should be insulated in order to prevent energy (heat) from escaping to the atmosphere (Figure 14). This will become more important as producers look to pick all the "low hanging fruit." Every Btu that escapes the plant process increases the energy required to produce a ton of asphalt mix. Components on the liquid asphalt tank farm should definitely be insulated since the tank farm is typically heated around the clock, seven days a week during the production season. The dryer "guzzles" fuel, but only when mix is being produced. The liquid asphalt tank farm "sips" fuel all of the time.

- **Energy savings:**
  - Baghouse exhaust fan **(80% speed = 50% energy)**
  - Burner fan **(50% speed = 12.5% energy)**
  - Much less noise – less worker stress – happier neighbors

FIGURE 12 Variable speed drives: What are they good for?

FIGURE 13 What can be done now?

- AC tank farm → Yes!
- AC piping → Yes!
- Pipe flanges → Yes!

Jacketed Asphalt Piping					
Asphalt Pipe Nominal Size	Hot-Oil Jacket Nominal Size	Loss Per Linear Foot BTU Per Hour		Loss Per Flange BTU Per Hour	
		Un-insulated Jacket	Insulated Jacket	Un-insulated	Insulated
3 inches	4 inches	1598	86	1890	120
4 inches	6 inches	2349	122	2600	134
5 inches	8 inches	3057	148	3240	178

Hot Oil Piping				
Pipe Diameter	Loss Per Linear Foot BTU Per Hour		Loss Per Flange BTU Per Hour	
	Un-insulated	Insulated	Un-insulated	Insulated
1-1/2 inches	676	47	1205	97
2 inches	846	54	1660	115
2-1/2 inches	1024	55	2155	125
3 inches	1243	72	2485	130

FIGURE 14 Insulating your plant.

Electrically heated products provided by most manufacturers include vertical AC tanks, horizontal AC tanks, and thermal fluid heaters. An additional component is the aggregate dryer. A typical 400 tph asphalt plant will have a 100 million Btu per hour burner. And 100 million Btu per hour converted to more familiar units, such as HP (horsepower), is 39,300 HP. The enormous electrical power required to supply that amount of energy make an electric dryer impractical at this point.

Since everything that gets hot on the asphalt plant allows energy to escape, should every surface above a given temperature be insulated? It depends. There are some things that get very hot that should be insulated, and there are some very hot things that perhaps shouldn't be insulated without careful consideration (Figure 15).

The drum on the left in Figure 16 is shown as a thermal image. Each color represents a different temperature. The maximum temperature shown in 842°F. One might assume that that drum should be insulated, but the following details are unknown:

- The maximum drum temperature at different firing rates.
- The maximum temperature while running different mixes.
- The drum shell material.
- The maximum operation temperature of the drum shell material.

The following are known:

- If the drum is insulated, it will get even hotter.
- If the drum is insulated, it will be impossible to measure the shell temperature.
- If the drum is insulated, it will be impossible see early signs of heat damage.

In consideration of these facts, the drum should not be insulated without collaboration with the equipment manufacturer.

FIGURE 15 Consider what can be done now.

FIGURE 16 Insulating your plant.

Should the plant duct work carrying gases from the drum to the baghouse be insulated? Probably not since the temperature of the dust is low, and radiation is low when the temperature is low.

Should the baghouse be insulated? The heat loss is not great, but an insulated baghouse can theoretically operate at a lower inlet gas temperature, so insulation on a baghouse could provide some energy savings.

Proper tuning and adjustment of plant components, such as the aggregate dryer burner, is important. Proper operation of asphalt plant subsystems (a team of components) such as the aggregate dryer system (burner, rotary dryer, exhaust system) is arguably even more important. The most important aspect of reducing the carbon footprint (making the most mix with the least amount of fuel) has to do with the entire plant operation.

The more continuously (minimal stops and starts) a continuous plant is operated, the less fuel is required for a day's production (Figure 17). Having adequate surge capability is necessary in order to keep the plant running while the haul trucks are returning to the plant.

Planning and communicating with customers (internal and external) about the next day's production needs can allow for much more efficient plant production. Efficient plant operation will result in a significantly lower carbon footprint.

This empirical information illustrates how important it is to plan the day's production without any unnecessary stops and starts (Figure 18).

FIGURE 17 Efficient plant operation: What can be done now?

FIGURE 18 Plant efficiency: operation.

The average RAP use in the USA is approximately 21%. Most producers are limited by RAP availability and specifications. Successful pavements with a high percentage of RAP have been designed, produced and placed for over 35 years (Figure 19). Current plant technology can produce quality mixes with high percentages of RAP. It is imperative that the mix specifications that limit RAP be examined and revised. Also necessary are common-sense specifications that ensure that producers produce high percentage RAP mixes using the necessary equipment (i.e., multiple RAP bins) and best practices (i.e., stockpiling, fractionization above 25% RAP, training, and mix design).

Some areas have almost no RAP and some other areas have millions of tons of excess RAP (Figure 20).

For the areas that have more RAP that can be used producing hot mix/warm mix, there is a product that the excess RAP can be used to produce. This product is called CCPR (Cold Central Plant Recycling) (Figure 21). It is approximately 97% RAP product that uses no heat energy.

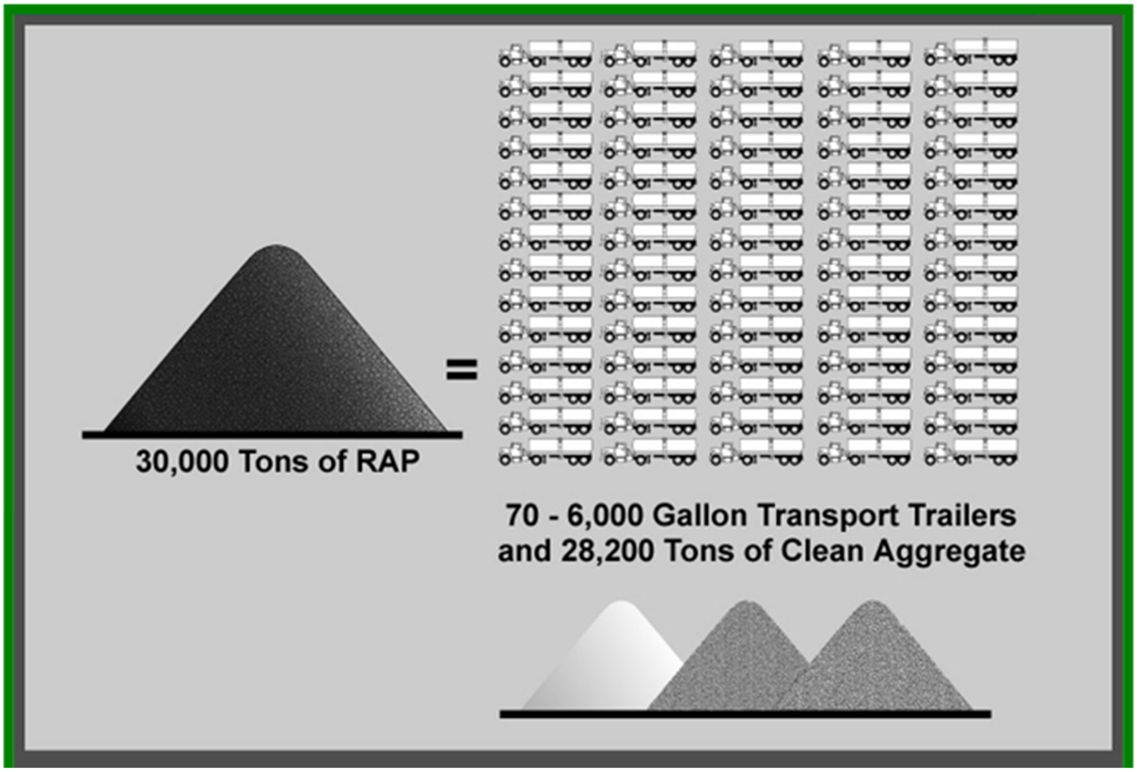


FIGURE 19 RAP Is worth the virgin material it replaces.

Even with aggressive recycling excess RAP is a growing situation in urban areas

FIGURE 20 Excess RAP is an urban issue.

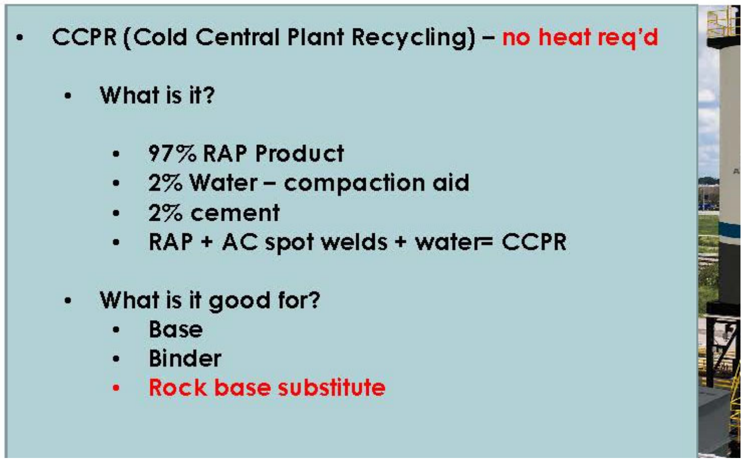


FIGURE 21 Cold central plant recycling: What can be done now?

It has been successfully tested and used on the NCAT Test Track as well as Interstate Highways (I-81 and I-64 in Virginia) as a base and binder layer. It is also a replacement for stone base in a parking lot application. In fact, 5 inches of CCPR can replace 8 inches of stone base. It is made from blending fractionated RAP with 5% free moisture (compaction aid), approximately 2% (or less) foamed liquid asphalt, and if required, a small percentage of dust. The moisture, dust, and foamed asphalt combine to form millions of tiny binder globules that "spot weld" the RAP particles together.

There are technologies available (foam and chemical) that allow hot mix to be made at significantly reduced temperatures (Figure 22). Reducing the mix temperature 50°F reduces the energy required (reduces carbon output) by a theoretical 11%. Some producers report higher savings. Mix made with these technologies can be hauled further and still be compactible, stores better (less oxygen in the voids for oxidation), oxidizes less during production, and does not produce smoke or odor.

Unfortunately, for many, smoking hot mix is the paradigm for what "good" mix looks like. The change will require education and specification. The sooner this industry moves toward warm mix the better. Figure 23 shows the difference in the load out emissions of mix made at typical temperatures compared to warm mix made at approximately 275°F.

At 5% aggregate moisture, just over 50% of the aggregate dryer fuel is used to remove moisture from the aggregate (Figure 24). Small reductions in aggregate

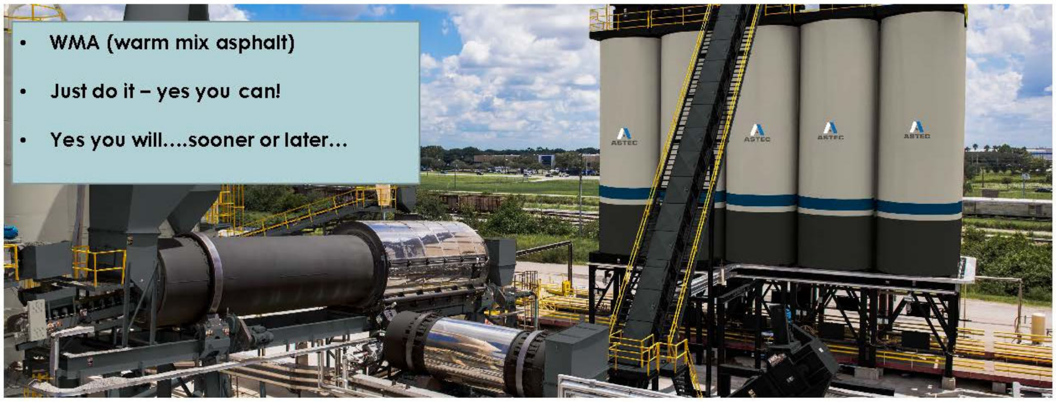


FIGURE 22 WMA: What can be done now?

FIGURE 23 Who is in charge?

FIGURE 24 Existing technology: operations.

moisture result in a significant reduction in fuel usage and the carbon footprint. Also, a small reduction in moisture will allow a significantly higher production per day.

In the United States, especially east of the Mississippi River, it makes sense to either pave and slope the stockpile area or cover the stockpiles as shown. In areas of the world that have much higher fuel costs, this is the norm. As carbon reduction goes from talk to action, this is something many producers should consider.

These bar graphs illustrate how currently doable cumulative changes in the plant operation can have a large impact on the plant (A3) carbon footprint (Figure 25).

- Scenario 1 is the base condition. The plant is burning No. 2 diesel fuel.
- Scenario 2 shows a 9% reduction for switching to natural gas.
- Scenario 3 shows a 20% reduction for using natural gas, paving and sloping the stockpile area, and making half of the mix produced at a lower temperature.
- Scenario 4 shows a 26% reduction for using natural gas with a 20% hydrogen blend, paving and sloping the stockpile area, producing all warm mix.

By making a few changes to how current plants are operated, significant reductions in the carbon footprint are possible.

The asphalt plant of the future in the United States might look something like what is shown in Figure 26. Everything is inside a building, including the stockpiles. As residential areas are located closer and closer to asphalt plants, there is a greater need than ever for the production facility to be a good neighbor (no smoke, no odor, no fugitive dust, and no sound). In addition to being a good neighbor, an asphalt production facility that looks more like a warehouse (big box) or such, is much more likely to be accepted.

