Preliminary (Stage 1) Alternatives Analysis Report Motor Vehicle Tires Containing N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)

Prepared for
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Abbreviations

44PD	N,N'-Di-sec-butyl-p-phenylenediamine
6PPD	N-(1,3-Dimethylbutyl)-N'-phenyl-p- phenylenediamine
6PPDQ	N-(1,3-Dimethylbutyl)-N'-phenyl-p- phenylenediamine quinone
7PPD	N-(1,4-Dimethylpentyl)-N'-phenyl-p-phenylenediamine
77PD	N,N'-Bis(1,4-dimethylpentyl)-p-phenylenediamine
AA	Alternatives Analysis
ASTM	American Society for Testing and Materials
CAFE	Corporate Average Fuel Economy
CalDTSC	California Department of Toxic Substances Control
CARB	California Air Resources Board
CAS	Chemical Abstracts Service Number
CASRN	Chemical Abstracts Service Registry Number
CCPD	N,N'-Dicyclohexyl-p-phenylenediamine
CCR	California Code of Regulations
CPPD	N-Cyclohexyl-N'-phenyl-p-phenylenediamine
CPSC	U.S. Consumer Product Safety Commission
CSI	Chemical Scoring Index
DAPD	Diaryl-p-phenylene diamine
DNA	Deoxyribonucleic Acid
DNPDA	N,N'-Di-2-naphthyl-p-phenylenediamine
DOPD	4,4'-Dioctyldiphenylamine
DPPD	N,N'-Diphenyl-p-phenylenediamine
DTPD	N,N'-Ditolyl-p-phenylenediamine
DTSC	Department of Toxic Substances Control
ECHA	European Chemicals Agency
EPDM	Ethylene Propylene Diene Monomer
EU	European Union
FHSA	Federal Hazardous Substances Act
FMVSS	Federal Motor Vehicle Safety Standards
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GPC	Global Product Classification
GRAS	Generally Recognized as Safe
GWP	Global Warming Potential
Hg	Mercury
HSDB	National Library of Medicine's Hazardous Substance Data Base
IMAP	Australia Inventory Multi-tiered Assessment and Prioritisation
IPCC	Intergovernmental Panel on Climate Change
IPPD	N-Isopropyl-N'-phenyl-p-phenylenediamine
K_{oc}	Log Organic Carbon Partition Coefficient
K_{ow}	Log Octanol-Water Partition Coefficient
LCA	Life Cycle Assessment
LOLI	Underwriters Laboratories, Inc.'s List of Lists
NESHAP	National Emission Standards for Hazardous Air Pollutants

NHTSA	National Highway Traffic Safety Administration
ODI	Office of Defects Investigation
ODP	Ozone-Depleting Potential
OE	Original Equipment
OEM	Original Equipment Manufacturer
OVSC	Office of Vehicle Safety Compliance
PBT	Persistent, Bioaccumulative, and Toxic
PPDs	Paraphenylene Diamines
PPE	Personal Protective Equipment
RE	Responsible Entity
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RRC	Rolling Resistance Coefficient
SBR	Styrene Butadiene Rubber
SCP	Safer Consumer Products
SMART	Shape Memory Alloy Radial Technology
SMILES	Simplified Molecular Input Line Entry System
TAC	California's Toxic Air Contaminant List
TIN	Tire Identification Number
TMQ	Poly(1,2-dihydro-2,2,4-trimethyl-quinoline)
TRWP	Tire and Road Wear Particles
UVCBs	Unknown or Variable Compositions, Complex Reaction Products, and Biological Materials
UL	Underwriters Laboratories, Inc.
UN	United Nations
USGS	United States Geological Survey
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
USPTO	United States Patent and Trademark Office
USTMA	U.S. Tire Manufacturers Association
UTQGS	Uniform Tire Quality Grading Standards
VOC	Volatile Organic Compound

Executive Summary

Effective October 1, 2023, The California Department of Toxic Substance Control (DTSC) listed motor vehicle tires containing N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD) as a "priority product" under the Safer Consumer Products (SCP) Regulations.

