Analyzing the Petroleum Asphalt Binder Supply Chain under Energy Transition Scenarios

by Wood Mackenzie Consulting on behalf of the Asphalt Institute Foundation

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About Wood Mackenzie Consulting

Wood Mackenzie has worked with clients to support their decision-making in the energy and natural resources industry for over 45 years. As the trusted source of commercial intelligence in the industry, we empower clients to make better strategic decisions by arming them with independent and objective analysis. Wood Mackenzie's consulting teams provide bespoke advisory services leveraging the expertise, data and models of Wood Mackenzie's broader research business.

About the Asphalt Institute Foundation

The Asphalt Institute Foundation is a public charity that meets the requirements of US Internal Revenue Code Section 501©(3) as a not-for-profit organization. The Asphalt Institute Foundation's mission is to conduct strategic research and educational activities that are designed to advance and improve both the liquid asphalt industry and the welfare of the general public.

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Foreword

Asphalt binder, a material widely used in paving, roofing and other sectors, plays a critical role in the global economy. Asphalt mixtures are a composite of asphalt binder, aggregates and other additives, with specific formulations designed for different applications. Asphalt binder, sometimes called bitumen, binds the aggregates and other additives together.

The United States alone has over 4 million miles of paved roads, of which around 94% are paved with asphalt mixtures. Asphalt mixtures are produced by thousands of individual plants across the US, each year producing a total of 400 million tons worth around US$30 billion.

Asphalt binder is produced by oil refineries as one of the many products of the crude oils they process. While asphalt binder is critical for asphalt mixtures, it constitutes a relatively small portion of a typical oil refinery's output compared to other key transport fuels such as gasoline, diesel and jet fuel.

The Asphalt Institute Foundation contracted Wood Mackenzie Consulting to conduct a study on likely pathways for asphalt binder as the world trends towards a low-carbon future. The objective of this report is to provide an understanding of asphalt binder market dynamics, summarize the major emissions abatement options across the asphalt pavement value chain and assess the potential speed of change for petroleum asphalt binder supply in various energy transition scenarios.

This report is intended to aid research and development, infrastructure planning, and policy development and implementation while providing investors, policymakers and customers a view of the future evolution of asphalt binder supply chains in the context of the energy transition.

Executive Summary

Asphalt mixtures are the backbone of road transport infrastructure. Their secure, sustainable supply is key to the functioning of the economy and the broader society. Asphalt mixtures rely on both mining and crude oil supply chains. By weight, a typical asphalt mixture consists of 95% aggregate formed of mined sand, gravel and crushed stone. The remaining 5% is asphalt binder, produced from the residues of crude oil at petroleum refineries. Other additives can be included in the mixture to further augment the qualities or produce modified binders. Asphalt binder holds the material aggregate together.

Carbon emissions from asphalt mixture manufacturing are difficult to abate due to the energy-intensive nature of their production, but asphalt's emission intensity is still lower than other comparable paving products. Emissions per unit of concrete are around three times higher than asphalt mixtures. Binder emissions are around 60% lower than most other oil products such as gasoline, diesel, and jet fuel because, unlike transportation fuels, binder is not combusted in its end use.

The energy transition presents two key challenges for the asphalt industry:

1. **Evolving asphalt binder supply sources:** Oil refiners mainly focus on the production of transport fuels such as gasoline and diesel, which are usually the most valuable products of crude oil. Whereas asphalt binder constitutes just 2% of the average refinery output. When global consumption of transport fuels starts falling in the 2030s, driven by vehicle electrification and fuel efficiency improvements, some oil refineries will face closure. Wood Mackenzie's base case Energy Transition Outlook sees a moderate reduction in refining capacity, with petroleum asphalt binder supply from existing production pathways staying mostly intact (see 'Introduction' below for more detail). But in the most ambitious and hard-to-achieve energy transition scenario, which is net zero, global refining capacity could fall by two-thirds by 2050. In that case, refinery closures would lead to asphalt binder supply falling below anticipated demand, potentially creating a need for alternate supplies and changing refinery economic incentives to close the gap.
2. **Reducing emissions:** Emissions occur at nearly every step in the asphalt pavement supply chain. The emission reduction potential of asphalt mixtures is heavily dependent on the activities of material suppliers during oil production, refining, aggregate mining as well as transportation, asphalt mixing, storage and paving operations. Other factors such as road design, performance requirements, location and the pace of electrification of the broader grid and construction equipment will also be key. To play their part in the energy transition, asphalt industry participants need to reduce their own emissions and those of their suppliers and customers, all the while balancing environmental considerations with quality and cost.

Key findings from the study

Asphalt binder supply security is paramount.
Refining capacity will shrink in proportion to declining transport fuel demand. In the base case scenario of our Energy Transition Outlook (ETO), which we think is the most likely, there is less risk of insufficient binder supply. But in a hard-to-achieve net zero scenario, binder production via existing oil refining routes could struggle to meet demand by the 2040s. If binder supply becomes scarce, binder prices would need to rise relative to crude oil and other oil products for oil refiners to feel incentivized to shift their production yields in favour of binder and away from transport fuels. Refinery closures may require new dedicated binder production capacity via greenfield plants or refinery conversions.

The entire asphalt supply chain has a part to play in reducing emissions.
Successful emission reduction will require proactive steps from all value chain participants. The pace of electrification and low carbon fuel use across the broader economy will have a strong influence on the emissions abatement potential of the asphalt supply chain, including in binder and aggregates production, asphalt mixing, transport, storage and paving operations. The abatement potential of asphalt mixtures is context-dependent, but material mixes, road designs and preservation programs that improve durability and require less frequent or intensive maintenance can make an outsized difference.

There is no 'one size fits all' solution to reducing emissions in asphalt.
Organizations make decisions based on local conditions and material cost and availability, and operational and material standards for road building are typically set by local or state agencies. Asphalt mixes vary between regions and low-carbon asphalt pavement solutions are context specific. Requirements for Environmental Product Declarations and standardized whole pavement life cycle assessments play an important role in reporting embodied emissions of materials in some but not all states, making it challenging to harmonize the adoption of best practices.

Policy support may be needed to enable warranty-based procurement processes.
Low-bid procurement practices fail to optimally balance the quality of paving materials with economic and environmental sustainability considerations. Moving to long-term warranty-based procurement would help ensure the durability and quality of materials, reducing the amount of maintenance required and thereby reducing emissions over the project lifecycle. Policy support may be needed to incentivize low-carbon materials and processes, building on policies such as the Low-Carbon Transportation Materials Grants program under the Inflation Reduction Act.

Decarbonization in the asphalt industry will require concerted action from players across the asphalt value chain and will only be possible with emissions reductions across the broader economy. The decarbonization roadmap on the next page summarizes some of the major abatement opportunities and their relevant time frames.