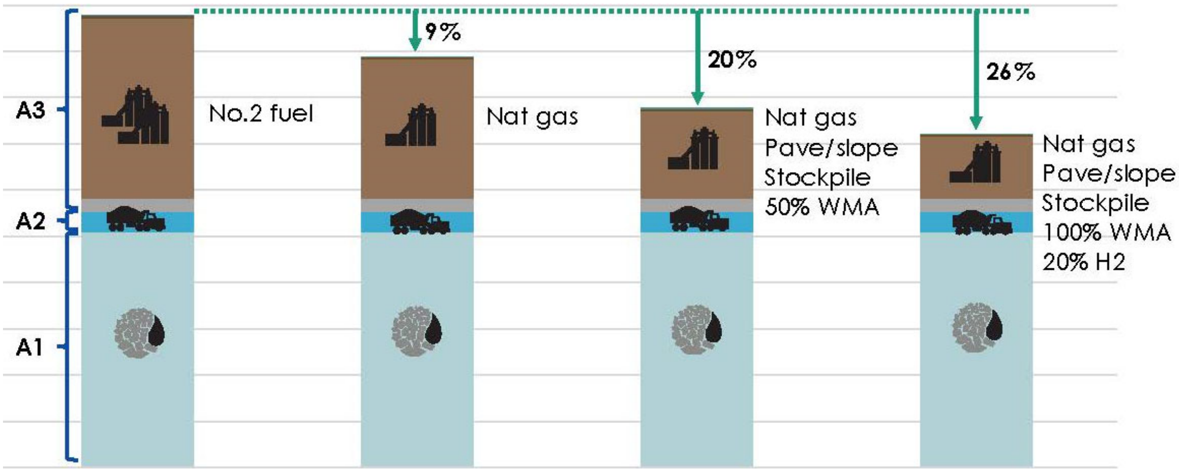


FIGURE 25 Cumulative changes to reduce carbon footprint.

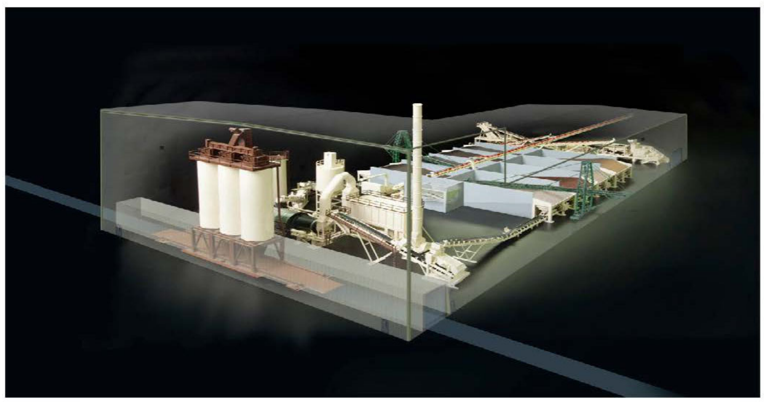


FIGURE 26 Covered indoor facilities.

We can safely predict that the low carbon plant of the future will have the following characteristics:

- Mixes made at reduced temperatures.
- Multiple RAP feed bins.
- Fractionated RAP.
- Alternative fuels.
- Less environmental impact.
- Better neighbors.
- Will use the latest technology to lower the carbon footprint.
- High quality, high percentage RAP mixes.

Reducing Greenhouse Gas Emissions from Asphalt

Contractor Perspective

CHENG LING
Pike Industries, A CRH Company

This presentation discussed how to reduce the greenhouse gas emissions (GHG) from asphalt specifically from an asphalt contractor's perspective. It covers the background information about the Buy Clean Policies status and asphalt EPD, lists out the key drivers and improvement opportunities for asphalt contractors, and presents the research and implementation needs for asphalt industry to reduce the carbon emissions (Figure 1).

Figure 2 is a snapshot of the Buy Clean Policies status at the state level (as of January 2024) which was taken from the FHWA sustainability website (1). Several states have already legislated Buy Clean Policies for transportation materials that use EPDs, including Oregon, California, Colorado, and Minnesota, along with recent additions from the states on the East Coast such as Maryland, and New Jersey. The state of New York also announced its "Buy Clean Concrete" mandate through the governor's executive order in late September 2023, with the specific requirements yet to be determined. Besides, there have been several other states that have considered such policy or legislation over the last couple of years, including Washington, Missouri, Illinois, Virginia, Delaware, and Massachusetts.

FIGURE 1 Presentation outline.

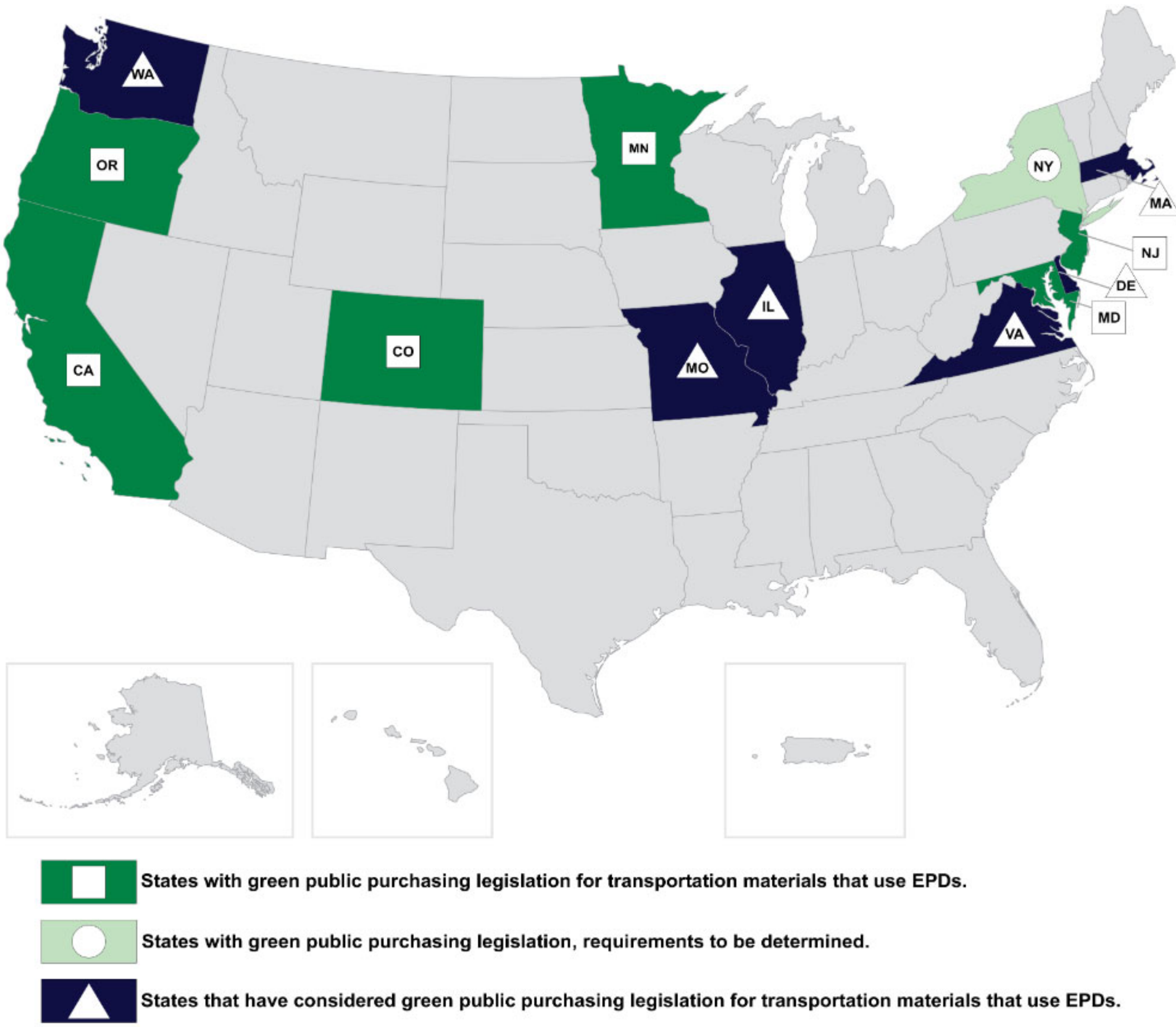
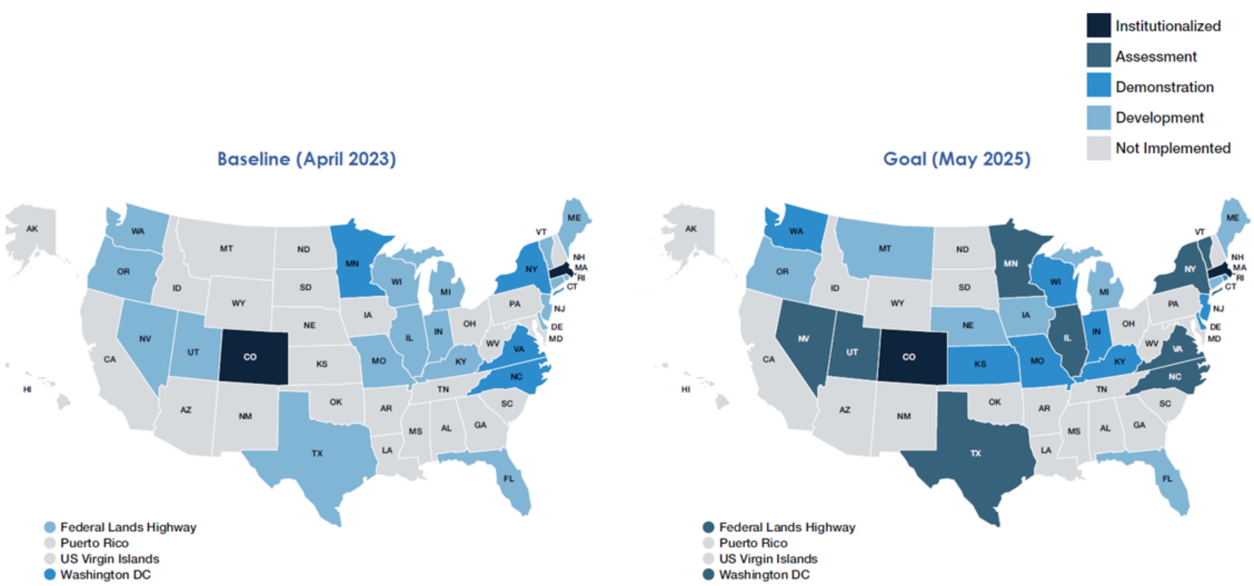


FIGURE 2 Snapshot of the Buy Clean Policies status at the state level.

According to the recently published Every Day Counts—7 (EDC-7) Summit and Baseline Report by FHWA (2), there are just three states (as of April 2023) that are under the demonstration, assessment or institutionalization of EPDs for sustainable project delivery with Colorado leading across the country joined by Minnesota and New York (Figure 3). There are 19 states that have already set the goal to demonstrate, assess or implement the EPDs by May 2025, according to the report.



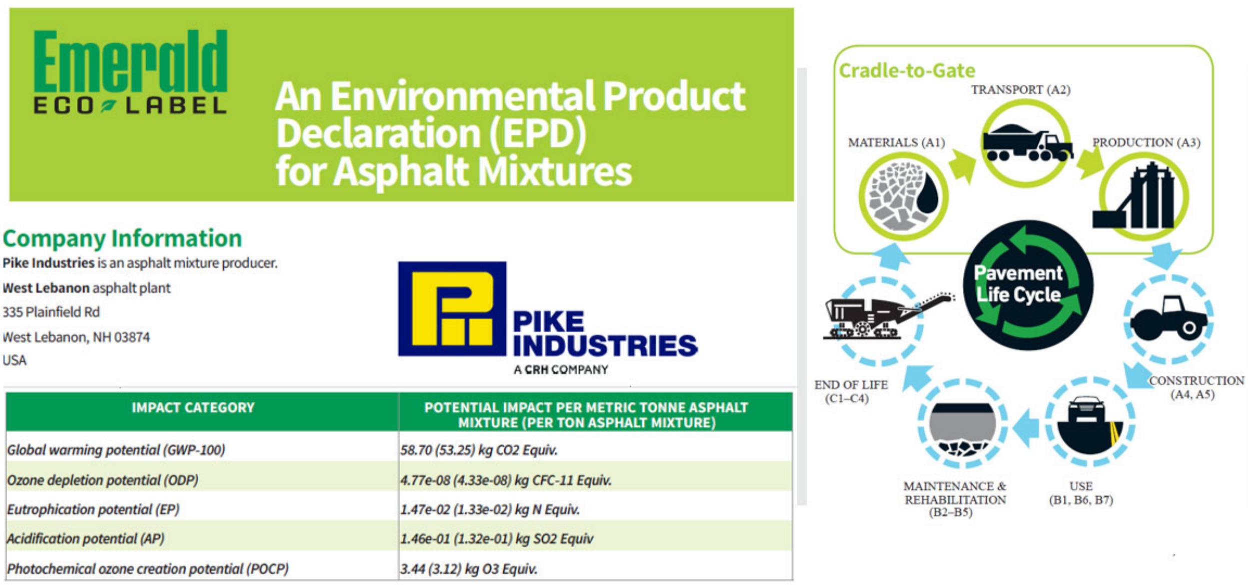
EDC-7 Summit Summary and Baseline Report by FHWA, May 2023

FIGURE 3 EPDs for sustainable project delivery.

An EPD for a typical mix produced out of an asphalt plant created using NAPA's EPD tool, lists five different types of environmental impacts including Global Warming Potential (GWP-100), Ozone Depletion Potential (ODP), Eutrophication Potential (EP), Acidification Potential (AP) and Photochemical Ozone Creation Potential (POCP) (Figure 4). The current focus for the industry is primarily on GWP; however, it should be noted that the asphalt mix EPD scope is limited to cradle-to-gate for now, which means that only Materials (A1), Transport (A2) and Production (A3) stages are included. Other stages such as Construction (A4, A5), Use (B1, B6, B7), Maintenance & Rehabilitation (B2-B5), and End of Life (C1-C4) are not currently included and have been identified as data gaps.

NAPA is the program operator of asphalt mix EPD in the United States and Figure 5 shows a snapshot of NAPA's web-based Emerald Eco-Label Tool which asphalt producers and contractors can use to create EPDs for their mixes after purchasing the license (3). Another great function that comes with the EPD tool is the Optimizer which the user can use to check the effects of different variable changes on the numbers listed on EPD. All published EPDs are available to the public on this website as well.

As of January 2023, there had been over 400 mixes with published EPDs out of 70 plants and 25 states (4). The numbers have likely gone up drastically since then due to the significantly increased interest from government agencies and industry. NAPA has also been working on developing an educational version of this program to be used by academia and research institutions, which will be rolled out possibly in late 2024.