This Stage 1 Alternatives Analysis (AA) report was prepared under the SCP Regulations on behalf of a Consortium[1] comprising some, but not all, manufacturers of the Priority Product for sale in California. As conceived by Gradient and the Consortium, the initial goal of an AA is to answer the following question: Do potentially safer, functionally acceptable, and technically feasible alternatives to the Priority Product exist that should be given a more in-depth consideration to determine if they qualify as acceptable alternatives?

This Stage 1 AA was based on available information and sought to determine whether there are possible alternatives to the priority product that should be considered in greater depth to evaluate if they are suitable alternatives to replace the priority product under regulatory guidelines (CalDTSC, 2017a). Important elements of this work were considering the requirements (legal, regulatory, or otherwise) for the priority product, determining the function of the chemical of concern in the priority product, determining whether simple elimination was possible and assessing relevant factors to identify those that would suggest a material difference exists that could affect the decision as to whether a possible alternative is a suitable replacement for the priority product. This last element required compiling extensive information on the potential hazards, potential performance, and chemical and physical properties of the possible alternatives.

6PPD is used in tires as an antidegradant, protecting the components of the tire from attack by ozone, oxygen, thermal degradation, and mechanical fatigue, *etc*. In late 2020, it was first reported that when it reacts with ozone, 6PPD forms a degradation product, 6PPD quinone (6PPDQ) (Tian *et al*. 2021); this reaction with ozone is part of the way in which 6PPD protects tire rubber from degradation. Without 6PPD, tires will quickly develop cracks and fractures as the rubber polymer is degraded. The antidegradant function of 6PPD in tires is therefore essential to their safe use, and elimination of 6PPD without replacement is not an option.

One way 6PPD and 6PPDQ may enter the environment is through tire and road wear particles (TRWP), which are produced as the tire grips the road surface during driving. Some 6PPD and 6PPDQ on the tire surface may also be washed off the tire by rain or vehicle washing. US EPA has also noted uncertainty about levels of 6PPDQ exposure to the environment from tires relative to other potential sources (Freedhoff, 2023).

Recent laboratory studies stated that 6PPDQ is acutely toxic to coho salmon, and those studies suggest that 6PPDQ exposure from stormwater runoff, under certain conditions, may result in mortality of these fish in streams and rivers located near roadways (Tian *et al*. 2021). Some other salmonid species may be similarly affected under similar circumstances, although with lower toxicological potency than coho, while other species apparently exhibit negligible toxicological susceptibility (see for example Brinkmann *et al*., 2022; Hiki and Yamamoto, 2022; Greer *et al*., 2023). The biological mechanisms by which the toxicity occurs, and why it affects some species and not others, is not yet known but is the subject of active research.

[1] The Consortium refers to the group of Responsible Entities that prepared this Stage 1 AA in accordance with the SCP Regulations.

It is important to note that while vehicle tires are large consumers of 6PPD, 6PPD is also used in other rubber products. Additionally, tire manufacturers began using 6PPD in tire manufacturing in the mid-1960s to early 1970s. However, significant declines in the coho salmon populations in California were observed as early as the 1940s, pre-dating the use of 6PPD in tires by several decades (California Dept. of Fish and Game, 2002).

In this Stage 1 AA we considered several different types of alternatives to 6PPD as an antidegradant in tires: (1) other phenylene diamines (PPDs) that are the most logical and possibly easiest to implement alternatives to 6PPD, and (2) non-PPD alternatives that likely pose greater challenges in terms of incorporation into tire chemistry.

For all of the alternatives under consideration, information is incomplete regarding their potential hazards to coho and other fish species, although for many alternatives, data are available on other types of hazards to determine if those alternatives are unsuitable. Similarly, for some of the alternatives, initial bench scale data on performance as an antiozonant is available but definitive data on the ability to use the possible alternative in manufacturing a tire and data on the performance of that tire in all of the required tests are lacking. At this point in time, we can state that five alternatives, 7PPD, IPPD, 77PD, CCPD and specialized graphene[2] (*e.g.,* Prophene™) warrant further evaluation as potential alternatives.[3] Consequently, since there do appear to be possible alternatives that merit additional consideration, a two stage AA as described by the SCP regulations is appropriate. It is expected that additional data will become available within the time frame of the second stage AA that will allow for a more detailed evaluation of a suitable alternative(s).

As required by the SCP regulations, the following is a summary of information contained in each section of the stage 1 AA report.