Table 1: Decarbonization roadmap for the asphalt industry

<table>
<tr><th colspan="2">Abatement opportunities</th><th>Today - 2030</th><th>2030 - 2040</th><th>2040 - 2050</th></tr>
<tr><td rowspan="5">Asphalt Industry & Road Agencies</td><td>Project manage-ment plans</td><td colspan="3">Prioritize road designs and maintenance plans to **maximize pavement durability** & minimize major rehabilitation requirements. More frequent preservation treatments reduce lifecycle emissions by making pavements more durable, increasing service life</td></tr>
<tr><td rowspan="2">Asphalt mix designs</td><td>Incorporate **recycled materials** up to ~20% of asphalt mix in regions where this is not current practice</td><td colspan="2">Continue R&D to improve performance & durability of mixes with a higher share of recycled materials. **Increase share** beyond 20% where feasible</td></tr>
<tr><td>Incorporate **alternative binder feedstocks** such as bio-based residues and waste products from agriculture & forestry as binder additives (up to 10% of binder content) as context allows</td><td colspan="2">**Continue R&D** on mixes with a higher share of alternative feedstocks to overcome performance, durability & cost challenges</td></tr>
<tr><td>Asphalt mix operations</td><td colspan="3">Increase use of **warm-mix asphalt processes** beyond current 40% of tonnage in US. Overcome barriers to wider adoption – including financial costs of equipment & additives and performance concerns – with policy support, continuing R&D, and industry education</td></tr>
<tr><td>Paving operations</td><td colspan="2">Increase use of **biofuels to power transport and paving equipment.** Establish targets for uptake of nascent electric equipment</td><td>Increase use of **electric equipment** which is currently nascent</td></tr>
<tr><td rowspan="2">Oil industry</td><td>Upstream operations</td><td colspan="2">For oil sands, implement **carbon capture** systems on fossil-fired steam and treatment units and maximize use of **solvents** in steam assisted gravity drainage. Minimize **methane flaring** and implement robust leak detection & repair programs</td><td>**Electrify platform and drilling equipment** involved in crude oil extraction</td></tr>
<tr><td>Refinery operations</td><td colspan="2">Reduce use of fossil fuels for fired boilers, heaters, and hydrotreating by shifting to **low-carbon fuels,** such as low carbon hydrogen. Increase efficiency through improved **equipment monitoring** and maintenance</td><td>Shift from steam turbine equipment to electric drives using **renewable power**</td></tr>
<tr><td rowspan="3">Economy-wide Decarbon-ization</td><td>Policy & regulation</td><td colspan="3">**Provide incentives** (such as tax credits and grants) to drive emissions reductions across the asphalt value chain and encourage a shift to long-term warranty-based pavement procurement to increase road service life.</td></tr>
<tr><td>Adjacent industries</td><td colspan="3">Power sector **shifts the electric grid** from fossil to renewable power generation. Heavy-duty vehicle and paving equipment manufacturers scale up production of EVs and other and low-carbon solutions</td></tr>
<tr><td colspan="4">**Asphalt decarbonization depends on the pace of decarbonization in the broader economy,** including the growth of renewables in power generation and the shift from oil-powered to electric vehicles & machinery</td></tr>
</table>

In our 2050 Base Case outlook

CO_2

24%
reduction in asphalt pavement cradle-to-grave emissions

75%
of global power supply is renewable

73%
of global heavy-duty vehicle stock remains oil-powered

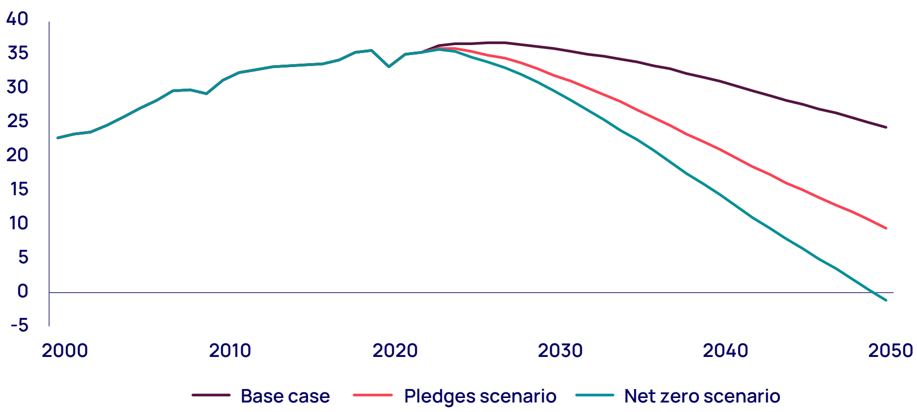
Introduction

Wood Mackenzie's Energy Transition Outlook[1] models three potential outcomes for the energy and natural resources sector. Our base case is consistent with a 2.5° C global warming outcome by 2050, falling short of the Paris Agreement. Global oil demand peaks at around 108 mb/d in 2031 and falls to 92 mb/d in 2050. In our accelerated pledges and net zero scenarios, global oil demand falls to around 50 mb/d and 30 mb/d in 2050, respectively.

Highlights from our outlook:

- Despite a rise in vehicle ownership, oil demand falls under all three energy transition scenarios due to fuel efficiency improvements and transport electrification, which is currently at 3%, but rises to 50% by 2050 in the base case
- Oil demand is sustained in the aviation and marine sectors, given the high cost of alternatives, such as sustainable aviation fuels (SAF), e-fuels and methanol and ammonia
- Bucking the trend, oil products used as a petrochemical feedstock continue to grow through 2050
- Demand in the OECD countries declines from 2025 at an increasing pace as they reduce their oil dependence, spurred by policies supportive of the energy transition
- Demand in other emerging economies continues to grow through the early 2040s, as India takes over from China as the largest liquids demand growth center by 2026
- China's demand peaks by 2027, turning to long-run decline as road transport electrification accelerates