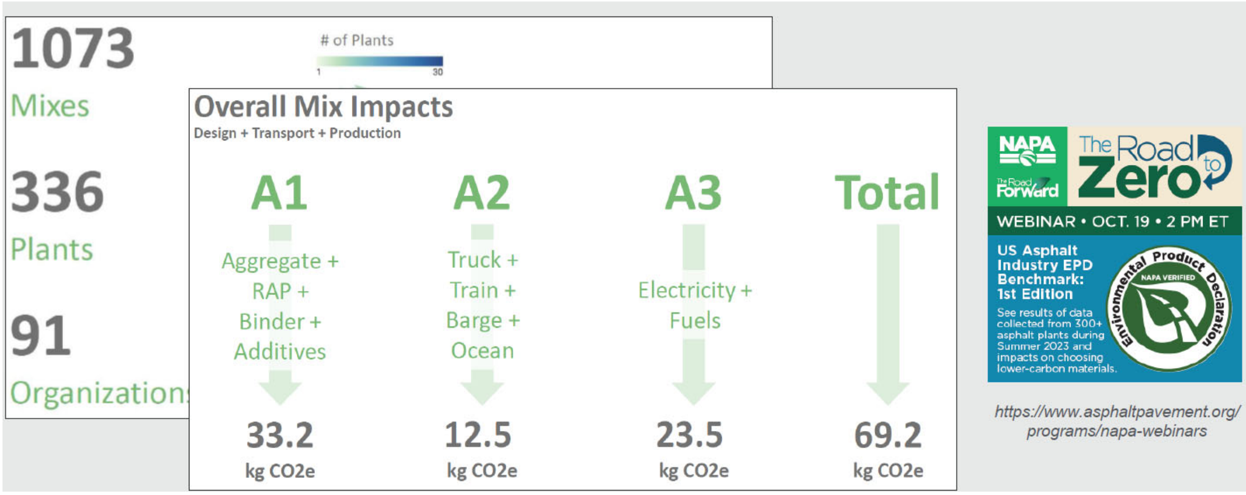
IMPACT CATEGORY	POTENTIAL IMPACT PER METRIC TONNE ASPHALT MIXTURE (PER TON ASPHALT MIXTURE)
Global warming potential (GWP-100)	58.70 (53.25) kg CO2 Equiv.
Ozone depletion potential (ODP)	4.77e-08 (4.33e-08) kg CFC-11 Equiv.
Eutrophication potential (EP)	1.47e-02 (1.33e-02) kg N Equiv.
Acidification potential (AP)	1.46e-01 (1.32e-01) kg SO2 Equiv
Photochemical ozone creation potential (POCP)	3.44 (3.12) kg O3 Equiv.

FIGURE 4 Asphalt EPD and its scope.

FIGURE 5 Snapshot of NAPA's web-based Emerald Eco-Label Tool.

In early 2023, NAPA launched the first nationwide benchmarking effort for asphalt mix EPDs for the asphalt industry to get a good understanding of where the national average stands (Figure 6). The effort was quite successful, and the preliminary results were released at the 2023 NAPA Midyear Meeting (5). NAPA was able to collect data from over 1,000 mixes out of 336 plants across 91 organizations and companies. The total average from A1 to A3 for asphalt mix is 69.2 kg CO_2e per ton, with 33.2 kg from A1, 12.5 kg from A2, and 23.5 kg from A3 (5). It was also found that the total average as well as the number in each stage varied from state to state and region to region. Therefore, this preliminary data should not be used directly by any state or local agency when attempting to establish the thresholds for their policies or specification regarding low carbon materials. In late 2023, NAPA held a webinar to go over further details about the benchmarking effort, and the webinar recordings can be found on NAPA's website (6).

The next few figures present some key drivers and improvement opportunities for asphalt contractors. Figure 7 provides a list of key drivers in reducing the GHG from asphalt. At the materials (A1) stage, the total binder content and the recycled binder content determine the virgin binder demand which is the highest CO_2 generator in the asphalt mix. Recycled aggregate could play a significant role, especially in aggregate-poor states and regions. At the transport (A2) stage, the haul distance of ingredient materials such as binder, aggregates, and recycled materials can have a significant impact as well. At the production (A3) stage, there are mainly two key areas affecting the GHG emissions from asphalt. The first one is about Btu consumption, which is directly related to the moisture control on the stockpiles and production temperature at the plant. The other key area is about the burner fuel, specifically on the fuel type and heating efficiency as well as plant insulation. Some of these key drivers are relatively controllable by contractors such as those highlighted in green in Figure 7. Others may be controllable to a lesser degree including the materials haul distance and fuel type. However, this may not apply to all, and each asphalt contractor should evaluate their local mixes and operations to determine their impacts.



Source: "Building A Better Benchmark" by WAP Sustainability Consulting, 2023 NAPA Midyear Meeting

FIGURE 6 NAPA's benchmarking effort.

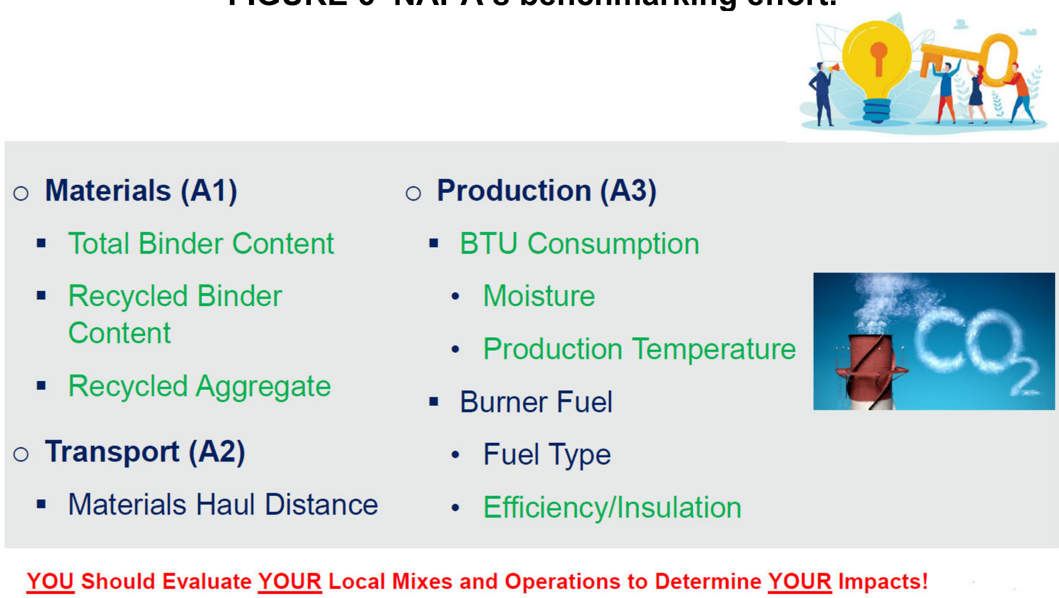


FIGURE 7 List of key drivers.

Isolated variable changes related to a base case can impact the GHG from asphalt (Figure 8). The base case is a mix with 5.0% total binder content, 20% RAP with 5% residual binder, and no RAS (reclaimed asphalt shingles). The average aggregate haul distance is around 20 miles. The plant production temperature is about 310°F. The average stockpile moisture is 5%. Natural gas is used as the primary source of fuel. On the left side of the figure in Figure 8, those green bars represent better scenarios, while on the other side of the figure, those red bars represent worse scenarios. For example, by changing the aggregate haul distance from 20 miles to 1 mile (basically using the locally sourced aggregates), the GHG emissions would be reduced by 1.98 kg CO2e per mix ton. By increasing the RAP by 5%, one would see a decrease of emissions by 1.79 kg. By lowering the moisture content in the stockpile by 1%, the emissions would be reduced by 1.47 kg. On the other side, if natural gas is not available and has to be replaced by propane, the GHG emissions would increase by 2.61 kg. The number could go even higher if No.2 oil is used, which would be an increase of 5.56 kg. If no suitable aggregates are available within a 20-mile radius and the producer must haul the aggregates from 50 miles away, the emissions would increase by 3.14 kg. Note these are just some cases of how different variables can impact the GHG emissions from asphalt based on example data.

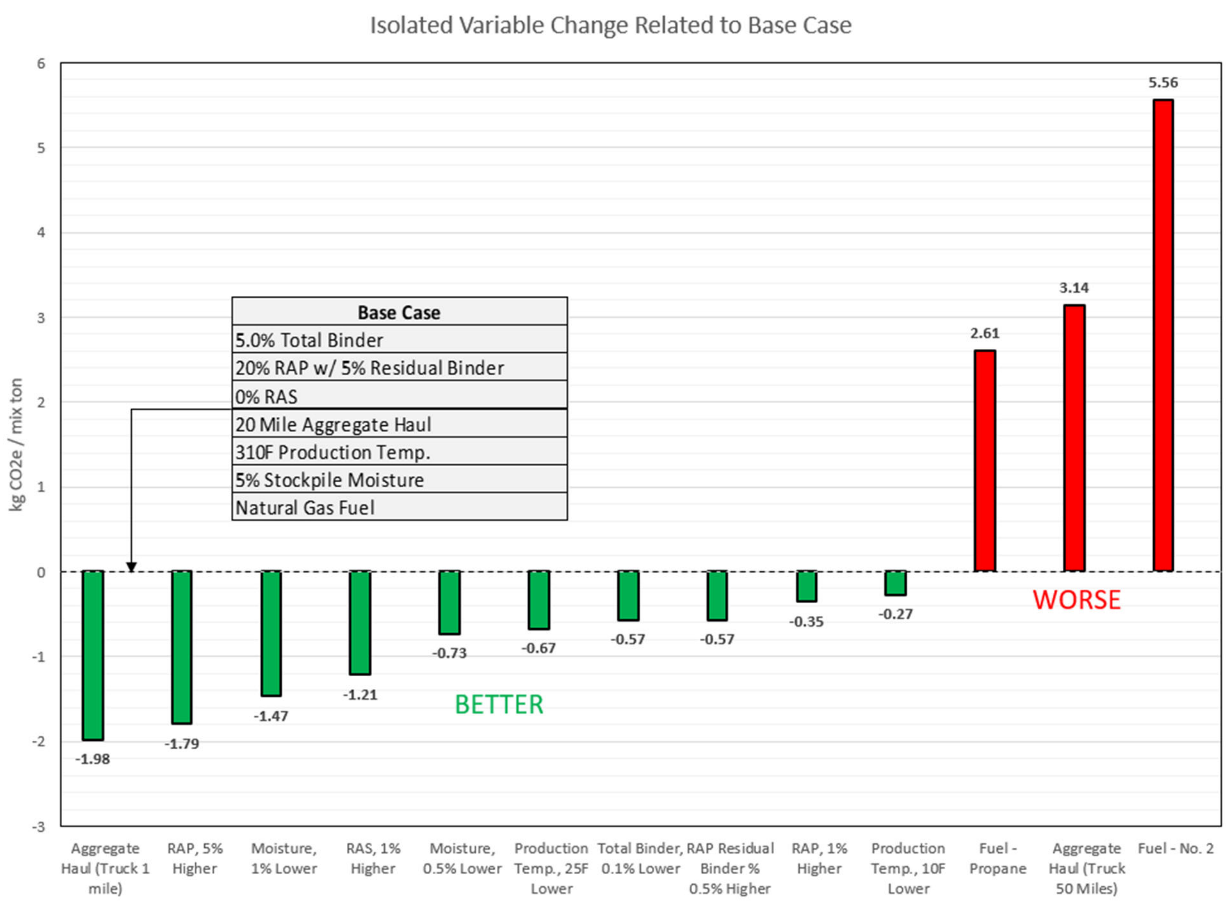


FIGURE 8 Isolated variable changes related to base case.

Let's take a further look at a couple of key drivers at each of the three stages included in asphalt mix EPD scope and what the improvement opportunities are for asphalt contractors. At the materials (A1) stage, the increased use of recycled asphalt materials can significantly reduce the emissions. As Figure 9 shows, by increasing the RAP from 20% to 40% in the example mix, the GHG emissions are reduced from 51.51 to 43.62 kg CO2e per mix ton, with most of the reduction coming from A1 due to the replacement of virgin binder and aggregates by RAP). That said, each 1% RAP can result in an impact of about 0.35 kg CO2e per mix ton.