- **Section 1** identifies the persons who oversaw the preparation of this report.
- **Section 2** identifies the Consortium members submitting this report and addresses how they will be submitting supply chain information as a separate confidential business information (CBI) submittal.
- **Section 3** identifies the Priority Product (motor vehicle tires containing 6PPD) and the chemical of concern (6PPD). Tables listing the manufacturers and their priority products, consistent with the product names on the submitted Priority Product Notifications (PPNs), are also included as appendix B. Section 3 identifies the function of the chemical of concern in the Priority Product (*i.e.*, antidegradation). Section 3 also discusses the many performance requirements of motor vehicle tires and identifies tests that are conducted to evaluate this performance. Key performance criteria include static and dynamic antioxidant and antiozonant operation modes, including but not limited to high speed performance, rolling resistance, endurance, wear rate, and traction in dry, wet, and snow conditions. Some of these performance criteria are related to product safety and are mandated by federal and state regulations. Other performance criteria are related to vehicle fuel efficiency or customer expectations (*e.g.*, tire warranty, ride comfort). Section 3 concludes with a discussion of how removal of 6PPD from tires without a functional replacement is not possible and thus an alternative performing the same function is required.

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[2] The materials referred to as graphene in this report are graphene-based materials (sometimes referred to as a graphene nano-platelet) with a surface area not greater than 180 m^2/g, and a carbon content greater than 99% and an oxygen content less than 1%. The lateral particle size of these materials is between 100 nm and 5 μm.

[3] This preliminary alternatives analysis outlines the process to assess whether alternatives can replace chemicals or technologies of concern based on their hazards, performance, and exposure potential. The term "hazard" as used throughout this document is used in keeping with the relevant guidance documents.

- **Section 4** begins with a scoping discussion that describes technologies that fall outside the scope of this AA. Alternative tire technologies, such as non-pneumatic tires, are not suitable alternatives because they would also require the use of antidegradant chemicals in their rubber compounds or cannot be currently mandated or implemented by tire manufacturers. Some of these technologies are currently theoretical and have not been demonstrated to be useable for cars, trucks or buses. A second non-viable option is a particle collector system which would reduce, somewhat, the load of particles emitted during tire use. This option is not suitable because it is beyond the ability of tire manufacturers to mandate such technologies and also because the technology's effectiveness in reducing migration of 6PPD to the environment appears limited. Although reduction in exposure potential does constitute a viable alternative under the SCP regulations, it is not clear that this technology could reduce exposure to the extent that would be considered meaningful.

  Section 4 next discusses how information was obtained to identify possible alternatives to 6PPD in motor vehicle tires. Following this approach, over 60 candidate alternatives for 6PPD were identified. The section describes how each of these possible alternatives was screened and scored in terms of its likely feasibility and how those that appeared promising were selected for full evaluation in the AA. The 40 possible alternatives selected to include in the full scope of the AA included 19 other phenylene diamines (PPDs) and 21 non-PPD based antidegradants.

  Section 4 concludes with a discussion of factors that were considered to be relevant to this Stage 1 AA. It includes a discussion of conceptual exposure models that show how individuals and environmental receptors may be exposed to 6PPD across the tire product life cycle. It also describes what is known regarding the relevance of each life cycle aspect noted in the SCP regulations to the evaluation of different alternatives. A life cycle assessment (LCA) is available for tires but is not available for 6PPD nor for any of the possible alternatives, making quantitative comparisons among the alternatives to determine whether there is a material difference impossible. More qualitative arguments, based on raw materials used in manufacturing 6PPD and the alternatives, their chemical properties and the required properties of any alternative (*e.g.*, lifespan of the product, ability to be recycled or repurposed) suggest that for the use, waste generation, recycling/reuse and end of life portions of the product lifecycle, there do appear to be potential material differences among the priority product and possible alternatives but this would need to be further explored in Stage 2. For other life stages (*i.e.*, raw materials extraction, intermediate materials processing, product manufacturing, product packaging, and operation and maintenance) there are unlikely to be material differences between the Priority Product and the possible alternatives. For the remaining life cycle stages (*i.e.*, resource consumption and distribution) it is unclear whether there will be differences among products because relevant data for the possible alternatives are lacking.

