By when will tire & rubber industry replace 6PPD?

Alternatives being evaluated "currently nowhere near scale needed to support the tire industry"

This year should see significant progress in the drive to find alternatives to 6PPD (6-para-phenylene-diamine) antioxidants, though advances will be incremental and system-based rather than involving any particular breakthrough chemistry.

That's according to Erick Sharp, founder and CEO of ACE Laboratories, which is actively involved in efforts to find a safer alternative to 6PPD: focusing mainly on supporting laboratory screenings of potential alternatives and assessing the migration of chemicals from wear particles into water.

Developed to protect against oxygen, ozone and cracking, 6PPD is used widely use in tire and rubber applications. Almost all commercial tires employ the ingredient, especially in the sidewall and tread compounds.

However, leaching of 6PPD from tire wear particles has been found to be harmful to certain species of salmon and trout in the US – via transformation by-product 6PPD-quinone (6PPDQ) on reaction with oxygen and ozone in the environment.

The issue has prompted regulators in the US, Europe and elsewhere to push for the phase-out of 6PPD with threats to impose restrictions on use of the long-established component of compounds used in the production of tires and rubber products.

Erick Sharp

California state regulators have been to the fore in this area, while Austrian and the Dutch authorities have initiated procedures that could lead to proposed restrictions on the use of 6PPD in the EU by the end of this year.

Tire manufacturers on both sides of the Atlantic are, therefore, now in a race to find alternatives to the use of 6PPD anti-degradants–including a coalition of 32 major tire makers based in California.

Coordinated by the US Tire Manufacturers Association (USTMA), the consortium has identified seven potential 6PPD alternatives, from the initial 60 candidates, which warrant further investigation.

Producers of synthetic rubber and chemical additives have also been highly active in this field, with potentially significantly advances reported by Asahi Kasei, Lanxess and Flexsys – among others.

"Through our laboratory screenings we feel there are alternatives that merit full scale evaluation," said Sharp, while pointing out that "none of these alternatives would be considered direct replacements for 6PPD.

Indeed, few in the industry expect to see a drop-in alternative emerge any time soon, particularly as the new chemistry will have to replicate the performance of 6PPD within rubber compounds across a wide range of processing and end-use conditions.

As Sharp of Ravenna, Ohio-based ACE Laboratories explains: "Most alternatives to 6PPD interact differently with the typical cure systems used in tire compounds. This means the substitution also requires adjustments to the incumbent cure package."

Meanwhile, added the US expert, most alternatives also require, at least, a dual combination of antiozonants to meet the same dynamic ozone and flex fatigue performance that 6PPD provides.

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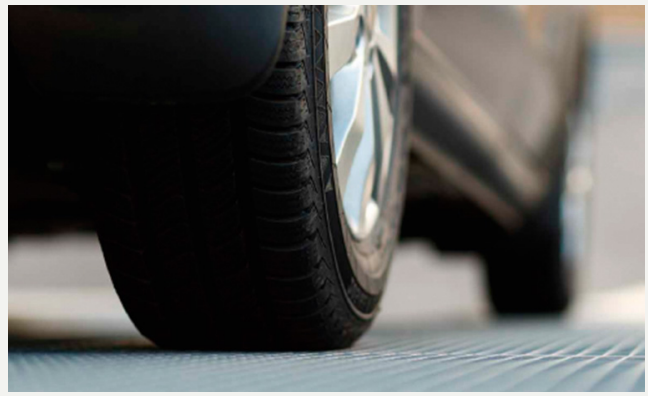
Emissions Analytics research



In a presentation to the ERJ Future Tire Conference, held 18-19 November 2025 in Prague, Nick Molden, founder & CEO of UK-based Emissions Analytics reported research showing that water and soil are more important than air as pathways by which tire particles affect humans and the environment – with road run-off a major vector.

Road surface water runoff, he said, washes into the environment every time it rains and is mostly connected to storm sewers or combined sewers through storm drains.

"They are not commonly connected to the sewage system and are, therefore, capable of entering our freshwater environments without treatment."