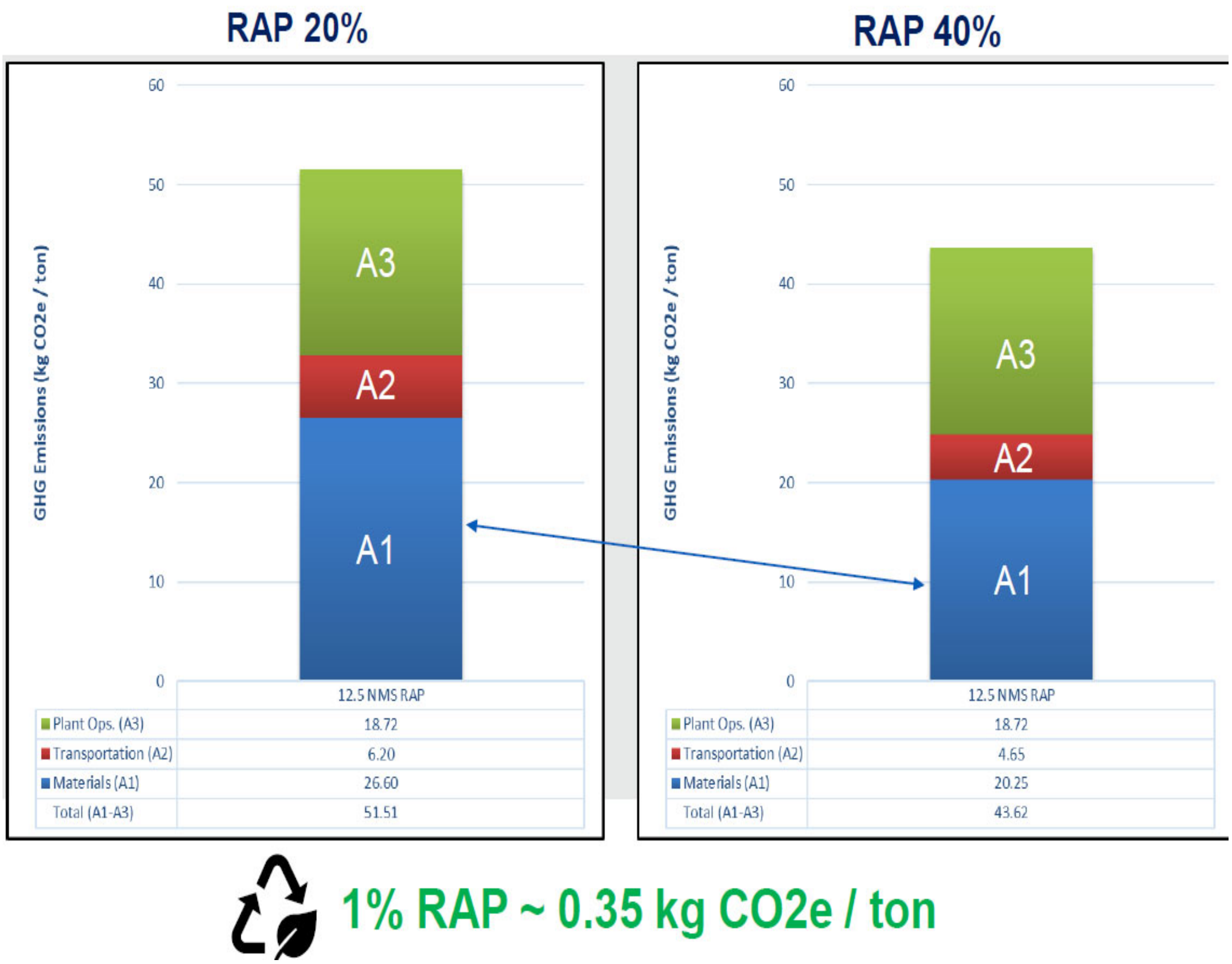


FIGURE 9 Key drivers at materials stage.

As we understand such impact, what can asphalt contractors do to leverage the opportunity? First, asphalt contractors should always maximize the addition of RAP or RAS, especially on nonagency mixes, and take advantage of rejuvenator use to balance off the high stiffness and other effects caused by aging within the recycled materials (Figure 10). Second, contractors should maximize the residual binder in the recycled materials through better RAP management and processing and the use of finer grind size on RAS. Third, plant modifications should be considered and assessed (e.g., increasing the recycle bins, changing the flight design, switching the drum type, and increasing the RAP collar size) to accommodate higher recycle use at the plant. The contractors should also strive to limit the moisture content in the RAP and work proactively with agencies toward favorable specifications.

Another key factor affecting the GHG emissions is the virgin binder demand. Contractors should right size the total binder in the mixes, and especially avoid overdesigning the VMA (voids in mineral aggregate), as every 0.25% VMA equals about 0.1% binder which could have an impact of 0.57 kg CO_2e per ton of mix (Figure 11). Contractors should also consider asphalt absorption when selecting aggregates, if possible, as by comparing an aggregate blend with 1% absorption versus another with 0.75% absorption; such 0.25% difference in absorption can cause a difference of 0.72 kg CO_2e in emissions.

At the transport (A2) stage, aggregate sourcing and transport can sometimes have a significant impact on GHG emissions from asphalt, especially in the aggregate-poor states and regions like Florida and Louisiana. Below is an example from NAPA's first report of Life Cycle Assessment of Asphalt Mixture in Support of an EPD (7), showing the impact of the aggregate trucking distance (four orange bars on the left in the figure) and haul type (four orange bars on the right) (Figure 12). It should be noted that while locally available aggregate use reduces the CO_2e impact, the mix and pavement performance must be achieved.

FIGURE 10 Recycle levers.

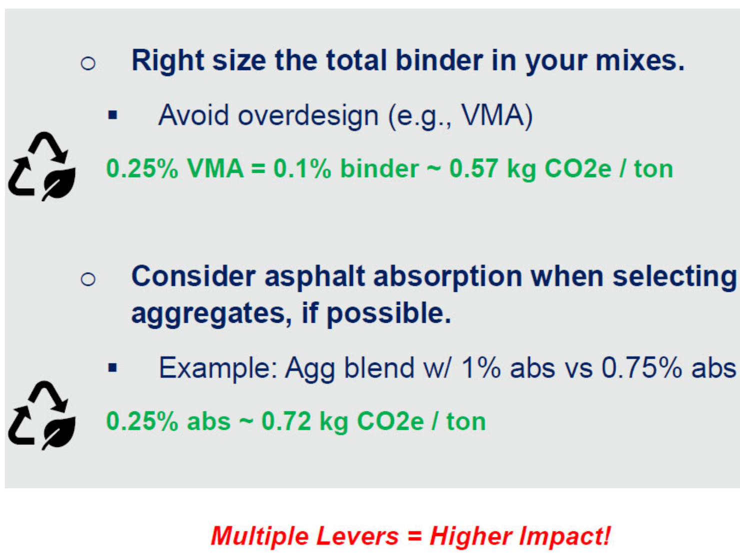


FIGURE 11 Binder demand levers.

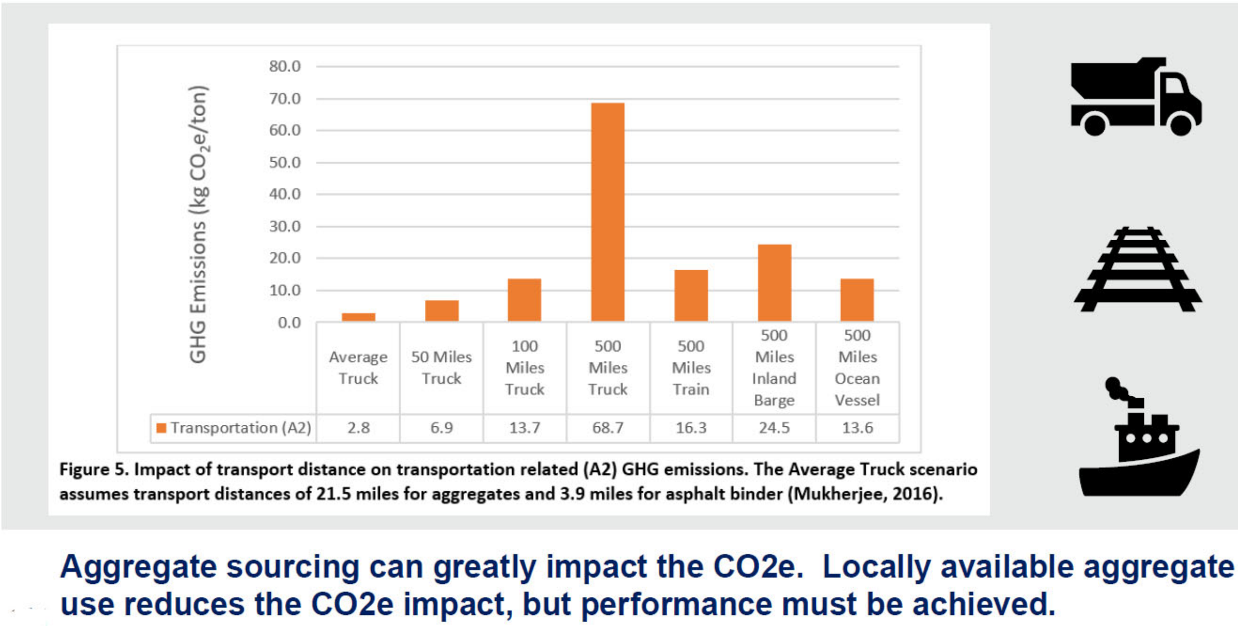


FIGURE 12 Aggregate transport impact.

At the production (A3) stage, stockpile moisture is one of the most significant factors influencing the emissions from asphalt. The rule of thumb is that every 1% moisture reduction can result in a decrease of 11% in Btu consumption, and an increase of 11% in production rate. There are multiple levers that the contractors could utilize, including using paved and sloped stockpile areas, building covered stockpiles, implementing loadout best practices (especially on raising the bucket up and loading out from the high side), and watching closely on aggregate supply management to prevent the wet materials from being shipped (Figure 13). Good communication between asphalt contractors and aggregate suppliers goes a long way in the stockpile management.

Plant production temperature is another key driver affecting GHG emissions at the production stage. The asphalt contractors should assess and determine if a lower temperature is achievable at each of their plants by asking themselves the following questions:

- Is the production temperature too hot?
- Has the temperature “creeped” up over the years?

- Do you have a plant foaming device? Are you using your plant foaming device optimally?
- Can you run chemical WMA technologies to drop temperature without undue risks?

Every 25°F temperature reduction can have an impact of 0.67 kg CO2e per ton if using natural gas as the fuel source. The reduction can go even further if using other types of fuel such as propane or residual fuel oil (RFO) (Figure 14).

FIGURE 13 Stockpile moisture levers.

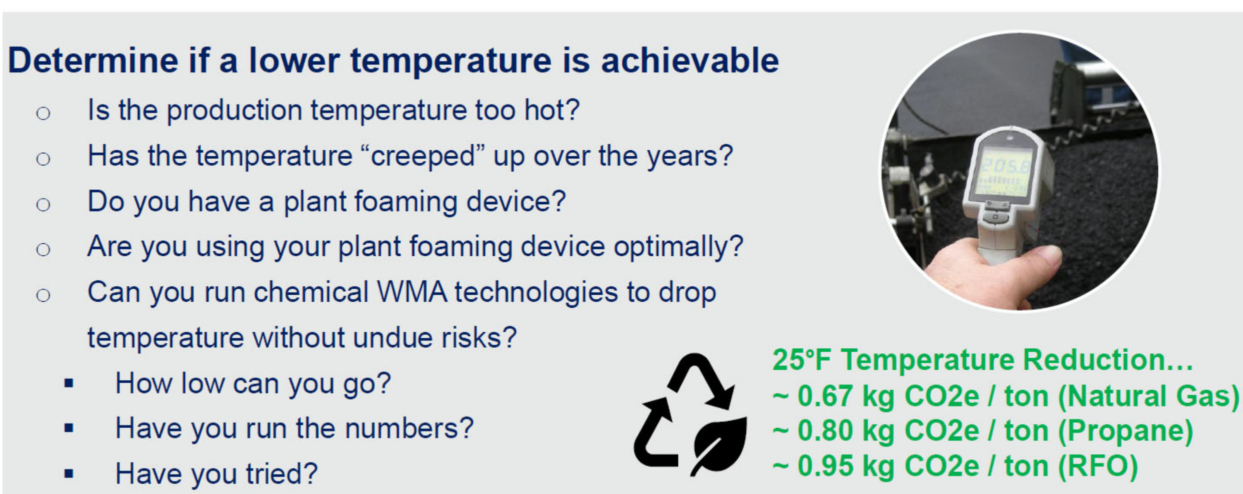


FIGURE 14 Production temperature.

The sustainability impacts of the abovementioned key drivers on GHG emissions, including RAP, binder, temperature reduction and warm mix asphalt, and moisture control are summarized in Figure 15 and Figure 16. A quick summary of these impacts is provided below:

- Every 1% RAP increase can lower the emissions by around 0.35 kg.
- Every 25°F temperature drop can reduce the emissions by 0.67 kg (if using natural gas).
- Every 0.1% binder can have an impact of 0.57 kg CO_2e per mix ton.
- Every 1% moisture reduction can result in a decrease in GHG emissions by 1.47 kg (if using natural gas).

It should be noted that the numbers shown above are just general estimates based on example data. Local conditions will drive actual data.

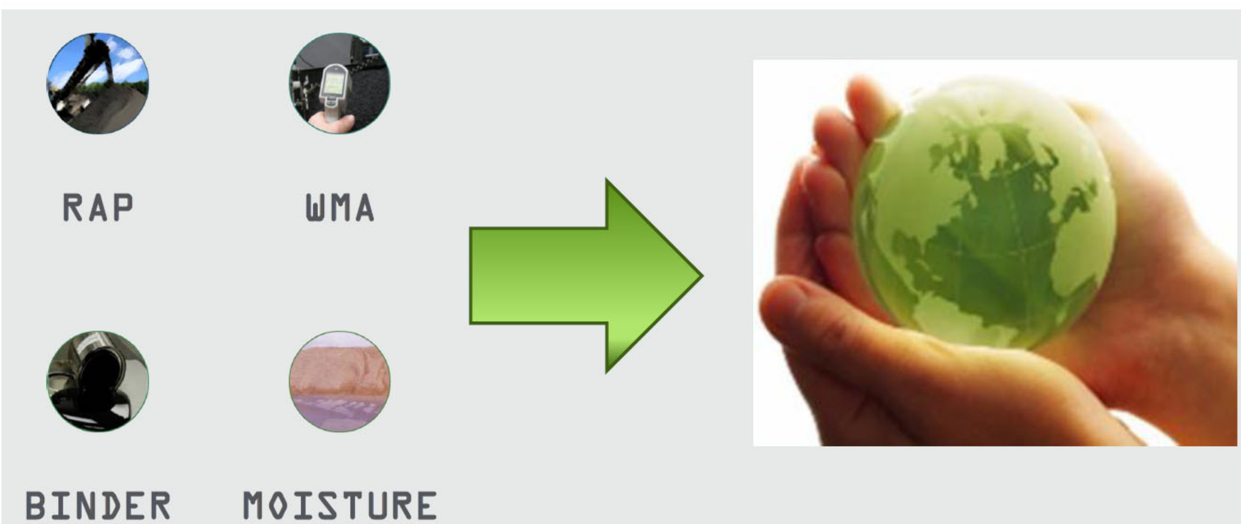


FIGURE 15 Sustainability impacts of key drivers on GHG emissions.