- **Section 5** begins with a review of health hazard information for the Priority Product and the possible alternatives. Overall, all of the alternatives involve reactive molecules, which was anticipated given that the requirement is for a chemical that can scavenge ozone and oxygen. We obtained data on the hazards of the possible alternatives from two primary data sources – European Chemicals Agency (ECHA) Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) dossiers and GreenScreens® conducted by ToxServices for the State of Washington, Department of Ecology. Using an adaptation of a published scoring approach, we found that 23 of the 40 possible alternatives had insufficient data to assign a hazard score. Of the 17 possible alternatives with sufficient data, 11 had scores estimating at least 25% potential hazard reduction relative to 6PPD. These 11 chemicals included 4 PPDs (77PD, 44PD, DTPD, and DAPD) and 7 non-PPDs (ethoxyquin, DLTP, TAPDT, two N-Phenyl naphthalamine derivatives, graphene, and an Irgazone 1520/Vulcazone AFS blend). Three of these possible alternatives had hazard scores that were an order of magnitude better than 6PPD: DLTP, graphene, and the Irgazone

1520/Vulcazone AFS blend. Note that a reduction in hazard alone does not define an appropriate alternative.

In addition to the hazard scoring, we also researched and tabulated available information about the potential of the possible alternatives to affect coho salmon or related salmonid species. Data on this subject are extremely limited. Only a single study has evaluated one possible alternative (77PD). Two studies evaluated the quinone transformation products of five possible alternatives (77PDQ, CPPDQ, DPPDQ, DTPDQ, and IPPDQ). These studies suggest there may be lower acute toxicity of 77PDQ, CPPDQ, DPPDQ, DTPDQ, and IPPDQ relative to 6PPDQ, however, these results are preliminary and unconfirmed.

Section 5 also discusses the preliminary and unpublished results of testing commissioned by USTMA and conducted by the US Geological Survey (USGS). This testing used *in vitro* (isolated cell) systems to study the potential toxicity of 6PPD and a small number of alternatives (the number of alternatives was limited so as to be able to have data to consider in the Stage 1 AA). The results of that testing showed differential toxicity relative to 6PPD, providing a preliminary indication that not all PPDs pose the same degree of hazard to coho as 6PPD.

We also explore potential environmental transformation products of the possible alternatives and examined their chemical and toxicological properties. Using ECHA dossiers as the source of transformation product information, we found that a number of PPDs likely share the same potential breakdown products as 6PPD (*e.g.*, aniline and p-benzoquinone). The extent to which transformation actually occurs from antidegradant in TRWP is unknown. For many of the possible alternatives, transformation product information was not available in the ECHA dossier. This lack of information represents a significant uncertainty in the AA and will need to be addressed in Stage 2.

Section 5 next discusses product performance. Performance information was grouped into three different source categories: historical data from patents and other information published before 2020 (the year the Tian *et al*. [2021] publication first appeared on-line); data from recent bench scale testing of a few alternatives by Flexsys (the same alternatives tested by USGS); and recent data from patents or other sources published in 2020 up to January 2024. In tables relevant to each category, the findings for each alternative regarding potential performance are summarized and the citation to the relevant study is provided. Based on those results, we also conclude whether further testing (beyond preliminary bench scale studies) is warranted. Based on this evaluation, fourteen different alternatives were determined to be appropriate for further performance evaluation. This included a number of PPDs (*e.g.*, 7PPD, 77PD, IPPD, CPPD, and CCPD), an anilinophenol, a quinoline amine and a specialized graphene. Note that an indication of acceptable antiozonant performance in screening type tests alone does not define an appropriate alternative.

Section 5 concludes with a review of relative exposure information for the Priority Product and the possible alternatives. We gathered chemical specific physiochemical data for all of the alternatives, as suggested in CalDTSC's "Alternatives Analysis Guide" (CalDTSC, 2017a). Some of the possible alternatives have substantially less water solubility than 6PPD (*e.g.*, DOPD, DLTP, RU997, and TAPDT) which could affect their environmental partitioning. Similarly, some have substantially higher log K_{ow} values (an indication of partitioning into organic materials) than 6PPD (*e.g.*, DLTP, Ru997/Irgazone 997 blend, TAPDT, and DOPD) which again could result in different environmental behavior. Some also have substantially different vapor pressures (some higher, some lower) which could affect workplace exposures. While this evaluation provided some insight into the ingredient-level exposure potential of the possible alternatives, ideally, we would compare the product-level exposure data, because the ingredients are meant to react and create a structure that is distinctly different from the individual ingredients. Because the relative importance of mobility in one environmental medium *versus* another is not clear, no product-level exposure information is available at this time for any alternative.