Figure 1: Energy Transition Outlook – global energy-related CO_2 emissions, Bt



Source: Wood Mackenzie

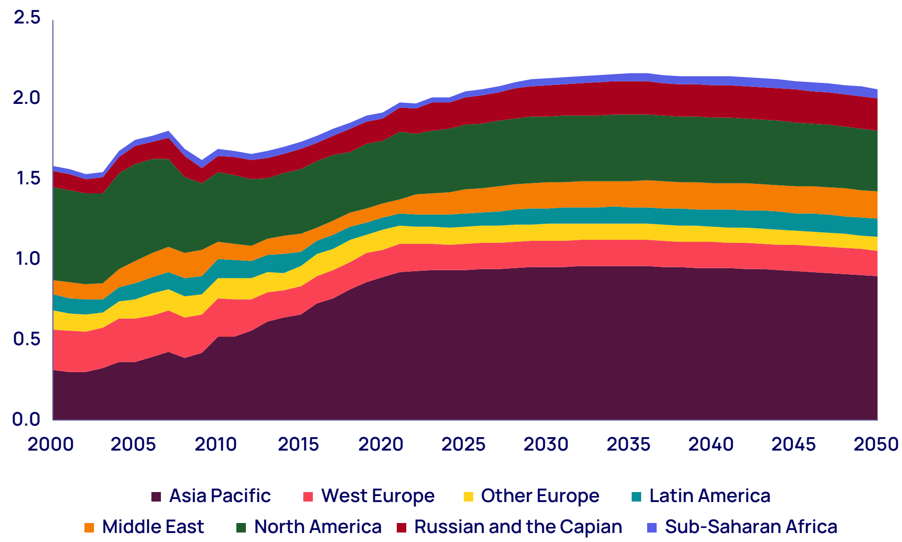
Outlook	Trajectory	Policy	Enablers
Base case	Consistent with 2.5˚C global warming	Evolution of current policies	Steady advancement of current and nascent technologies
Pledges scenario	Consistent with below 2˚C warming (global net zero by 2060)	Aligned with net zero pledges announced in the run-up to COP28	Incorporates policy response to the current energy crisis, and geopolitical challenges facing the global economy
Net zero 2050 scenario	Consistent with 1.5˚C warming (global net zero by 2050)	Aligned with most ambitious goal of Paris Agreement	Immediate peak energy; rapid hydrogen and carbon removal deployment; consumer shift

[1] Modelling in this study uses the 2023 edition of Wood Mackenzie's Energy Transition Outlook

Unlike most oil products, asphalt binder demand will not decline sharply because the world is expected to consistently need paving materials. Global asphalt binder demand is expected to remain relatively stable, driven by maintenance and new paving construction. However, since asphalt binder accounts for just 2% of global oil refinery output, it will have limited influence on refiners' decisions to reduce capacity or continue operating, which are driven primarily by transport fuel demand.

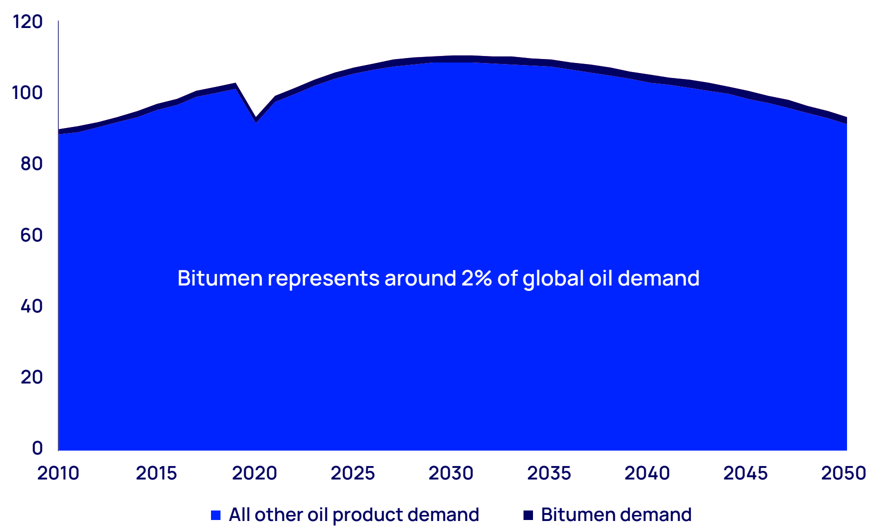
The study included quantifying emissions across the asphalt pavement value chain and modelling emissions across the three energy transition scenarios described above. The following pages delve into this analysis and describe the key levers available to reduce emissions across the value chain.

Figure 2: Global asphalt binder demand, mb/d



Source: Wood Mackenzie Energy Transition Outlook

Figure 3: Asphalt binder vs all other oil product demand, mb/d



Source: Wood Mackenzie Energy Transition Outlook

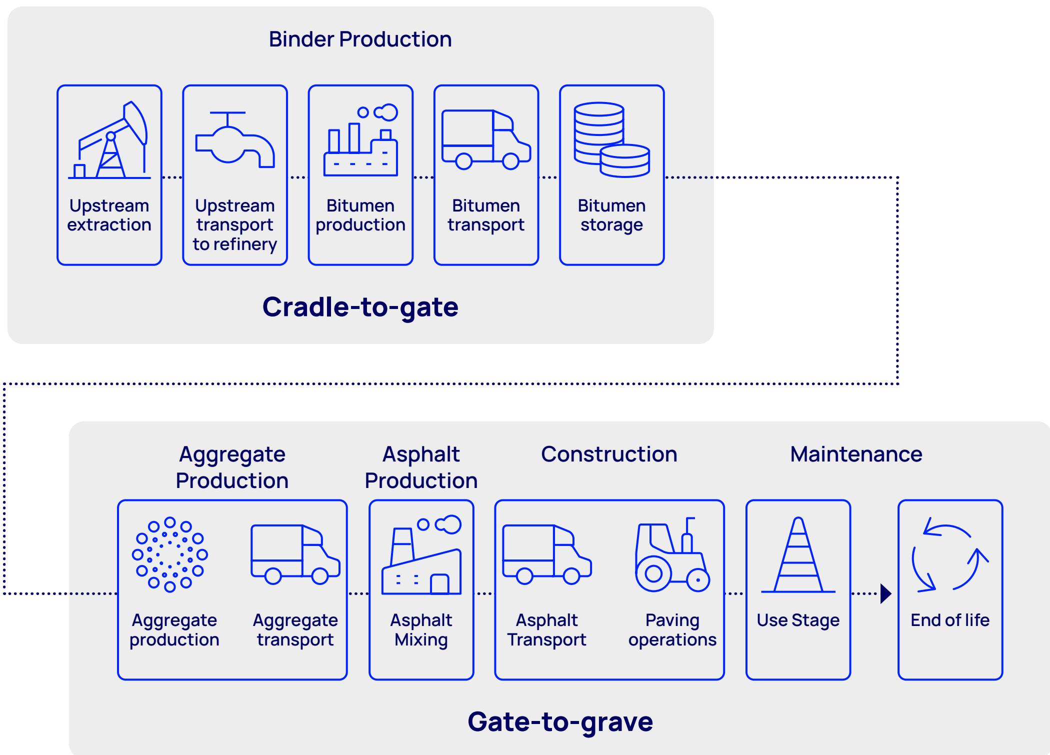
Asphalt pavement industry emissions outlook

Carbon emissions occur at all stages of the asphalt pavement value chain, and decarbonizing lifecycle emissions will require proactive steps from stakeholders across the industry. Public agencies' paving project management plans heavily influence carbon reduction results. The selection of more durable asphalt mixes and road designs requiring less frequent or intensive maintenance can also significantly reduce lifecycle emissions.