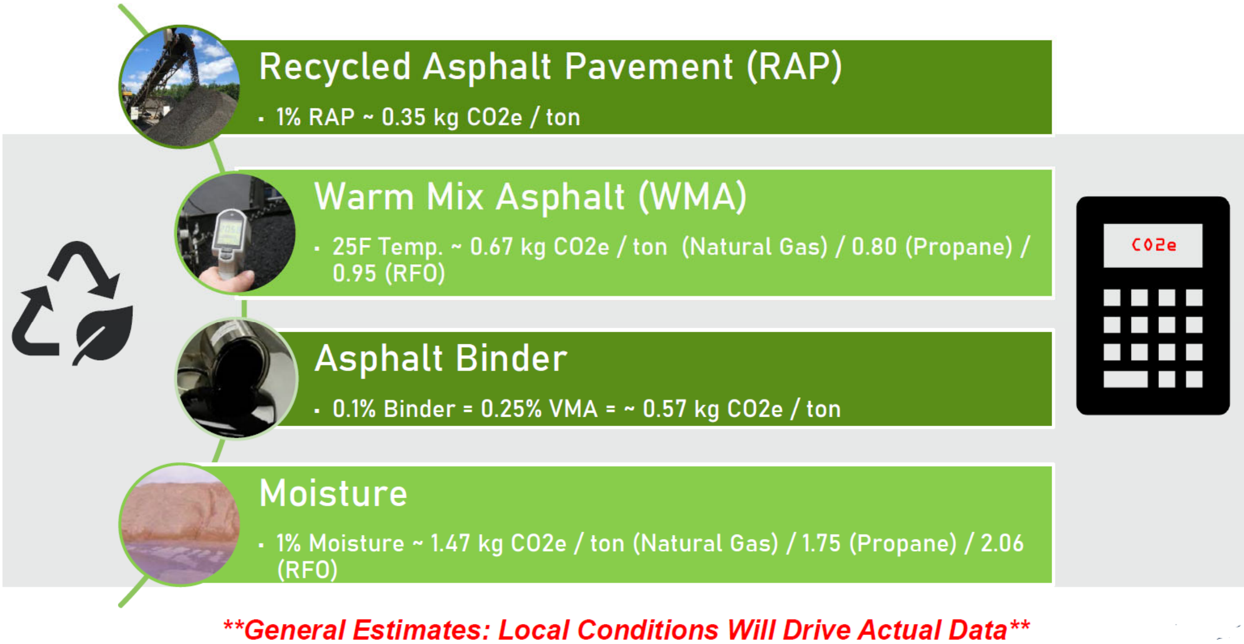


FIGURE 16 Sustainability impacts of key drivers on GHG emissions.

The following figures discuss the research and implementation needs for the asphalt industry. The suggested focus areas on the material side are shown in Figure 17). These include but are not limited to:

- Search new forms of binder and binder replacement, especially around bio-based materials.
- Investigate carbon-sequestering synthetic aggregates, which have been evaluated in the ready mixed concrete industry but not much in the asphalt industry.
- Increase the use of recycled asphalt materials, particularly beyond 40% recycled binder ratio.
- Research the use of other recycled materials such as rubber, glasses, and plastics from the circular economy standpoint.
- Eliminate or reduce the use of hydrated lime, which has been a very carbon intensive material used in asphalt mixes.

- Search new forms of binder and/or binder replacement
- Investigate carbon-sequestering synthetic aggregates
- Increase the use of recycled asphalt materials
- Research the use of other recycled materials
- Eliminate or reduce the use of hydrated lime

https://wiki.opensourceecology.org/wiki/Bio-Asphalt

FIGURE 17 Materials.

The asphalt industry should continue to support and leverage the balanced mix design (BMD) to optimize the ingredient materials in the mix and improve the overall mix and pavement performance (Figure 18). The transportation agencies and asphalt contractors should work together to implement BMD and develop relevant specifications.

On asphalt production, the contractors should continue to develop and implement best practices for better moisture control and evaluate and adopt temperature reduction technologies such as WMA, half warm mix asphalt (HWMA), and cold mix asphalt (CMA) (Figure 19). Contractors should also consider and invest in the plant upgrade for increased use of RAP/RAS and to improve the energy efficiency for asphalt plants. To keep track of the energy use at the plant, contractors are encouraged to take advantage of the Asphalt Plant Energy Performance Peer Exchange (APEX) program developed by NAPA partnered with EPA (8).

Although the construction stage is not currently included in the asphalt mix EPD scope, there are certain things that the asphalt industry could and probably should look at sooner rather than later, such as equipment electrification, roller pattern optimization and intelligent compaction (IC), and eventually toward automated construction (Figure 20).

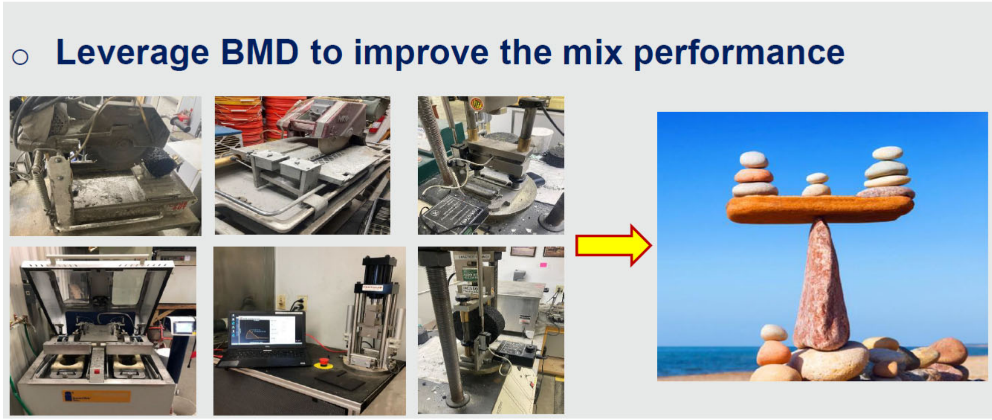


FIGURE 18 Design.

FIGURE 19 Production.

FIGURE 20 Construction.

One of the critical components in reducing the GHG emissions from asphalt is the partnership between agencies and the asphalt industry (Figure 21). A great example of such partnership is the climate challenge program launched by FHWA in late 2020 (9). The program identified more than 35 projects from 27 agencies including 25 state DOTs and two local agencies and provided over $7 million funding along with technical assistance to all these agencies. One of the specific requirements for all applying agencies on these projects is that they should work together with the asphalt industry including asphalt contractors, consultants, and academia. It is anticipated that the outcome of these projects will likely have significant influence on the development of specifications regarding asphalt mix EPDs and other sustainability initiatives at the state and local levels.

There are a couple of key takeaways from this presentation (Figure 22). First, leading practices that save money almost always have a positive sustainability impact, such as reducing aggregate moisture, lowering production temperature, reducing virgin binder demand, increasing the use of recycled materials, using locally available aggregates, and so forth. In addition, sustainability impacts must be considered and included in the decision-making process now and moving forward when conducting cost-benefit analysis, as both economics and sustainability impacts should be weighed.

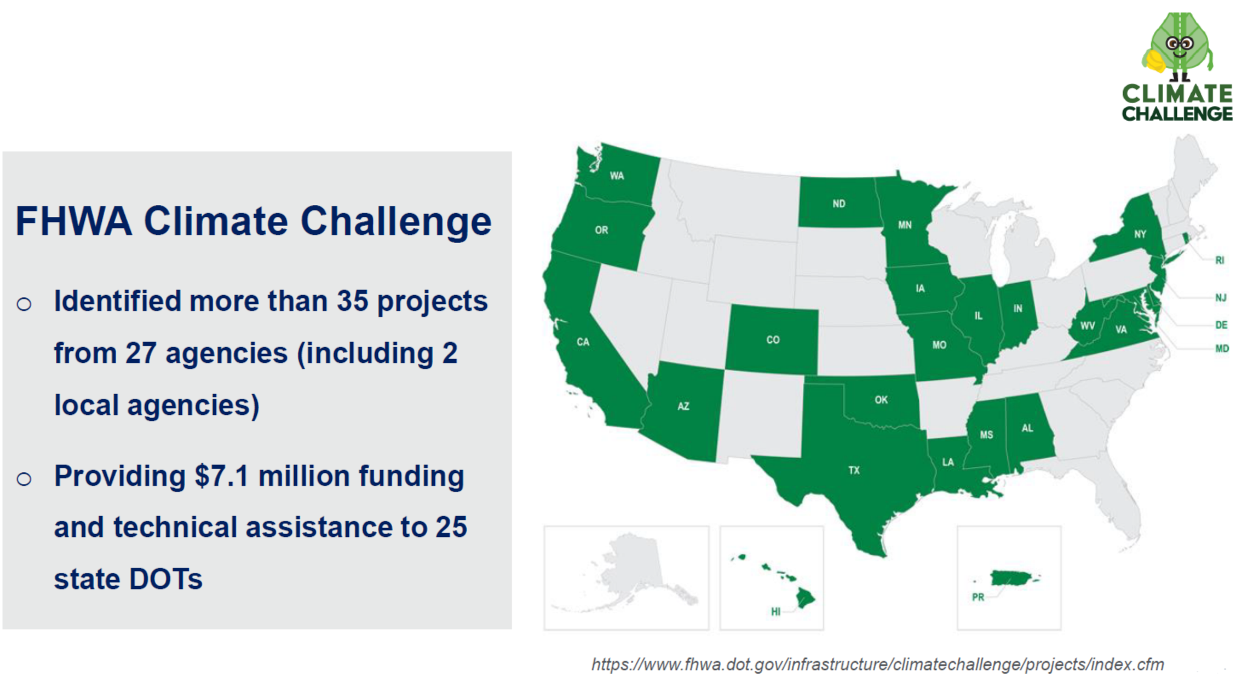


FIGURE 21 Partnering to reduce GHG emissions.

FIGURE 22 Key takeaways.

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Virginia DOT Perspective on Reducing Environmental Impacts of Pavement Rehabilitation

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Virginia Department of Transportation

The following presents a discussion on ways to reduce the environmental impacts of pavement rehabilitation using asphalt mixtures from an agency perspective. Included is a discussion of background information and examples of what a specifying agency might be able to do to reduce these impacts.

Figure 1 provides an incomplete list of potential environmental impacts that could be assessed when considering the impacts of pavement rehabilitation. The impacts of pavements are often quantified in terms of their greenhouse gas (GHG) emissions, ozone depletion, terrestrial acidification, eutrophication, and photochemical ozone creation potential. These terms are often simplified by reporting only the GHG emissions. This reporting process is the result of an LCA.

FIGURE 1 Environmental impacts (Source: circularecology.com).

An LCA is a process that can be used to describe the environmental impact of a product or a process from raw materials extraction to disposal (or end of life). Often, the entire life cycle is not represented due to uncertainties and the analysis may be shortened to only include those components up to and including production (cradle-to-gate), up to and including construction (cradle-to-laid), or other endpoints. Figure 2 shows that the purpose of the LCA is to quantify the environmental impacts to help support decision-making. LCA can also be used to assess trade-offs associated with different decisions by having a common frame of reference. For pavements, the various endpoints are summarized as follows: Materials (A1), Transport (A2), Production (A3), Construction Transport (A4), Construction (A5), Use (B1, B6, and B7), Maintenance and Rehabilitation (B2-B5), and End of Life (C1-C4) as shown in Figure 3.

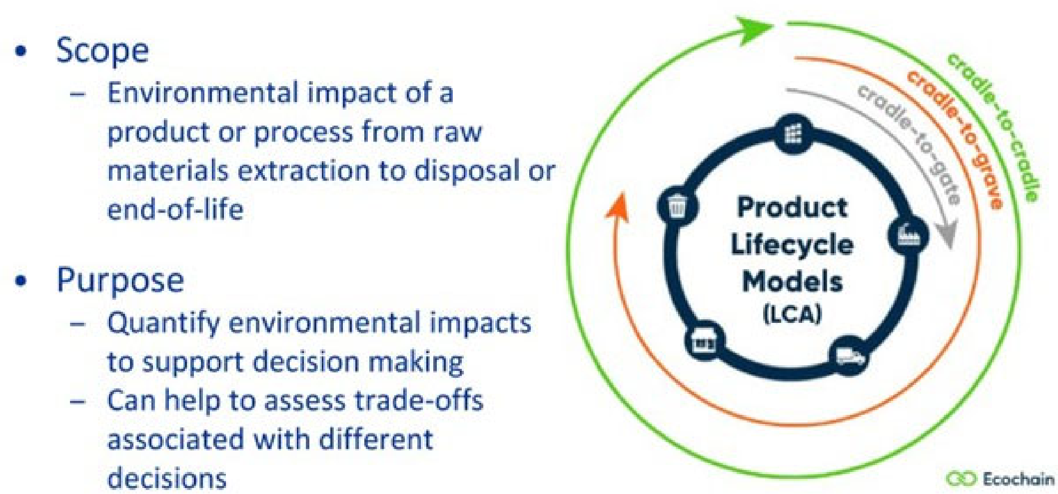

FIGURE 2 Life-cycle assessment scope and purpose (Source: Ecochain).

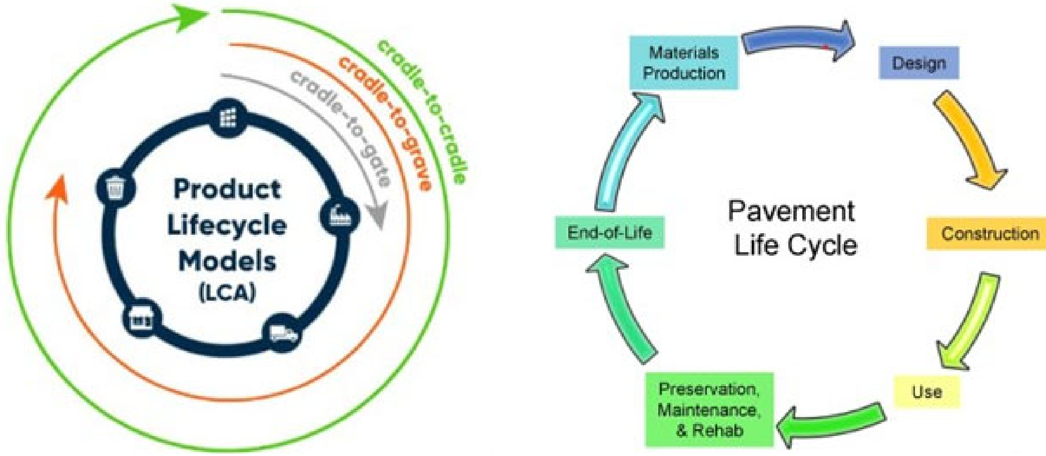

FIGURE 3 Life-cycle assessment
(Source: Ecochain and FHWA Tech Brief, 2014).