- **Section 6** presents the conclusions of the Stage 1 AA. This section describes how information on chemical hazard, performance and exposure potential, described in detail in Section 5, are aggregated into an overall comparison table (Table 5.15) and used to determine whether a particular possible alternative should be further evaluated in the Stage 2 AA. Chemicals selected for evaluation in Stage 2 had (1) similar or reduced overall hazard relative to 6PPD based on the available information, (2) screening level performance data indicating a potential to perform in tires as an antiozonant, and (3) acceptable physical/chemical properties indicative of exposure potential. The chemicals that met these criteria were: 7PPD, IPPD, 77PD, CCPD, a specialized graphene. Thirty-five of the 40 alternatives evaluated were eliminated from further consideration in Stage 2 either because they have so many data gaps in terms of toxicological hazard that they could not be confidently evaluated, or due to a lack of performance data or because available data indicated they would not perform well against ozone. No alternatives were excluded based on relative exposure potential. Because the Stage 1 AA determined there were possible alternatives to the Priority Product, the report concludes that a Stage 2 AA is appropriate.
- **Section 7** discusses the proposed WorkPlan for the Stage 2 AA. This includes a table of expected timing for meetings with DTSC and the types of additional information that will be gathered to support the Stage 2 assessment.
- **Section 8** discusses uncertainties encountered in preparing this Stage 1 AA and the potential implications these may have for the results of the Stage 2 AA. For example, any potential acute aquatic toxicity hazards reported in salmonids may not represent potential hazards or risk associated with their presence in a final vehicle tire product, as any potential hazard of these chemicals is dependent upon their potential migration from vehicle tires and TRWP, which if any, remains unclear. This section also includes suggestions for how these uncertainties can be reduced in the Stage 2 analysis.
- **Section 9** lists the report references.

Appendices providing some of the supporting data and other relevant information are included at the end of the report.

1 Preparer Information

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[4] Submitting on behalf of a Responsible Entity group comprised of the responsible entities listed here.

2 Consortium Members and Supply Chain Information

USTMA 6PPD Alternatives Analysis Consortium Membership

( ) indicates name(s) used for PPN if different

American Kenda Rubber Industrial Co., LTD (America Kenda Rubber Ind Co.)
Apollo Tires (US) Inc. (Apollo Tyres Limited)
Bridgestone Americas, Inc.
CEAT Ltd.
China Manufacturers Alliance, LLC
Continental Tire the Americas, LLC
GITI Tire (USA), Ltd. (Giti Tire)
Hankook Tire America Corp.
Jiangsu General Science Technology Co., Ltd.
JK Tyre & Industries Limited
Kumho Tire U.S.A., Inc. (Kumho Tire)
Linglong Americas, Inc.
Maxxis International – USA (Maxxis Technology Center) (Cheng Shin USA Tech Center)
Michelin North America, Inc. (+ PT. Multistrada Arah Sarana Tbk)
Nexen Tire America, Inc. (Nexen Tire Corporation)
Nokian Tyres Inc. (Nokian Tyres US Operations LLC)
North American Commercial Tire Resources Inc. (Guizhou Tyre Co., Ltd.)
Otani Radial Tire Co, Ltd and Otani Tire Co, Ltd
Pirelli Tire LLC
Prinx Chengshan Holdings, Ltd
Prometeon Tyre Group Commercial Solutions, LLC
Qingdao Sentury Tire Co., Ltd.
Sailun North Americas (Sailun Group Co., Ltd)
Shandong Haohua Tire Co., Ltd
Shandong Jinyu Tire Co., Ltd
Sumitomo Rubber Industries, Inc.
The Goodyear Tire & Rubber Company
Toyo Tire Holdings of Americas Inc.
Yokohama Tire Corporation (+ Yokohama TWS North America, Inc.)
ZC Rubber America Inc.