The study found that average **cradle-to-gate** emissions from binder production, transport and storage are 88 $tnCO_2e$/lane mile in North America. Broadening the scope to include aggregates production and transport, as shown in Figure 5, asphalt mixture production in the mixing plant, and the paving operations associated with constructing a lane mile of road, total **cradle-to-pave** emissions are 222 $tnCO_2e$/lane mile.[2,3] Within cradle-to-pave, the most emission-generating steps are upstream crude oil extraction and asphalt production at the mixing plant.

But emissions from materials production and initial road laying stages are only a part of the picture. Extending the boundary to consider the use-stage and end-of-life stage of the pavement, that is **cradle-to-grave,** provides a more complete view. The large scale of use-stage emissions underscores the importance of using this broader, more holistic scope to quantify greenhouse gas emissions from asphalt pavements. Pavement design, mixture selection, road durability, preservation and maintenance programs have a significant impact on cradle-to-grave emissions. For example, polymer-modified asphalt binders are associated with higher cradle-to-gate emissions, but they may result in lower cradle-to-grave embodied carbon emissions due to the improved durability and extended service life of these pavements.

Figure 4: Asphalt pavement value chain



[2] Assuming asphalt-paved lanes of 1-mile length, 12-foot width, 9-inch depth.
[3] Sources: Wood Mackenzie analysis; Miller et al (2024). "EPD Benchmark for Asphalt Mixtures." National Asphalt Pavement Association; Wildnauer et al (2019). "Life Cycle Assessment of Asphalt Binder." Asphalt Institute; Saboori et al (2022). "Pavement Life Cycle Inventories for California." University of California Pavement Research Center; Farina et al (2024). "Mechanistic-empirical pavement design to include mechanical performance of rubberized asphalt pavements in the use stage of life cycle assessment." Michigan State University.

The research also examined the impact of various project management plans and asphalt mixture designs on cradle-to-grave emissions. Assessed project management plans included a mill-and-fill approach without pavement preservation and mill-and-fill approaches with preservation techniques introduced early to extend pavement service life. Meanwhile, assessed asphalt mixture designs included mixtures with no reclaimed asphalt pavement (RAP), mixtures with 22% RAP, and those incorporating polymer (SBS) modified asphalt binders.

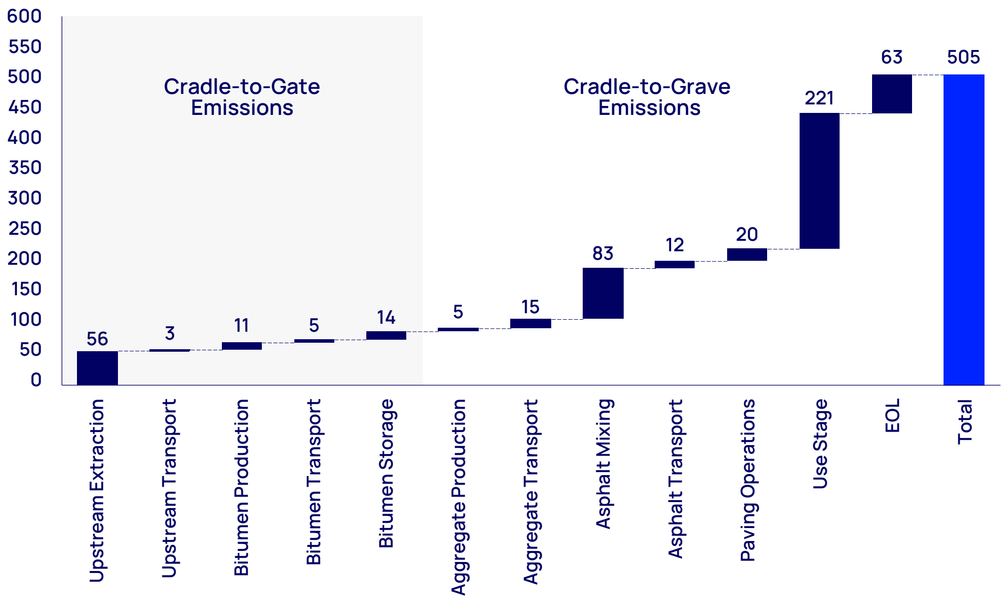
The assessment of three example road designs and management plans (detailed in Table 2), as shown in Figure 6, illustrates that more durable pavements tend to have lower lifecycle emissions. Example 1, which includes only major rehabilitation and no pavement preservation, resulted in high emissions, with over 50% of total emissions stemming from maintenance and upkeep. While upstream emissions from extraction are substantial, the long-term impact of frequent rehabilitation cannot be ignored.

By incorporating periodic preservation treatments, Example 2 highlights a reduction in cradle-to-grave emissions by about 17% (while reducing use stage emissions by 31%) in comparison with Example 1. This strategy, which included a slurry seal every five years, lowered emissions at both stages and the frequency of major rehabilitation.

Example 3 utilized SBS, leading to slightly higher cradle-to-gate emissions but reduced cradle-to-grave emissions by about 20% (while reducing use stage emissions by 57%) in comparison with Example 1. This demonstrates the potential for material innovations to improve the quality of asphalt paving, decreasing the need for frequent carbon-intensive rehabilitation and, consequently, lowering overall lifecycle emissions.

These findings underscore the need for policymakers to adopt a holistic lifecycle approach for identifying pavement emission hot-spots. Focusing solely on cradle-to-gate emissions may overlook substantial carbon savings achievable through strategic maintenance and material selection. By considering the entire value chain, industry participants can make informed decisions that positively impact emissions abatement in pavement.

Figure 5: Asphalt cradle-to-grave emissions, $tnCO_2e$ per lane mile



Source: Wood Mackenzie

Figure 6: Influence of performance and extended service life on cradle-to-grave emissions intensity (condensed timeline)

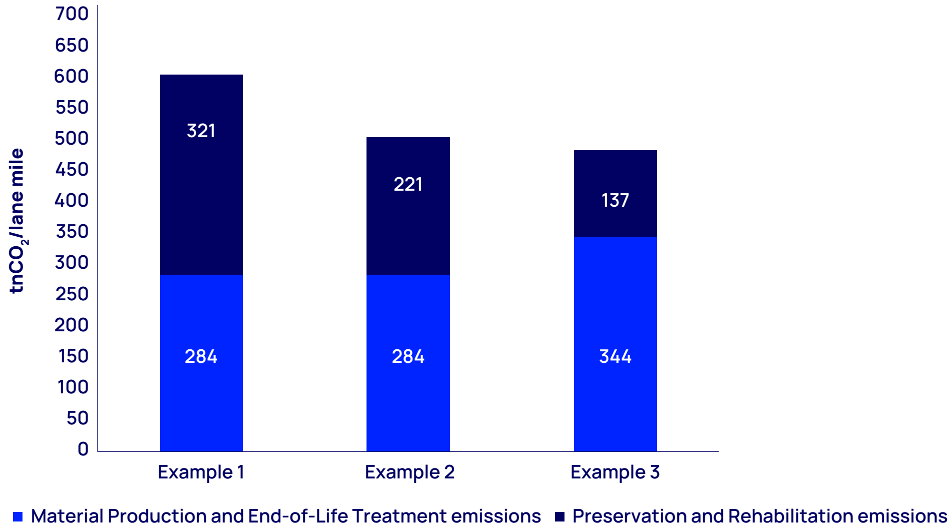


Table 2: Parameters used in cradle-to-grave emissions examples

The 3 examples show the emissions impact of changing a single variable in the asphalt mixture or use phase treatment