The results of an LCA may be reported as part of an EPD as shown in Figure 4. The EPD is a standardized reporting mechanism based on an LCA and is externally verified by an independent third party. Most current EPDs report only the process included in A1-A3 (shown in Figure 4). Often, some of the background information for A1 must be assumed and is often done using either national or regional averages or even industry or product-specific averages.

Reducing the environmental impacts during rehabilitation of an asphalt pavement can be done in many ways. Figure 5 shows that some of these ways can be influenced by the agency, and some can only be influenced by the contractor. From an agency perspective, the type of mixture used and RAP content required can be adjusted to result in a lower environmental impact. From an industry perspective, the mixture producer can adjust their production processes to reduce fuel consumption or change their fuel type depending on what is available in their area among other changes.

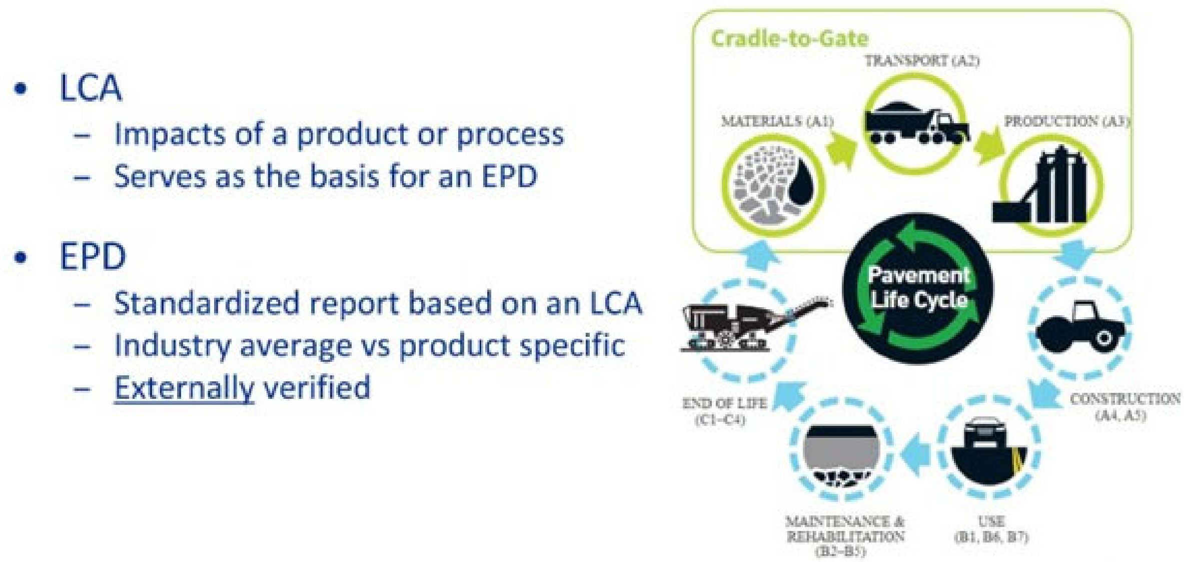

FIGURE 4 LCA and EPD.

- Reducing impacts can take many forms
  - Increasing service life
  - Reducing virgin materials
  - Using less carbon intensive materials
  - Reducing other environmental effects
- Agency emphasis vs industry emphasis
  - Mix type selection, RAP content, etc.
  - Covered stockpiles, plant fuel use, etc.

FIGURE 5 Environmental impacts.

Figure 6 shows a partial list of the efforts underway by the Virginia Department of Transportation to reduce the environmental impacts of pavement rehabilitation. These efforts include research into the use of increased RAP contents and use of WMA additives, in-place pavement recycling techniques, and recent efforts within the Climate Challenge Program Grant.

Figure 7 shows that the national average RAP content in asphalt mixtures is approximately 21.1% compared to 15.6% in 2009. For pavement owners (such as agencies) there can be an average savings of approximately $7.80 per ton. Including one ton of RAP avoids the release of approximately 27 kg CO2eq.

FIGURE 6 Pavement sustainability efforts by VDOT.

FIGURE 7 RAP benefits (Source: NAPA*).*

Figure 8 shows that the average use of WMA is approximately 41% nationally. Use of WMA is permissive by the Virginia Department of Transportation (VDOT) and nearly all asphalt mixtures placed on VDOT projects use some type of WMA additive. The use of WMA does not always guarantee production temperature reductions as sometimes the additives are used as a compaction aid.

Figure 9 states that benefits from WMA primarily come from the potential for reducing production temperatures. Other benefits include reduced worker exposure to higher temperatures and reduced aging. Extended haul times may be experienced when production occurs at higher temperatures. VTRC Report 19-R18 shows similar performance of WMA through the study of cored specimens tested in the laboratory and pavement management system data.

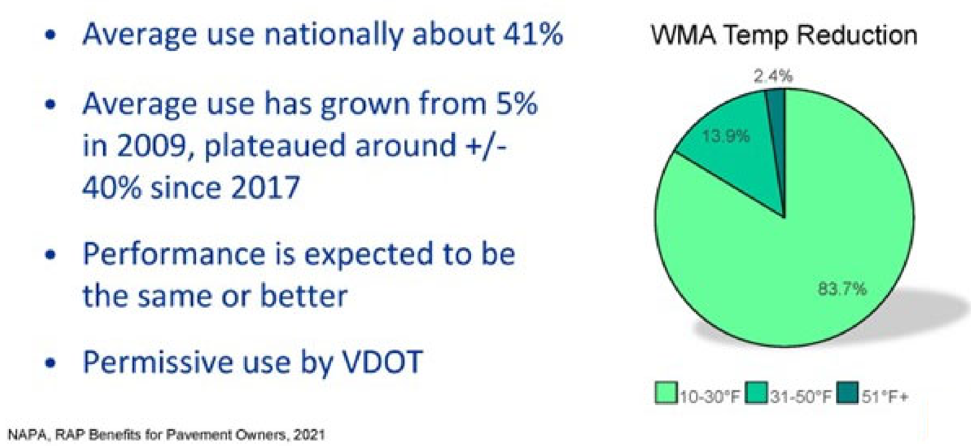

FIGURE 8 WMA use (Source: NAPA).

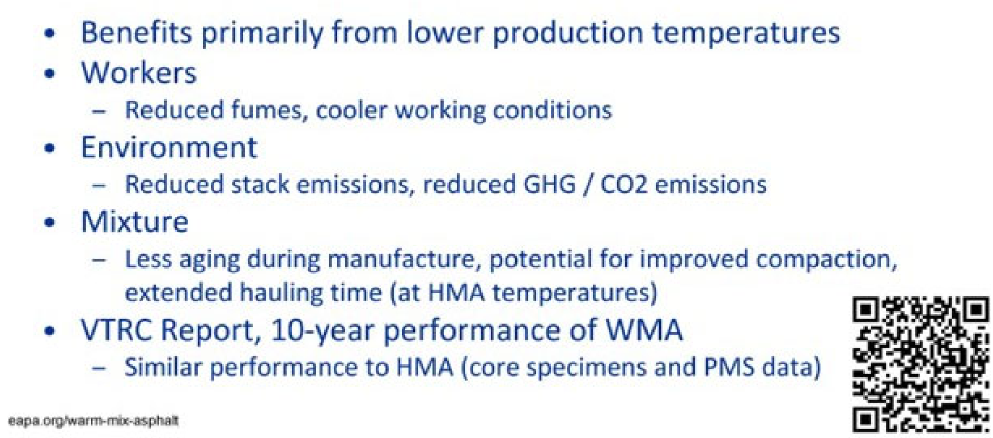

FIGURE 9 WMA benefits (Source: eapa.org/warm-mix-asphalt).

Figure 10 provides some background information on various in-place pavement recycling processes. These processes can all be used to produce a pavement section with reduced environmental impacts. VDOT and other agencies have extensive experience with these techniques on low- to high-volume roadways.

Figures 11 and 12 present an overview of two pavement reconstruction and widening projects completed on Interstate 64 (I-64) near Williamsburg, VA. Segment II was completed in 2019 and Segment III was completed in 2021. Full-depth reclamation (FDR) and CCPR were used to add new lanes to the median side of the existing lanes using imported materials. After building two new lanes, traffic was shifted to these lanes and the existing lanes were reconstructed using the same techniques. Figure 12 shows the pavement cross section for Segment II that consisted of 4 inches of new SMA (stone matrix asphalt) surface placed over 6 inches of CCPR produced using RAP from existing stockpiles. The CCPR was placed on top of a 2-inch-thick open graded drainage layer that was added on top of the 12-inch-thick FDR layer. The FDR was comprised of the existing pavement foundation for the existing lanes and imported crushed concrete and RAP for the new lanes (termed imported FDR).

FIGURE 10 Pavement recycling.

FIGURE 11 I-64 reconstruction and widening.

FIGURE 12 I-64 construction sequence.

Figure 13 shows a close-up of the imported FDR material and the production of the FDR in the existing lanes. Figure 14 shows the CCPR plant and placement of the CCPR material using conventional paving equipment.

Figure 15 shows a plan view of instruments that were placed in Segments II and III during construction to quantify the performance of the recycled pavement system. Instruments were installed in the right wheel path of the right lane to measure pressure, strain, temperature, and moisture content.

I-64 had benefits as it recycled more than 500,000 tons of material using CCPR and FDR. These benefits can be realized on high-volume roads. Instrumentation showed a low-strain environment which would expect a perpetual-type performance. Figure 16 shows a graph of strain measurements that indicate the I-64 Segment II project was built as a low-strain pavement section. The results were similar to results from the VDOT-sponsored test section at the NCAT Test Track that includes FDR and CCPR (Section S12). Section S12 was similarly found to have a low-strain environment and was tested for 30 million ESALs without significant structural deterioration between 2012 and 2021.

FIGURE 13 FDR.

FIGURE 14 CCPR.

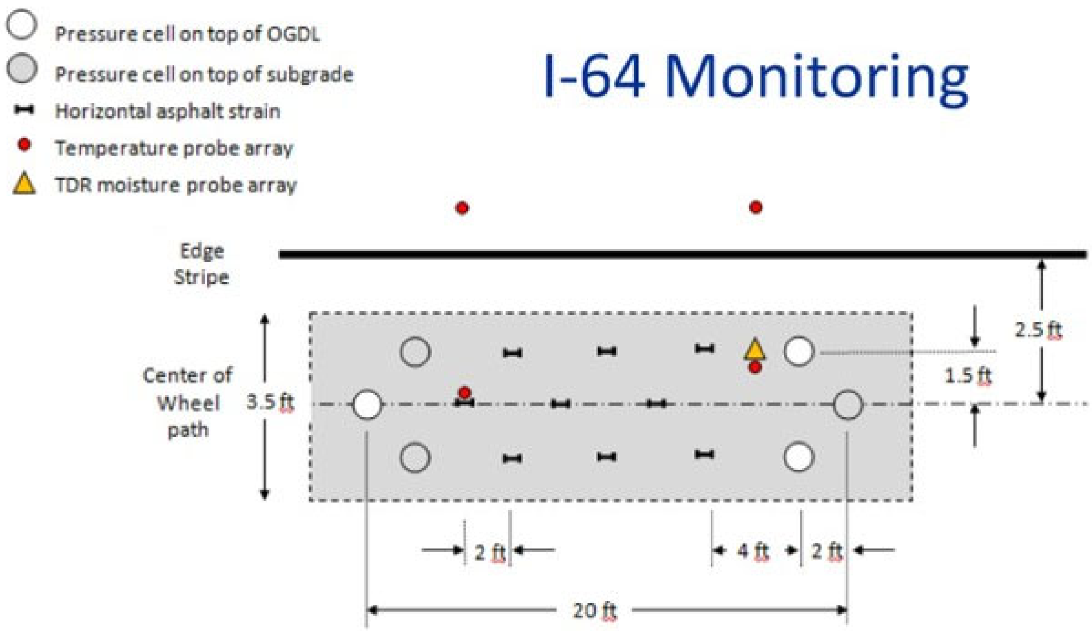

FIGURE 15 I-64 monitoring.

Figure 16 shows that more than 500,000 tons of material was recycled during the construction of Segments II and III. Figure 17 shows the results from a FHWA study that reported the recycling processes used on the I-64 projects resulted in a 20–40% energy reduction and a CO2eq reduction of 15–40% when compared to a traditional asphalt pavement section. The lower end of the reduction range comes from the use of imported materials in the new lanes and reflects this higher energy used to haul these materials to the project site.

Figure 18 shows an overview of the FHWA-sponsored Climate Challenge Program. VDOT is a participant in the program. In addition to collecting fuel use data from various projects, the Virginia project team has begun to investigate the impact of different variables on the GWP data available from published EPDs for 45 different asphalt mixtures.