Information regarding supply chain is being submitted to DTSC by USTMA as confidential business information and is not included in this report.

3 Priority Product Information

3.1 Priority Product Made by Consortium Members Participating in This Alternatives Analysis Report

This Consortium comprises some but not all manufacturers of motor vehicle tires containing 6PPD. Products made by these responsible entities that fall within the scope of the priority product listing are shown in Appendix B. Requirements under 29 CFR § 1910.1200 to provide a Safety Data Sheet (SDS) do not apply to tire manufacturers for a new, finished tire, since a new tire is an article as defined in 29 CFR § 1910.1200(c). Therefore, to meet the requirement in 22 CCR § 69505.7(e)(4) to provide "any Material Safety Data Sheets and/or Safety Data Sheets related to the Priority Product," we are providing as an example a Safety Data sheet for Santoflex™ 6PPD Pastilles prepared by Flexsys (Appendix C), which is publicly available on the Flexsys website. We are aware that 6PPD may be available in other forms, including liquid form, and that other 6PPD suppliers would have their own SDSs. This SDS is intended as an example to meet the regulatory requirement.

3.1.1 Overview of Motor Vehicle Tire Composition and Manufacturing

Tires[5] are the only part of a vehicle that contacts the road, and that connection is vital in helping to keep motorists safe. Tires play an essential role in vehicle safety by transferring the driver's inputs from the vehicle to the road. Additionally, tires support the weight of the vehicle, facilitate steering for maintaining vehicle control, grip the road for acceleration and braking, and must perform in a variety of weather conditions. Tires are highly engineered products whose performance must meet applicable Federal Motor Vehicle Safety Standards, vehicle manufacturers' ride, handling, and traction criteria, rolling resistance requirements important in meeting fuel efficiency targets, and customer expectations for quality and performance.

The product the public knows as a tire is formed from various components (*e.g.*, sidewall, tread, inner liner). These components are in turn composed of different compounds, that is, mixtures of rubber polymers, also known as elastomers, and various additives. The tire components also include materials such as textile or steel cords. An important aspect of the tire is its use of vulcanized rubber. Vulcanization is a process in which heat is applied to the "green", or uncured, rubber compound causing a chemical reaction among sulfur, other chemicals, and polymers (elastomers) in the rubber compound. These reactions result in chemical bonds (cross links) between the polymer (elastomer) chains to produce cured tires.

The general structure of a passenger car tire, including some key components, is shown in Figure 3.1, and the typical structure of a radial medium commercial truck and bus tire is shown in Figure 3.2.

[5] As used in this document, "tire" means a pneumatic radial tire used with motor vehicles (*e.g.*, passenger cars and light duty trucks, motorcycles, and heavy duty trucks and buses).

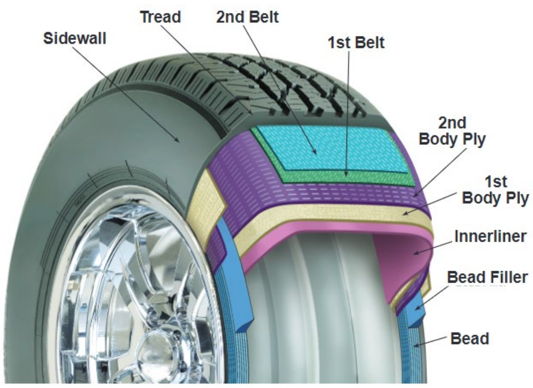

Figure 3.1 Typical Construction Features of a Pneumatic Radial Passenger Car Tire. Source: USTMA, 2017a

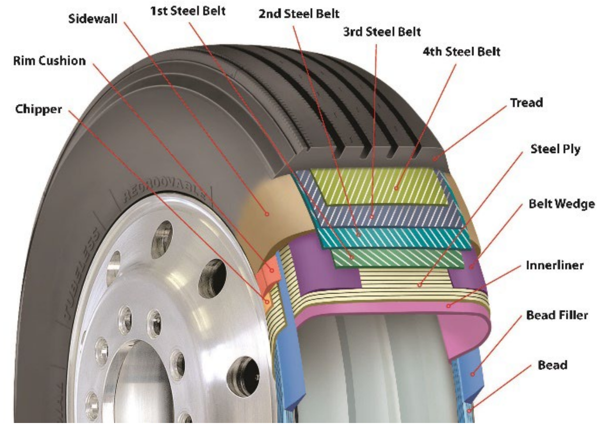

Figure 3.2 Typical Construction Features of a Pneumatic Radial Medium Commercial Truck/Bus Tire. Source: USTMA, 2017b

An explanation of some key tire components and the function they serve in a tire is given below.