Example 1 – RAP mixture with no preservation treatments								
Mixture	RAP 22%	Year 0	Year 9	Year 18	Year 27	Year 36	Year 45	Year 50
Initial lay	Reconstruction, 9”							
Use Stage (Preservation and Rehabilitation)	Mill & Fill, 2.5”							
End-of-life	FDR, 9”							

Example 2 – RAP mixture with preservation treatments							
Mixture	RAP 22%	Year 0	Year 5	Year 15	Year 20	Year 45	Year 50
Initial lay	Reconstruction, 9”						
Use Stage (Preservation and Rehabilitation)	Slurry Seal						
	Mill & Fill, 2.5”						
End-of-life	FDR, 9”						

Example 3 – SBS mixture with preservation treatments								
Mixture	SBS 3.5%	Year 0	Year 7	Year 20	Year 27	Year 40	Year 47	Year 50
Initial lay	Reconstruction, 9”							
Use Stage (Preservation and Rehabilitation)	Slurry Seal							
	Mill & Fill, 2.5”							
End-of-life	FDR, 9”							

Emissions abatement opportunities and future scenarios

The potential for emissions abatement depends on the progression of the energy transition globally and the cumulative action of participants along the value chain.

Below are some key levers to reducing emissions. All measures require additional investment and considering properties of the final asphalt mixture relative to its intended application:

- **Upstream crude oil producers** can reduce methane flaring and leakage, shift to lower carbon power sources, electrify platform and drilling equipment, use carbon capture and solvents for oil sands. Current efforts of upstream oil producers are focused on minimizing methane flaring and leakage. Oil sands producers are starting to implement carbon capture and greater use of solvents. But it will be difficult to reduce emissions as remaining crude oil reserves become more challenging to extract. Upstream emissions are among the most challenging to abate given that platform electrification and carbon capture retrofitting are high-cost and complex to implement.
- **Refiners** can reduce fossil fuel use for fired boilers and heaters and adopt hydrotreating by shifting to low-carbon fuels, such as low-carbon hydrogen. Refiners have made progress on operational efficiency given the inherent cost incentive, but the large-scale consumption of fuel and power limits the replacement of fossil fuels for boilers and heaters. The use of low-carbon hydrogen for hydrotreating is currently nascent.
- **Asphalt mixing plants** can use more warm-mix processes and reduce burner use of fuel oil in favor of lower carbon fuels, including natural gas, biofuels or low carbon hydrogen. Shifting from fuel oil to natural gas burners will require investment but represents a low-hanging fruit for emissions abatement, thanks to the widespread availability of natural gas and the common use of gas burners. Shifting to a reduced-temperature warm mix asphalt process can lower fuel and electricity consumption compared to hot mix asphalt, but its applicability depends on specific plant configurations and asphalt quality requirements.
- **Paving and maintenance** can use more biodiesel to power transport and paving equipment, as well as increase the use of electric equipment. With diesel consumption being the primary emissions driver, bio and renewable diesel options, such as biodiesel and hydrotreated vegetable oils, offer effective drop-in solutions for existing equipment in the short term. Over the long term, the adoption of electrified paving equipment, coupled with low-carbon electricity, can further reduce emissions. Electrified equipment is nascent, but availability and affordability are expected to improve over time.

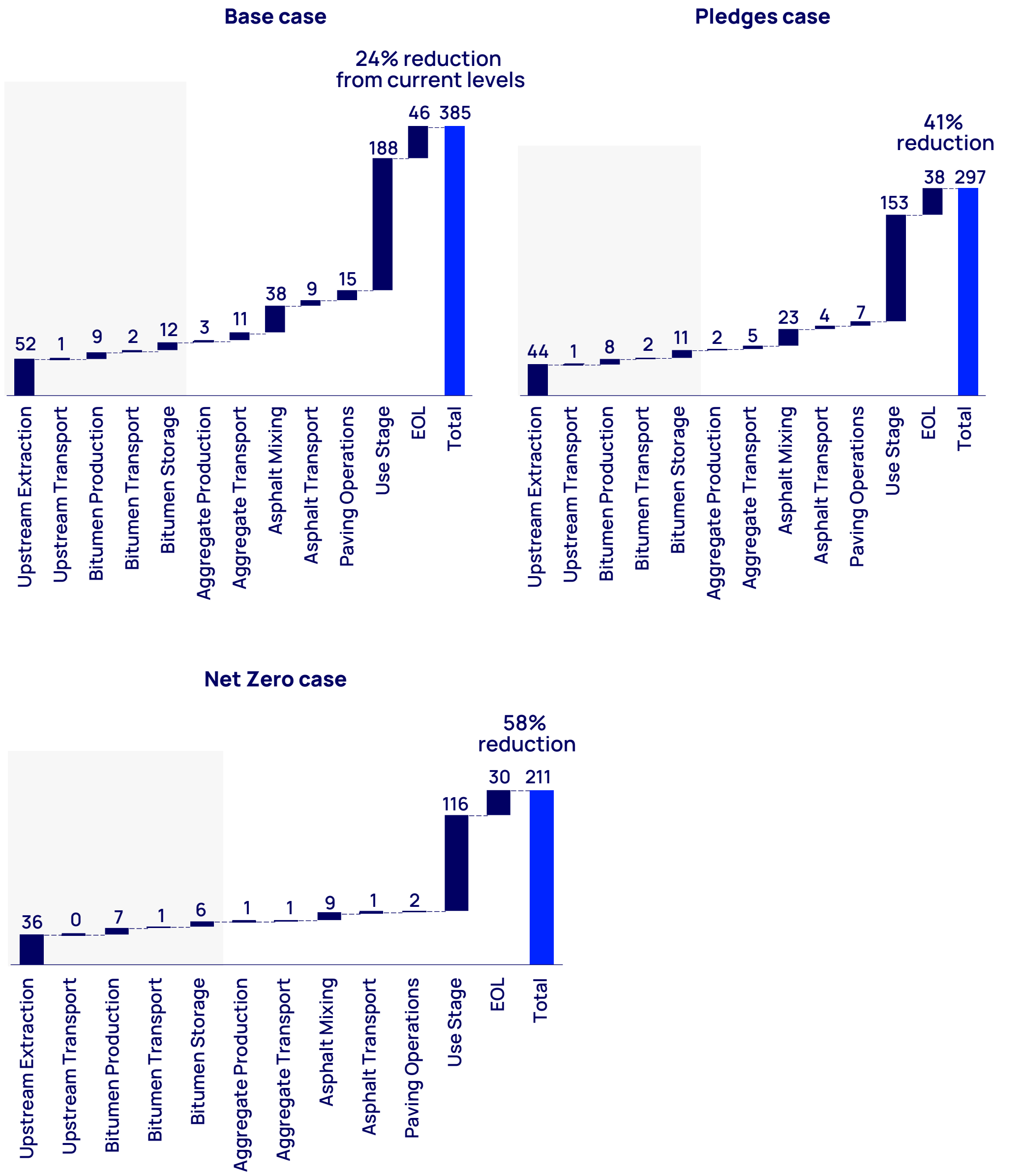
We evaluated emissions in the asphalt industry under the three energy transition scenarios described above: base case, pledges and net zero. Our analysis, based on a material and emissions model of the value chain, assesses how these scenarios could impact emissions in the asphalt pavement industry over time.