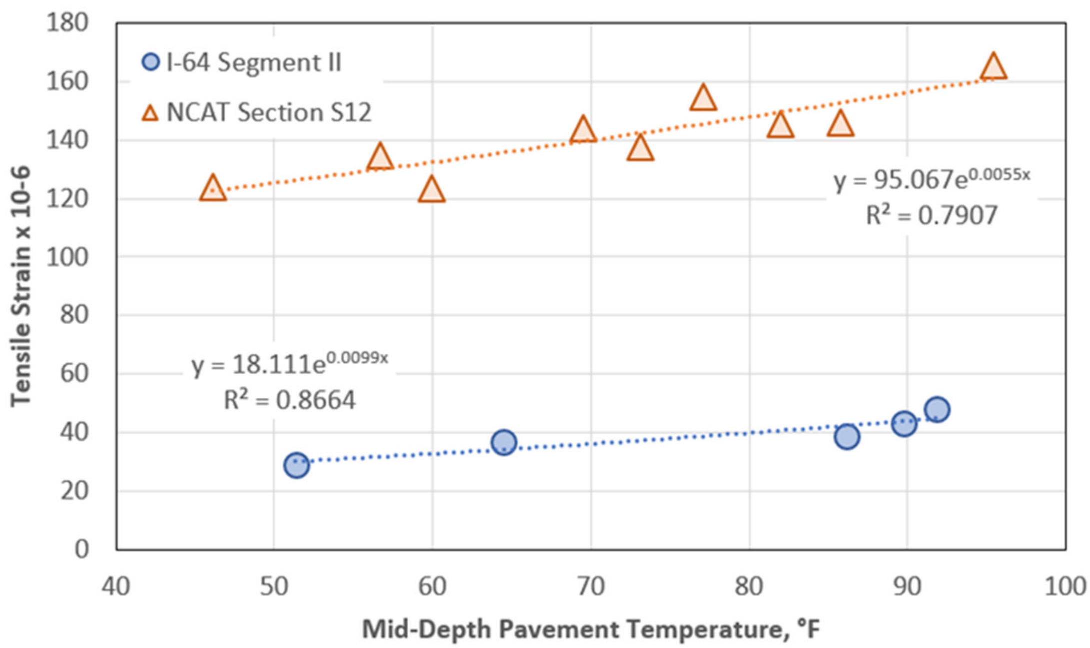

FIGURE 16 Strain measurements.

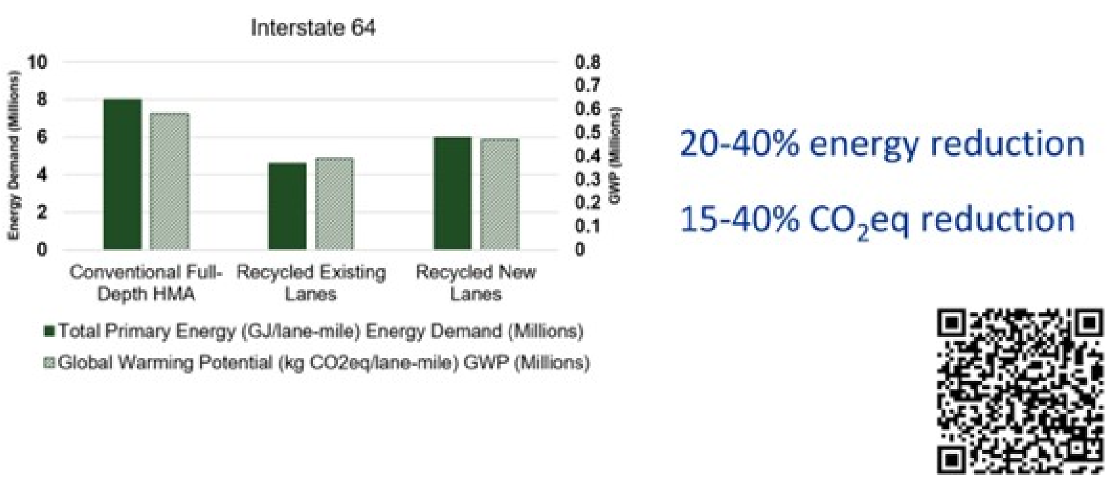

FIGURE 17 I-64 benefits (Source: https://www.fhwa.gov/pavement/sustainability/case_studies/hif19078.pdf).

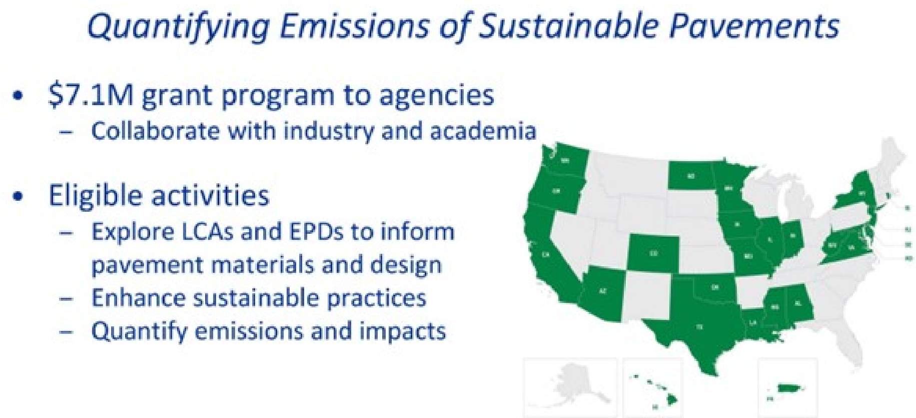

FIGURE 18 Overview of FHWA Climate Challenge Program.

Figures 19–21 show some of the findings from investigating published EPDs for 45 Virginia-based asphalt mixtures. Figure 19 shows that the materials production (A1) has the greatest average impact and greatest range when compared to transport of construction materials to the plant (A2) and production of the mixture (A3). Transport (A2) was found to have the least impact on the overall GWP.

Figure 20 shows the average (and range) GWP for mixtures with respect to mixture type considering only A1–A3. The numbers at the base of each column indicate the number of mixtures in that column. It is not surprising that the GWP is reduced for base mixtures compared to surface and intermediate mixtures since these mixtures tend to have the lowest binder contents. Similarly, SMA mixtures were expected to have the greatest GWP given their overall increased production efforts and generally higher binder contents.

Figure 21 shows the average (and range) GWP for mixtures with respect to RAP content considering only A1–A3. The numbers at the base of each column indicate the number of mixtures in that column. This figure shows that those mixtures having a higher RAP content also tend to have the lowest GWP values. The maximum RAP content found in the Virginia-based EPDs was 30% so it is not surprising there is little difference in the GWP results between mixtures using 20–29% and 30% RAP.

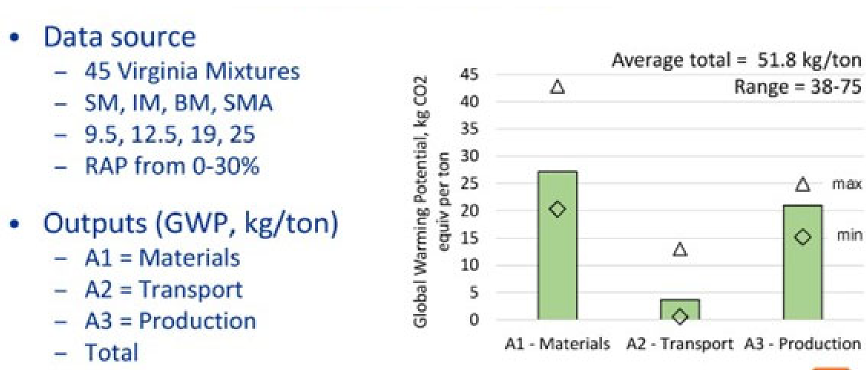

FIGURE 19 Current activities: asphalt mixture EPD data.

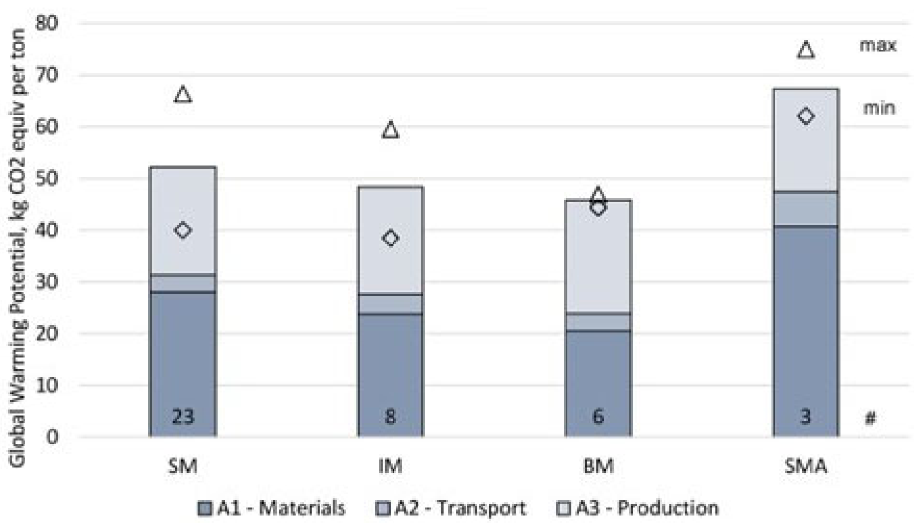

FIGURE 20 Mix type (SM = surface mixture, IM = intermediate mixture, BM = base mixture, SMA = stone matrix asphalt).

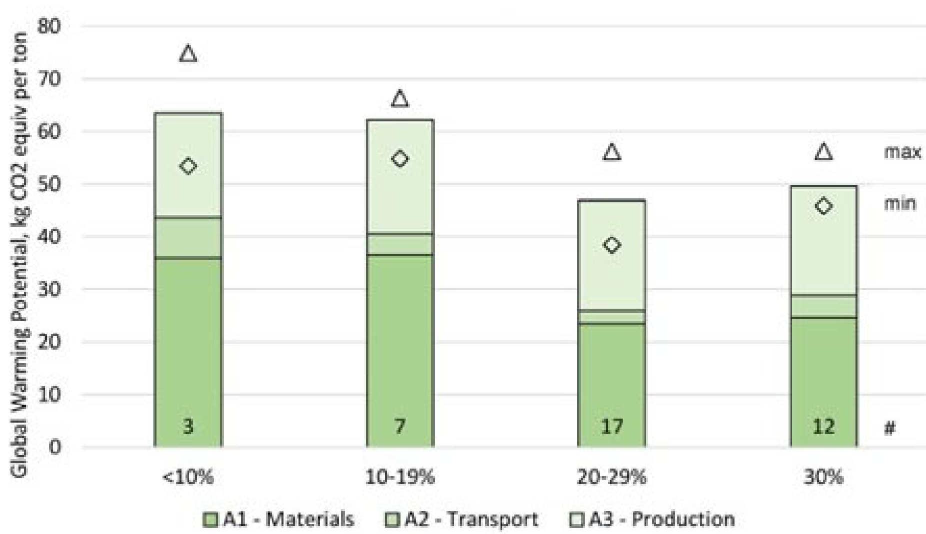

FIGURE 21 RAP content.

Figures 22 and 23 reflect on the importance of this topic. It is well documented that there have been adverse changes in the frequency, intensity, and duration of extreme weather events. In addition, there are negative health effects related to increasing temperature and reduced air and water quality. For these reasons, it is important for the pavement community to consider ways to reduce the environmental impacts of pavement rehabilitation.

Why Does it Matter?

FIGURE 22 Consider environmental impact.

FIGURE 23 Quality of life.

Summary of Key Takeaways

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The life-cycle phases of cradle-to-gate are captured in materials (A1), transport (A2), and production (A3). The pavement life cycle of cradle-to-gate for asphalt mixtures offers a framework to identify opportunities to reduce the GWP. To understand the impact of changes that could be made by a plant manufacturer, paving contractor, or agency, a baseline was established. The baseline numbers were taken from a reference from the General Services Administration (GSA) based on goals set in the Inflation Reduction Act (IRA). These limits are shown in Table 1. A change in approximately 10 kilograms of carbon dioxide equivalent per metric ton (kgCO2e/t) can shift an asphalt mixture from the 20% limit to the 40% limit, or the 40% limit to the "better than average limit." As a rule of thumb, a change in 10 kgCO2e/t is considered impactful. Of course, these are approximate, and you should evaluate your local mixtures and operations to determine your specific impacts.

To understand the influence of various components of the asphalt mixture on the GWP, a study was undertaken (1). The biggest impacts to the carbon footprint are 1) asphalt binder, 2) fuel, 3) transportation, and 4) electricity. As shown in Table 2, an increase in 1% neat binder can cause an increase of 6.3 kgCO2e/t.

TABLE 1 GSA IRA Limits for Low Embodied Carbon Asphalt, May 16, 2023 (1) (EPD— Reported GWPs, in kilograms of carbon dioxide equivalent per metric ton, kgCO2e/t).

Top 20% Limit	Top 40% Limit	Better Than Average Limit
55.4	64.8	72.6

Conversely, a decrease in 1% neat binder can cause a decrease of 6.3 kgCO2e/t. Changing from a neat binder to a 3.5% styrene-butadiene-styrene (SBS) modified binder can cause an increase of 7.57 kgCO2e/t. Adding hydrated lime can cause an increase of 13.57 kgCO2e/t. Adding 1% RAP can cause a reduction of 0.357 kgCO2e/t, therefore adding 40% RAP can cause a reduction of 14.28 kgCO2e/t.

The GWP of asphalt mixtures needs to be regionalized. States have different benchmarks based on climatic conditions, aggregate availability, and other factors. For example, the impact of aggregate availability is shown in Table 3. For the top 40% limit, Florida and Louisiana are at 18.7 and 24.0 kgCO2e/t, respectively. Those states have challenges with aggregate availability which result in long haul distances. All other states have the top 40% limit of 1.4 kgCO2e/t.

TABLE 2 A1: Impact of Mix Specifications on GWP (1)
Starting Point: 36.6 kgCO2e/ton mix.

A1 Material	Mass balanced with	GWP Intensity kgCO2e/ton mix ingredient (*/shtn)	Adjustment factor for using ingredient for additional 1% of mixture by mass kgCO2e/ton mixture (*/shtn)
Neat Binder	Aggregate	631.51 (573.06)	+6.30 (+5.71)
3.5% SBS Modified Binder	Aggregate	758.71 (688.49)	+7.57 (+6.86)
Lime	Aggregate	1389.0 (1259.9)	+13.87 (+12.58)
RAP	Aggregate + Neat Binder	0.781 (0.710)	-0.357 (-0.325)
Aggregate (USLCI, prescribed)	Neat Binder	1.94 (1.761)	-6.30 (-5.71)

TABLE 3 A2: Impact of Aggregate Availability on GWP (1).