For example, he said, in England there are more than 18,000 outfalls associated with the motorways and main roads and likely more than a million local highway drains discharging directly to watercourses.

However, the chemical composition of tire compounds is a more significant factor than wear mass, Molden describing leaching and evaporation of organic chemicals as a "material contributor" to pollution.

Highlighting broader issues around the environmental impact of tire wear emissions, Molden stated that with around 6 million tonnes of tire wear generated annually worldwide, "water pollution is about much more than 6PPD-quinone and coho salmon."

According to Molden, what remains poorly understood are: the most important pathways for affecting humans; the health effects of tire nanoparticles; the rate of road wear emissions, and their chemical composition; and the composition and impact of resuspended road dust

Further research, the Future Tire presenter added, is also needed on: the chemical composition of tire emissions, how tire wear particles degrade in the environment; health and environmental risks from chronic exposure; and which vehicles and roads lead to the highest emission levels.

"ACE has long predicted that the replacement of 6PPD would be a system replacement and not just a one-for-one material replacement," Sharp continued in a written statement to ERJ.

There has been encouraging progress in this area, with the development of methodology to analyse chemical migration from wear particles into water.

According to Sharp, this has been "highly beneficial" in understanding how 6PPD and 6PPDq reach peak concentrations in water streams and "allowed for the assessment of other solutions such as torturous path barriers and molecular weight modification."

Asked about likely areas of progress in 2026, Sharp expects that the industry will see a lot of work on system changes as well as on evaluating full anti-degradant and cure systems.

"There have been recent industry claims of an even closer offset being developed," he added. "I expect we will see data and evaluations start on that technology as well.

"Now that options are advancing, we should see more clarity on timelines and expectations for regulators. Any new findings in human impact studies could greatly impact timelines and requirements. Progress and efforts in 2025 were fruitful and should fuel accelerated progress in 2026."

Sharp went on to note that most of the alternatives being evaluated are not commercially full-scale or are "currently nowhere near scale [needed] to support the tire industry. This means reaching a full-scale solution will require chemical plant design builds, potentially retrofitting chemical plants, and potentially technology licensing deals to meet demand."

Concluded the ACE Laboratories expert: "Companies will want to see strong performance in industry evaluations before they begin with those large expenses. Because of those challenges, I feel we are still over five years away from a complete industry solution."

Modified SBR approach

Japanese group Asahi Kasei, however, does have commercial-scale production of its synthetic rubber-based solution in its sights for this year, according to a statement from the petrochemicals major's European office.

Asahi has developed a selectively hydrogenated styrene-butadiene rubber (HSBR) that offers enhanced ozone resistance, thereby reducing the usage of 6PPD in tire tread and sidewall applications. The polymer has also been found to show improved mechanical properties.

For instance, it reported that if high-cis butadiene rubber (BR) is replaced by the HSBR in a natural rubber (NR)/BR blend, then the equivalent NR/HSBR compound showed about twice the fatigue resistance with respect to the NR/BR compound.

A particular target for the HSBR is in tire sidewalls, which are most exposed to UV and ozone, as well as being constantly subjected to cyclic stress during driving. Usage of the modified HSBR in the sidewall could eventually reduce the frequency & need of tire replacements due to degradation, believes Asahi.

Asahi has previously reported that the HSBR was being "tested by many tire manufacturers worldwide" and had received positive feedback. It was also working to improve the fuel-efficiency of tires incorporating the elastomer in treads and sidewalls.

Asked about the current status of the development programme, Daisuke Hayata, technical sales & business development manager of the rubber department at Asahi Kasei Europe said: "Our main target for 2026 is the commercialisation of our selectively hydrogenated SBR."

"We are currently working very closely with various tire manufacturers, providing technical support to achieve a smooth adaptation of our new material." Hayata added in a 15 Jan written statement for this feature.

Reiterated the Asahi Kasei Europe

manager: "We [have] made significant progress in regard to material development and registration at both tire and non-tire manufacturers. The next step is the market launch of the HSBR. We are aiming for commercialization within the current calendar year 2026."