Our base case projects a 25% reduction in emissions intensity in the asphalt pavement value chain, accounting for current efforts to decarbonize grid electricity, implement carbon capture, utilization, and storage (CCUS) upstream, and transition to lower-carbon hydrogen and alternative fuels.

In the pledges scenario, we anticipate a 41% reduction in emissions in the asphalt value chain. This would require scaling existing technologies and deploying innovative solutions.

The global net-zero scenario would require a 58% reduction in emissions from current levels in the asphalt pavement industry. This ambitious global goal will demand substantial investment in low-carbon technologies and aggressive abatement measures across the entire value chain. Asphalt production is considered a hard-to-abate sector due to its use of fossil-based feedstock and the energy intensive processing required. This can still be compatible with a net zero scenario if other carbon capture, abatement and offsets are deployed at a global level. Our analysis does not include the potential emissions impact of sequestered biogenic carbon from bio-based modifiers or additives (see 'Areas for further study' below).

Figure 7: 2050 emissions



Future supply scenarios

Our study also addresses a key question on the supply side: how can future asphalt binder supply requirements be met under various energy transition scenarios?

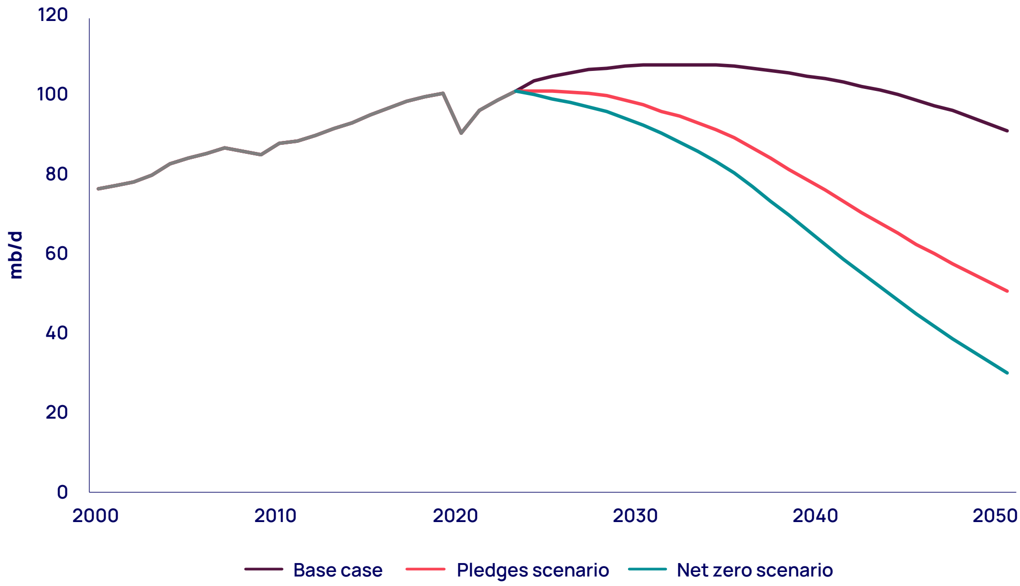
We evaluated the potential scale of asphalt binder supply in each ETO scenario. Assuming refining configurations and the mix of oil product yields is steady, our analysis suggests that while a shortage of asphalt binder is unlikely in our base case, under a more ambitious and hard-to-achieve net zero scenario, declining refining capacity could reduce the supply of asphalt binder from oil refineries. Reduced throughput of crude oil could create a need for refiners to reconfigure their infrastructure to increase their asphalt binder yield by idling residual conversion units, adding additional dedicated production capacity or diversifying into alternate feedstock sources.

In the chart below we show a conceptual view of the market balance for asphalt binder in each scenario. In each case, North American asphalt binder demand is about 400,000 barrels per day, with a similar level of demand across all scenarios since the energy transition is not expected to impact society's need for paving significantly.

In the base case, supply from existing refinery sources meets demand at approximately 400,000 barrels per day. In the net zero scenario, where about two-thirds of global refining capacity is closed by 2050, refinery binder supply would drop significantly to around 200,000 barrels per day, assuming no action taken by the refining sector. This would create a shortfall of 200,000 barrels per day, requiring changes to existing binder production pathways to meet demand. In the pledges scenario, a similar trend is observed, but with a smaller gap, requiring around 55,000 barrels per day from future production pathways.

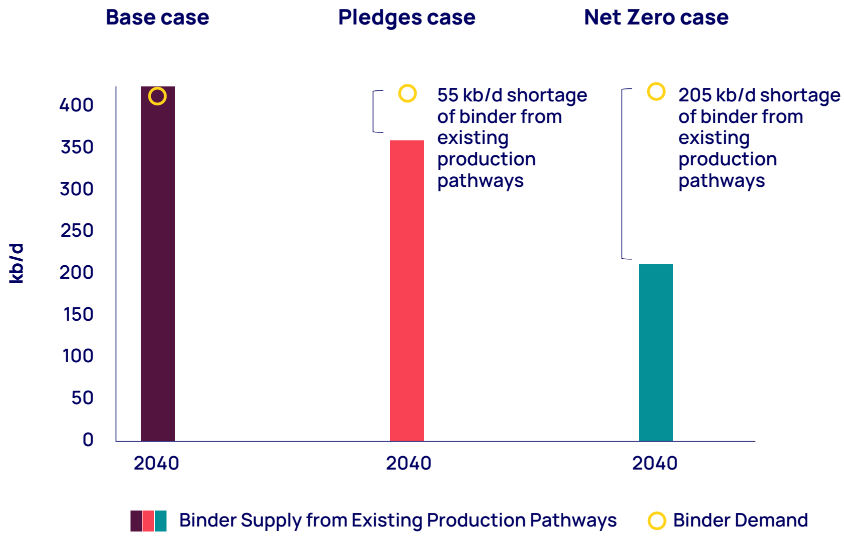
While the base case outcome remains most likely, the potential supply outcome in a net zero scenario highlights the need for proactive planning for potential investment in future binder production pathways to ensure a resilient and sustainable future for the asphalt pavement industry. In the next part of our analysis, we delve deeper into the most promising options to diversify supply and meet the requirements of asphalt binder demand.