A2 by State	**Florida** kgCO2e/ton (kgCO2e/shtn)	**Louisiana** kgCO2e/ton mix (kgCO2e/shtn)	**All Others** kgCO2e/ton mix (kgCO2e/shtn)
20%	3.3 (3.0)	15.7 (14.2)	0.21 (0.18)
40%	18.7 (17.0)	24.0 (21.8)	1.4 (1.2)
50%	36.9 (33.5)	28.7 (26.0)	2.5 (2.2)
Average	41.3 (37.5)	28.9 (26.2)	1.9 (3.5)

As a rule of thumb, a change in 10 kgCO2e/t is considered impactful. We can assume a particular asphalt mixture has the cradle-to-gate (A1 to A3) GWP of 70 kgCO2e/t as shown in Table 1. Information from each of the presenters was summarized to gain additional insight into the relative GWP of potential changes that could be made. Individuals should evaluate their local mixtures and operations to determine their specific impacts.

Reducing Asphalt Carbon Footprint at Asphalt Plants

To gain insight into the relative impact on GWP of A1, A2, and A3, EPD data was taken from NAPA's 2022 "GHG Emissions Inventory for Asphalt Mix Production in the United States" and Plant Carbon Footprint data was taken from Astec proprietary calculations as shown in Figure 1. Third-party verification is in progress (2). In general, A1 (materials) is 52%, A2 (transport) is 5%, and A3 (plant operations is 43%). For A3 alone, the drum/dryer burner is 90.3% and power is 8.1%.

As shown in Figure 2, there are a few examples that can be highlighted.

- Scenario 2. Changing from No. 2 fuel to natural gas results in a 29% reduction in kgCO2e/t for A3, or a 9% reduction in kgCO2e/t for A1, A2, and A3. If the cradle-to-gate were 70 kgCO2e/t with No. 2 fuel, this would be approximately a reduction of 6.3 kgCO2e/t.
- Scenario 3. In addition to scenario 2, if placing aggregates on a paved and sloped surface resulting in 2% lower moisture content and 50% of the asphalt mixture were produced with WMA at a 75ºF reduction in temperature, another 11% reduction in kgCO2e/t for A1, A2, and A3 would result. If the cradle-to-gate were 70 kgCO2e/t for scenario 2, this would be approximately a reduction of 7.7 kgCO2e/t.
- Scenario 4. In addition to scenario 3, if 100% of the asphalt mixture were produced with WMA at a 75ºF reduction in temperature and 20% H_2 fuel enrichment was used, another 6% reduction in kgCO2e/t for A1, A2, and A3 would result. If the cradle-to-gate were 70 kgCO2e/t for scenario 3, this would be approximately a reduction of 4.2 kgCO2e/t.

- Overall. Applying all the adjustment from the baseline to scenario 4, the 26% reduction would total 18.2 kgCO2e/t assuming the cradle-to-gate started at 70 kgCO2e/t.

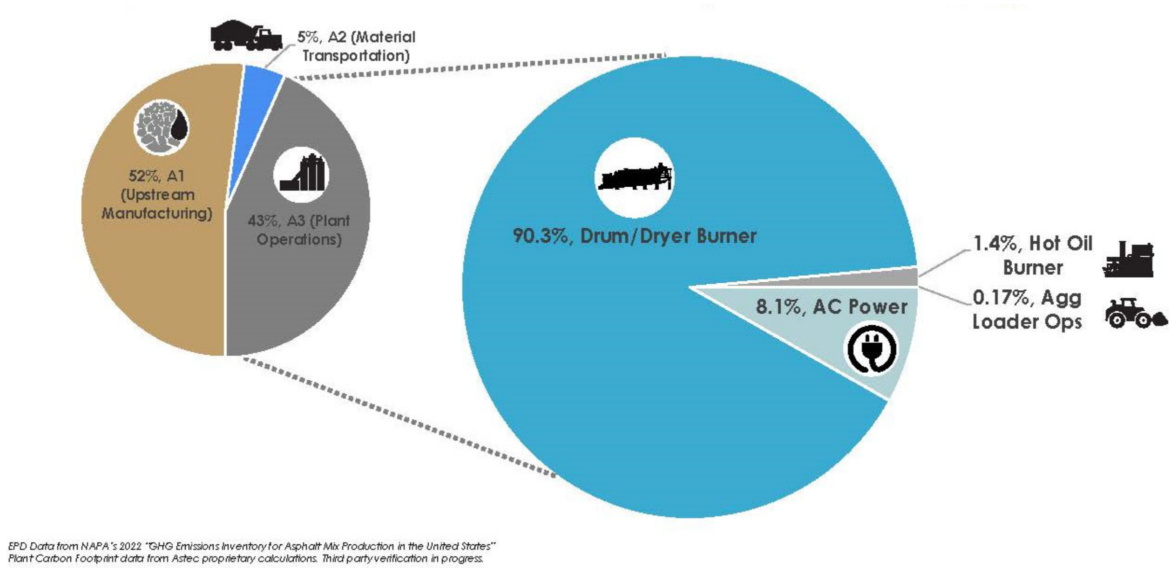

FIGURE 1 Asphalt plant carbon footprint (2).

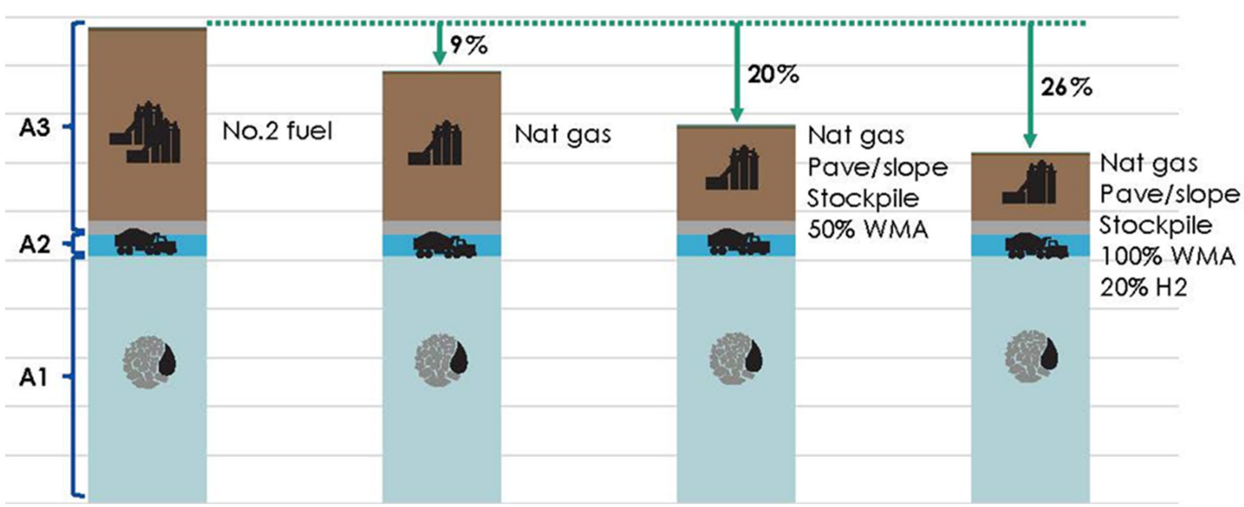

FIGURE 2 How A1, A2 and A2 add up (2).

Other notable changes at the plant that can reduce the GWP include:

- Using a VFD can reduce energy from the baghouse exhaust by 50% and the burner fan by 12.5%.
- Insulating pipes can result in 90% reduction in Btu/hour/linear foot.
- Operating continuously versus 3 startups per day can reduce fuel by 25–35%.

Reducing Green House Gas Emissions from Asphalt—Contractor Perspective

An asphalt paving contractor will design an asphalt mixture, produce it at their plant and place it on a project. For the cradle-to-gate (A1 to A3), several factors which impact the GWP are summarized in Table 4. These are general estimates and local conditions will determine the actual data.

TABLE 4 Influence of Various Components of an Asphalt Mixture on GWP (3).

A1 (Material) or A3 (Production) Adjustment	Reduction in GWP kgCO2e/t
1% RAP Increase	0.35
WMA with 25ºF Temperature Reduction	0.67 (natural gas)
WMA with 25ºF Temperature Reduction	0.80 (propane)
0.1% Asphalt Binder Reduction	0.57
1% Moisture Reduction	1.47 (natural gas)
1% Moisture Reduction	1.75 (propane)

Adding 1% RAP can cause a GWP reduction of 0.35 kgCO2e/t, therefore adding 40% RAP can result in a GWP reduction of 14.0 kgCO2e/t. Lowering the production temperature with WMA by 25ºF can result in a GWP reduction of 0.70 kgCO2e/t. A reduction of 75ºF can result in a GWP reduction of 2.1 kgCO2e/t. A reduction of 1 and 2% moisture can result in a GWP reduction of 1.5 and 3.0 kgCO2e/t, respectively. Again, these are general estimates and local conditions will determine the actual data.

Changes to isolated variables can impact the GHG from asphalt as shown on Figure 3. The base case is a mix with 5.0% total binder content, 20% RAP with 5% residual binder, and no RAS. The average aggregate haul distance is around 20 miles. The plant production temperature is about 310ºF. The average stockpile moisture is 5%.

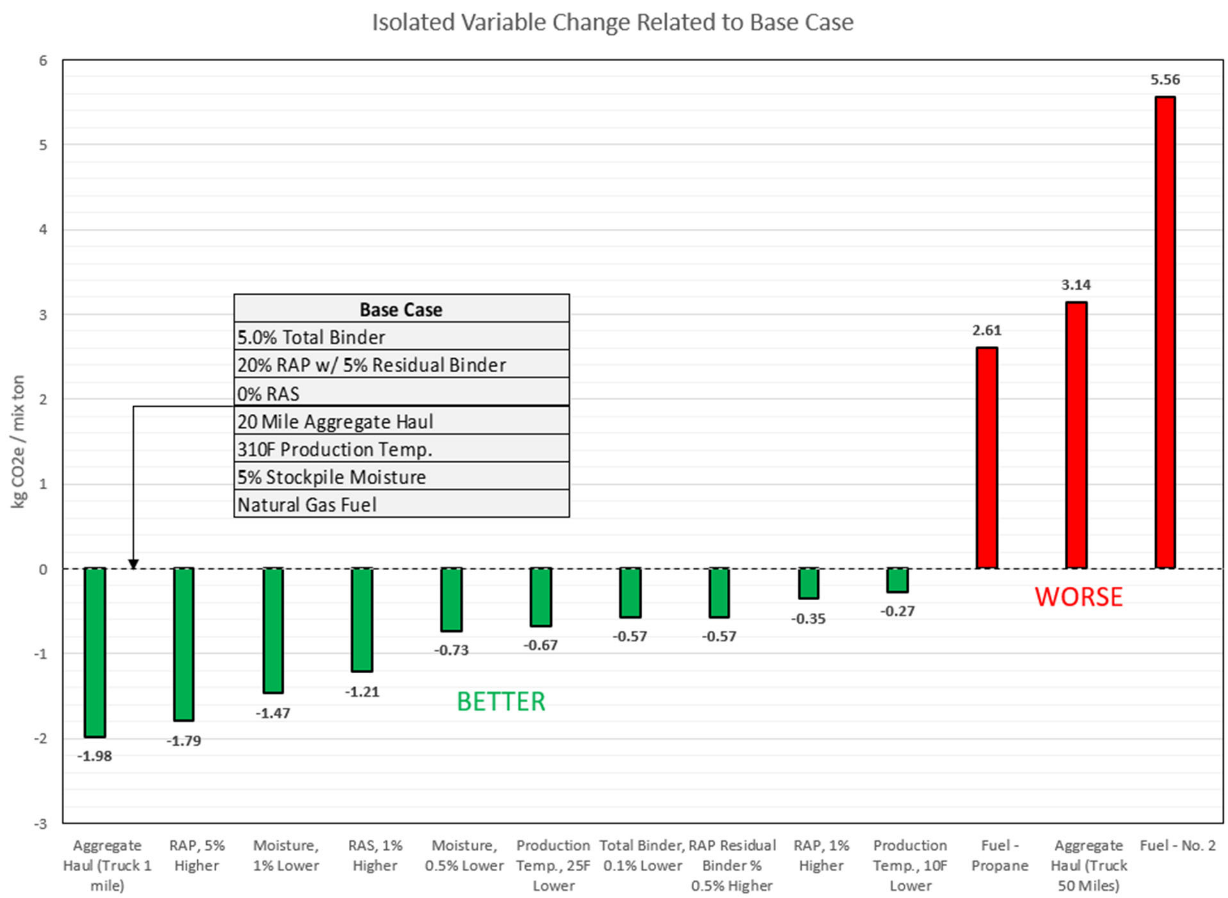

FIGURE 3 Impact on GHG emissions from isolated variables (3).

Natural gas is used as the primary source of fuel. On the left side of Figure 3, the green bars represent better scenarios, while on the right side of the figure, the red bars represent worse scenarios. For example, by changing the aggregate haul distance from 20 miles to 1 mile (basically using the locally sourced aggregates), the GHG emissions would be reduced by 1.98 kg CO2e per mix ton. By increasing the RAP by 5%, one would see a decrease of emissions by 1.79 kg. By lowering the moisture content in the stockpile by 1%, the emissions would be reduced by 1.47 kg. On the other side, if natural gas is not available and has to be replaced by propane, the GHG emissions would increase by 2.61 kg. The number could go even higher if No.2 oil is used, which would be an increase of 5.56 kg. If no suitable aggregates are available within a 20-mile radius and the producer must haul the aggregates from 50 miles away, the emissions would increase by 3.14 kg. Note these are just some cases of how different isolated variables can impact the GHG emissions from asphalt based on the example data.

Virginia DOT Perspective on Reducing Environmental Impacts of Pavement Rehabilitation

Agencies like the Virginia DOT have implemented higher RAP contents, warm mix asphalt, and in-place recycling. These techniques have been shown to result in energy and CO2e reductions (4).

Closure

This session on asphalt pavement carbon footprint reduction was held with a broad group of asphalt pavement stakeholders including representatives from a state DOT, asphalt plant manufacturer, and asphalt mixture producer and contractor. The session was designed to identify techniques that could be used to reduce asphalt pavement carbon footprint today. Further, FHWA held a workshop to identify techniques and rank their priority (5). The information collected through the workshop may also be used by the stakeholders to inform future activities that support asphalt pavement carbon footprint reduction.

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