CCPD alternative speciality chemicals major Lanxess has developed a rubber anti-degradant employing n,n'-dicyclohexyl-1,4-phenylene diamine (CCPD), which is said to offer an alternative to the use of 6PPD in tires. Citing lab results, Lanxess believes the product, labelled Vulkanox 4060, is a potential 6PPD replacement.

The rubber chemical, reported Lanxess, "shows similarly strong antioxidant and antiozonant performance results in rubber tests, while having a more favourable product safety profile."

For use in compounds based on diene rubbers such as NR, BR, SBR and blends, Vulkanox 4060 "offers very good protection against oxidation, ozone attack, and flex cracking," the company added.

In testing, aged for 28 days at 60°C, the tensile strength of a reference compound was reduced by about 22%, whereas in compounds with CCPD the tensile strength reduced by only 13% – similar results to those seen with 6PPD.

Among other claims, Lanxess said the new product exhibits: "Exceptional resistance to oxidative aging; very good ozone protection; shields rubber surfaces from ozone-induced damage; and enhances flex cracking resistance."

The company noted that the chemical structure of Vulkanox 4060 also has the potential to form quinones: the quinone formation from para-phenylene-diamines (PPDs) is an integral part of the rubber protection against ozone.

OECD Guideline 203 standardised testing of the toxicity of the potential ozonation product CCPD-quinone to coho salmon was completed "with no mortality or abnormal behaviour observed."

While the performance and safety profile is still being tested, Lanxess said it is targeting global registration of Vulkanox 4060, with a roadmap covering studies of all potential human health and environmental safety concerns of related chemicals – as required under EU REACH.

CCPD is being produced in pre-commercial scale at Lanxess facilities, with plans to "ramp-up the production in the next years, which goes hand in hand with different product safety studies."

In a 23 Jan update for ERJ, Lanxess said: By around February we expect to finish the Annex VII (1-10 t/a) registration under EU-REACh. Furthermore, we are expecting the EU-REACh registration of above 1000 t/a in Q2 2026 and continue to move towards commercialisation of Vulkanox 4060."

Furthermore, Lanxess noted that the CCPD production process "is known and proven in a pre-commercial state. It is possible to produce CCPD without greenfield investments. Large volumes of all major raw materials for CCPD are available on the market. CCPD is a solid product that can be used in existing tire manufacturing mixing assets."

'Breakthrough' claim

In November 2025, Akron, Ohio-based tire additives supplier Flexsys claimed a breakthrough with the introduction of "the industry's first viable alternative" to 6PPD antioxidants.

Without providing further details, Flexsys said its alternative employs chemistry outside the 'PPD family', so avoiding the formation of 'quinone' by-product entirely.

According to Flexsys, its R&D team 'is on track' to meet targets including "providing short- and long-term protection to tires against degradation" while maintaining high safety standards and durability.

Furthermore, Flexsys said introducing the replacement involves 'minimal change' in rubber compound formulations, while the new additives are also said to meet environmental and regulatory benchmarks.

Flexsys is now engaged in 'extensive testing' to allow 6PPD to be replaced at a rapid pace, meet tire safety standards and comply with environmental regulations.

The US-based company said it is also optimising the process chemistry to allow for "efficient world-scale production," while continuing work with regulatory agencies globally to have the new chemistry fully approved for commercial use.

Asked for an update for this report, a Flexsys spokesman declined to provide information further to that given in the November announcement.

BRIEFS

Technology: Researchers at the University of Delaware in the US have developed a technique to remove anti-degradant substance 6PPD from end-of-life tires (ELTs). The process, developed by the center for plastics innovation and department of chemical and biomolecular engineering, 'upgrades 6PPD' into safe chemicals and turns leftover crumb rubber into aromatics and carbon black. Led by Dion Vlachos, University of Delaware Dan Rich chair in energy, the research tried to remove 6PPD from ELTs via chemical extraction, the US university team reported 20 Nov. The process involved heating 'millimetre-sized' pieces of tire or crumb rubber in a microwave reactor: using a chemical solvent to quickly separate the 6PPD from the other molecules present. Once the 6PPD molecules are removed, they can be chemically converted into safe chemicals that can be used or sold for a small price, according to the release.