Figure 8: Global oil demand - Wood Mackenzie Energy Transition Outlook scenarios



Source: Wood Mackenzie

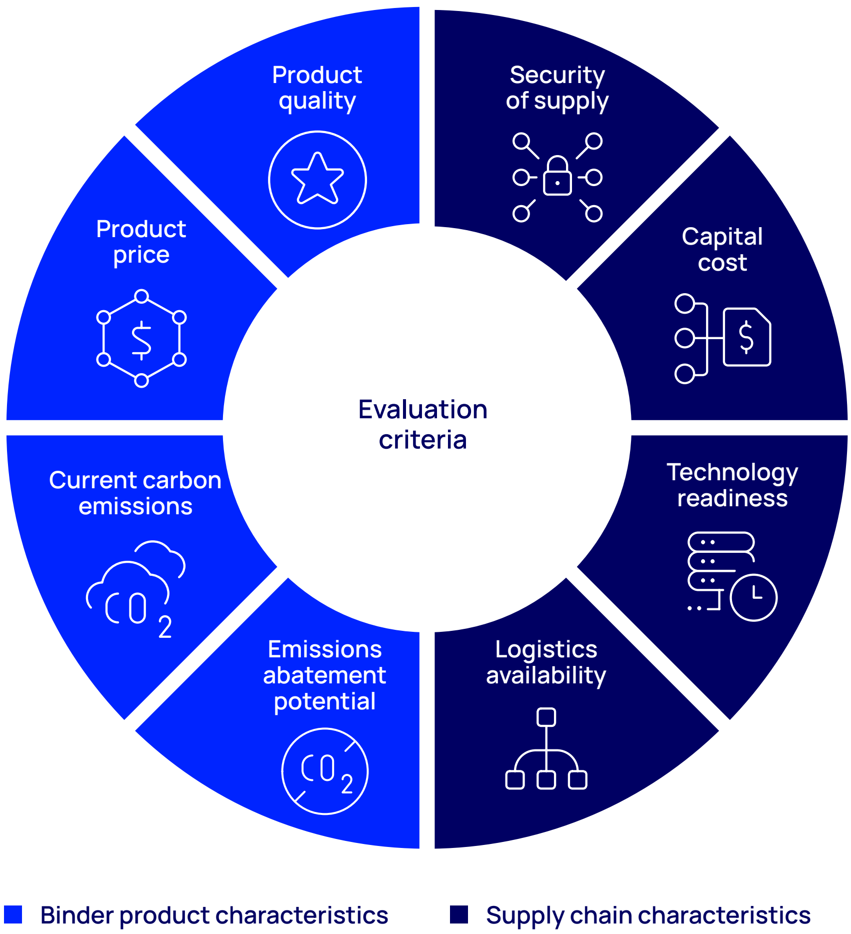
Figure 9: North America asphalt binder market balance by scenario



Source: Wood Mackenzie

We developed a framework to evaluate the feasibility of various options for providing additional asphalt binder supply in the event of reduced oil refining capacity. For each option, we considered a range of metrics shown below. Additionally, we assessed the potential supply scale of each option to determine its feasibility as a supply source.

Figure 10: Evaluation criteria for supply options



Source: Wood Mackenzie

Yield shifts: the biggest impact could be made by yield shifts at existing refineries, as refiners have some flexibility to shift their production between products. Refinery closures would result in a tighter binder market and higher prices relative to crude oil and other oil products, providing the incentive refiners need to shift production towards asphalt binders. Refineries could reoptimize their yields by diverting existing heavy residue streams away from upgrading units, such as cokers and visbreakers, which typically convert the material into transport fuels, and redirecting them into asphalt binder production units instead. This option could be readily available to many refiners at lower cost. In North America, coker volumes today are larger than binder production, suggesting that a small percentage change in coking would impact binder supply significantly.

The potential for yield shifts has some noteworthy limits, as refineries have capacity and quality limits on the volume of heavy residue that can be processed into asphalt binder. Upstream of the asphalt binder producing facilities, the crude and vacuum distillation units will also be constrained by the total volume of heavy crudes that can be processed. While cut points—the temperature at which crude oil distils into separate fractions—can be optimized to increase residue yields, there may be impacts on residue quality and a need to reconfigure the plant or equipment at the refinery to scale up production further.

Refinery conversions: refineries that are facing closure can be converted to focus on producing asphalt binder. This could involve significant capital costs depending on the nature of the project, from lower-cost crude train modifications to higher-cost new processing units. Refinery conversions could add materially to supply, but the capital costs required and the need to source suitable heavy crudes will limit the feasibility of this option.

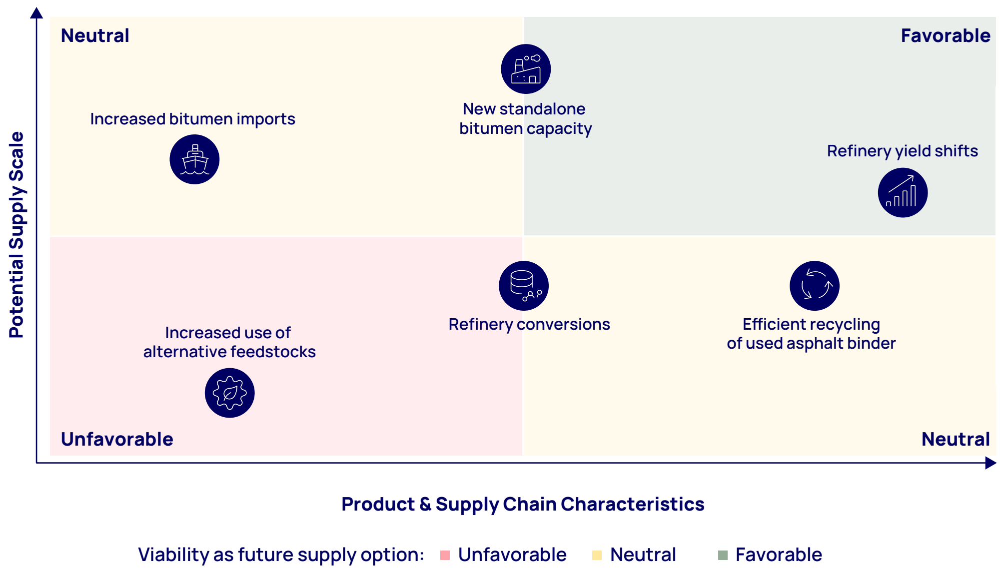
New standalone asphalt binder facilities: a limited number of new greenfield standalone asphalt binder-focused production facilities could be developed to supply asphalt binder, while minimizing the production of transport fuels that may become less desirable under energy transition scenarios. Small-scale standalone facilities may import heavy crudes to produce asphalt binder and a lighter distillate product. This approach could add significant additional supply, but it requires large capital investment and sources of suitable heavy crudes as feedstock.

