Turbostratic Graphene as a 6PPD Alternative in Tire Compounds

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THE PROBLEM: 6PPD AND ITS ENVIRONMENTAL IMPACT

6PPD (N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine) has been a standard additive in tire sidewall compounds for decades. It prevents rubber degradation from ozone and oxygen exposure — both of which cause sidewall cracking and premature tire failure. Without an effective antiozonant, tire durability drops significantly.

The problem is what happens after the tire meets the road. 6PPD reacts with ozone to form 6PPD-quinone, a transformation product that washes off tire rubber onto road surfaces and into stormwater systems. Research published in 2020 identified 6PPD-quinone as the primary cause of coho salmon pre-spawn mortality in urban stormwater-impacted waterways — including those draining into Puget Sound. Coho return rates in some urban streams dropped as low as zero during rain events. The compound is acutely toxic to coho at concentrations as low as 0.1 micrograms per liter.

Regulatory and industry pressure to replace 6PPD has grown substantially since that finding. The challenge is that no drop-in replacement has yet matched 6PPD's antiozonant performance across all tire compound types and service conditions.

FARADYNE'S TECHNOLOGY: TURBOSTRATIC GRAPHENE

Faradyne Power Systems produces turbostratic graphene under two commercial grades: ProCene and ProCnano. Graphene is a single-atom-thick layer of carbon atoms arranged in a hexagonal lattice — one of the strongest and most conductive materials known to science.

Turbostratic means the graphene layers are rotationally disordered relative to each other, unlike pristine (structurally ordered) graphene. This disorder creates larger interlayer spacing and higher surface chemical activity — properties that turn out to be useful in rubber compound applications.

Faradyne's graphene is produced from graphite via a solvent process. The resulting material has:

- Plate aspect ratios of 500 to 15,000 (plate width up to 15 microns, thickness under 1 nanometer)
- Higher electrochemical surface activity compared to pristine graphene grades
- Disordered structure that facilitates rubber penetration and dispersion at the nanoscale

THE CASE FOR GRAPHENE AS A 6PPD REPLACEMENT

The antiozonant function of 6PPD works by scavenging free radicals and intercepting ozone before it attacks the rubber polymer chains. Graphene's aromatic carbon ring structure gives it a similar capability: the extended pi-electron system can act as a free radical trap and antioxidant in rubber matrices. This has been reported in peer-reviewed literature and is the basis for Faradyne's sidewall compound development program.

The critical distinction from 6PPD is chemical inertness. Faradyne's graphene grades do not produce reactive quinone-type transformation products. Graphene is not water-soluble and does not readily leach from rubber into stormwater in the same way small-molecule additives do. This makes it a structurally different class of solution — not just a chemical substitute, but a material that stays bound in the compound.

It is important to note that Faradyne does not claim graphene fully replicates 6PPD performance under all conditions at current tested loadings. The company's position is that graphene represents a technically credible candidate for partial or full replacement, with ongoing lab work defining the performance envelope.

WHERE THE LAB WORK STANDS

Faradyne is conducting an independent testing program in partnership with Akron Polymer Solutions (APS) and Akron Rubber Development Laboratory (ARDL) — both recognized tire industry research organizations based in Akron, Ohio.

The sidewall compound study tested ProCene and ProCnano at 2.5 and 5.0 parts per hundred rubber (phr) against a control compound containing conventional TMQ antioxidant and 6PPD. Key findings to date:

- 300% modulus was equivalent across all graphene-containing compounds and the standard control — meaning the rubber stiffness profile, which affects ride quality and durability, was not adversely affected.
- Tear strength was directionally comparable. Prophene (a pristine graphene benchmark from APS) showed a slight advantage; Faradyne grades performed within 5% across both grades and loadings.
- ProCnano at 5 phr showed better abrasion resistance than the pristine graphene benchmark — relevant for sidewall scuff durability.
- Aging resistance (tensile strength retention after 72 and 120 hours at 100 degrees C) was lower for graphene-only compounds versus the TMQ/6PPD control. This is the primary open technical question. Testing was designed as a full replacement study; supplementing graphene with reduced levels of conventional antioxidants is expected to close this gap and is part of the next study phase.
- Cure characteristics (vulcanization time and crosslink density) were equivalent — graphene does not disrupt the tire manufacturing process.

Ozone resistance testing and fatigue resistance data from the current study are pending laboratory analysis. Those results will be incorporated into Faradyne's technical documentation when available.

PATH TO COMMERCIAL ADOPTION

Translating lab results into commercial tire production involves several stages. Faradyne's near-term program focuses on completing the current sidewall study, running a supplementary test series to establish the optimal graphene-plus-reduced-antioxidant formulation, and generating a full technical package suitable for presentation to tire manufacturers.

Tire manufacturers typically require a multi-year qualification process before adopting new compound additives for production — particularly for OEM-supplied tires where vehicle manufacturer specifications apply. Aftermarket and replacement tire channels move faster. Faradyne is targeting initial commercial engagement with U.S.-based tier-2 and tier-3 tire manufacturers as the practical first step.

The company does not project a specific commercial launch date at this stage. The science is progressing, and the regulatory environment around 6PPD is accelerating industry interest in alternatives.

For technical questions or follow-up: Luis Gonzalez, VP Business Development, Faradyne Power Systems Corp.

Primary research reference: Akron Polymer Solutions, Evaluation of Faradyne Power Graphene (ProCene, ProCnano), October 2024. Supporting literature: Paschall, Halasa, Rodgers, Terrill, Rubber News, November 2021.