Efficient recycling: some virgin binder material requirements could be displaced through efficient recycling of used asphalt binder. This holds promise as a sustainable and cost-effective option for asphalt supply since recycling lowers the cost and emissions impact of paving projects by reducing reliance on raw materials. Recycled binder use is widespread at mix levels of 15% to 25%, but the viability of higher mix levels is limited by the brittleness of aged binder and further R&D is needed to improve their performance. Recycled binder use varies between regions depending on the availability of recycling infrastructure.

Increased use of alternative feedstocks: Increased use of alternative feedstocks as binder extenders or replacements may include bio-based residues and waste products from agriculture, forestry and other sources. Alternative feedstocks have an important role to play as binder additives with less than 10% binder content, given their low cradle-to-gate embodied emissions profile. But high costs, current supply limitations and performance challenges at higher mixture rates limit their utility as a binder extender or replacement. Further research and development is required to improve quality, increase supply and reduce costs.

Increased imports: increased reliance on asphalt binder imports from Latin America or other overseas producers could raise supply security concerns and may make this option less viable. The US currently imports around 15% of its asphalt from Canada, thanks to the close integration of upstream supply chains between the two countries. But if asphalt binder production capacity declines in the US and Canada, the countries may require more imports and Latin America is the most likely candidate for these due to the abundance of heavy bituminous crudes across the region. Import infrastructure is limited within North America as the region is largely self-sufficient. So, capital investment in infrastructure to facilitate imports may be needed. The relatively high cost of asphalt binder transport, shipping, storage and onward distribution would make binders more expensive. It would create a commercial case for investment in additional domestic standalone production facilities.

Figure 11: Attractiveness of future asphalt binder supply options



Source: Wood Mackenzie

While the viability of each of the supply options described above will depend on uncertainties around policy, technology development, consumer behavior and other factors, the analysis provides policymakers and industry participants with a conceptual view of the future asphalt binder supply options at their disposal.

Interviews with stakeholders in asphalt binder value chain

As part of our research, we interviewed a range of industry stakeholders, including oil refiners, additive manufacturers, emulsion and preservation companies, paving contractors, and public agencies to gain their perspectives on asphalt binder supply and challenges of the energy transition. Our discussions revealed their diverse approaches to tackling this issue. Below, we have paraphrased selected quotes from the interviews. These are intended as highlights of our discussions with industry stakeholders and do not represent the opinions of either the Asphalt Institute Foundation or Wood Mackenzie:

Road management plans considering preservation versus major rehabilitation:

- Demand for preservation treatments is driven by transportation departments and agencies. As these organizations seek more environmentally friendly solutions, extending road life through preservation emerges as the most effective strategy to reduce both costs and environmental impact.
- Preservation treatments and emulsions will become increasingly important as they contribute to longer road life and maximize the value of every dollar spent on road maintenance.

Alternative and bio-based binders

- If roads constructed with a high proportion of low-carbon materials fail to meet durability standards, this approach is not sustainable in the long term or on a lifecycle basis. While climate action goals are important, ensuring the performance of our roads remains a critical concern.
- Quality should be the primary consideration. While some bio-based binders perform well, many either become too soft and prone to deformation or too hard and susceptible to cracking. The effective options are often significantly more expensive. Therefore, bio-based binders are best suited as enhancements to petroleum-based binders rather than complete replacements.
- Many alternative products gain approval and may perform well in the short term, but some are subsequently banned by agencies due to issues like poor adhesion or moisture resistance. Since our specifications don’t currently address bio-based rejuvenators or additives, we need to develop specific testing protocols to evaluate their performance and suitability for our projects.

Existing binder supply pathways

- While there is awareness of the potential impact of a refinery closure in our state, it's not currently a pressing concern. A more immediate threat to our binder supply is the possibility of refiners prioritizing the production of higher-value oil products over asphalt.
- The ability to produce asphalt adds flexibility to a refinery's operations. While asphalt margins are currently lower than those for coke, a decline in coke or fuel oil margins could make asphalt production more attractive.
- The production of asphalt will be adjusted based on market demand and product margins. If margins decline or crude oil cuts are implemented, asphalt production may decrease. However, there are no immediate plans to completely cease asphalt production.
- Regardless of energy transition scenarios, there will continue to be demand for asphalt. However, it's important to note that no refinery configuration is designed to produce only asphalt. The production of gasoline and diesel will remain essential.

Environmental Product Declarations (EPDs)

- EPDs have not yet impacted our bidding process. While federally funded projects often require EPDs, our state market has not adopted this requirement. However, recognizing the growing trend in other states, we are proactively preparing to meet future EPD demands.

Carbon emissions regulations and costs

- While there is growing momentum towards decarbonization in the construction industry, current efforts are largely voluntary rather than mandated. This suggests the industry is still in the early stages of implementing significant changes.
- There is a lack of consumer demand for low-carbon products, and customers are unwilling to pay a premium for them. Without a strong push from transportation departments or a significant shift in consumer preferences, it's challenging to justify the increased costs associated with low-carbon solutions, particularly in a competitive, low-bid market.

Scope for future research

The study highlights several areas that would benefit from additional research to enhance asphalt sustainability:

- **Emissions and durability:** policymakers and industry standards should incorporate emissions estimates not just on a per-ton basis, but also account for the durability and treatments of roads over time.
- **Biogenic carbon sequestration:** research is needed to assess the lifecycle performance of bio-based materials and quantify potential emissions offsets through the use of biogenic carbon.
- **Impact of road roughness:** research should focus on quantifying how road roughness affects vehicle fuel economy, linking road quality to broader environmental impacts.
- **Advocacy for warranty-based contracting mechanisms:** since the current low-bid system may not be the best way to achieve pavement durability, advocacy for long-term warranty based contracting is needed to help ensure the durability and performance of pavements over their entire lifecycle.
- **Collective action:** industry participants should engage in dedicated discussions to address emissions across the value chain, promoting collaboration among suppliers and customers.
- **Future road designs:** investigating optimal road designs that accommodate heavier electric vehicles is crucial, considering their impact on road durability.
- **Resilience to extreme weather:** more research is needed on how to enhance the resilience of asphalt pavements to extreme weather, examining the balance between durability and potential emissions during production.

These areas present opportunities for advancing sustainable practices in the asphalt industry while addressing the challenges posed by evolving technologies and climate conditions.

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