- **Bead:** The tire bead is the portion (or component) of the tire that sits on the rim of the wheel. Tire beads are steel wire bundles that are coated with a specific rubber compound and secure the tire to the metal wheel.
- **Bead Filler:** A rubber compound placed above the bead that may be used between the body plies which wrap around the bead to enhance ride and handling characteristics.
- **Belts:** Typically, two belts with steel cords laid at opposing angles form a hoop under a tire's tread. Belts provide stability to the tread area of the tire, which minimizes wear and contributes to vehicle handling and traction. The steel belt is coated with a rubber compound that is called a belt coat or belt skim compound.
- **Body Plies:** Most car tires have one or two body plies, each typically comprised of textiles cords within a rubber layer. Truck and bus tires typically use steel cords for body plies. Body plies function as the base structure of the tire and provide the strength to contain the inflation pressure.
- **Inner liner:** A rubber compound used to retain the inflation pressure inside the tire.
- **Sidewall:** A rubber compound used to cover the body plies on the sides of the tire, which provides abrasion, scuff, and weathering resistance.
- **Tread:** Located on the road contacting portion of the tire, the tread rubber compound and tread pattern provide grip and abrasion resistance contributing to traction and treadwear.

All of these components have to be permanently bonded together in order for the tire to properly and safely function.

3.1.1.1 Tire materials and tire compounding

As noted above, each of the components of a tire are composed of uniquely formulated rubber compounds and may include reinforcing materials such as steel and textiles. Compounding, the science of selecting and combining materials for a specific tire component, is complex. Categories of materials used in tire compounding include the following:

- **Natural Rubber:** Natural rubber provides specific performance characteristics to tires, such as tear and fatigue crack resistance. Some tires, especially truck and bus tires, use natural rubber in tread compounds to provide reduced rolling resistance (the resistance the tire encounters when rolling down the road, an important consideration for fuel efficiency). Natual rubber is a form of polyisoprene which is obtained by tapping rubber trees (*Hevea brasiliensis*).
- **Synthetic Polymers:** The two main synthetic rubber polymers, or elastomers, used in tire manufacturing are butadiene rubber and styrene butadiene rubber (SBR). These synthetic rubber polymers are used in combination with natural rubber. The physical and chemical properties of these rubber polymers determine the performance of each component in the tire as well as the overall tire performance. Another important synthetic rubber is halogenated polyisobutylene rubber, commonly known as halobutyl rubber, which is used in the inner liner. This material causes the inner liner to have reduced air permeability, which helps to keep the tire inflated.
- **Fillers:** Multiple grades of carbon black and coupled/uncoupled precipitated amorphous silica are used as fillers to reinforce the rubber and modify its properties resulting in improved wear performance and traction.
- **Antidegradants:** Antidegradants are added to rubber compounds to protect tires from overly rapid deterioration by ozone, oxygen, fatigue, and heat. Antidegradants include both antioxidants, which help to keep rubber from breaking down due to the effects of temperature and oxygen exposure, and antiozonants, which are used to impede the effects of exposure to ozone on the surface of the tire. Antidegradants in tires must serve in two load performance conditions, static and dynamic operations modes, which describe when the tire is at rest or flexing under motion, respectively.
- **Processing aids:** Bio-based oils, low aromatic petroleum oils, pine tar, and resins are the most common softening agents used in rubber compounding. Tackifying resins can be added to increase the rubber compound stickiness (tack) which helps the various tire components stick together during assembly of tire components.
- **Curing Systems:** Sulfur, chemical accelerators (often derivatives of benzothiazole), stearic acid, and zinc oxide are crucial ingredients for vulcanization, which transforms soft uncured rubber into a solid elastic article during tire curing. Curing systems not only enable vulcanization, but also shorten the vulcanization time and impact the length and number of crosslinks in the rubber matrix which in turn affects the rubber's properties.

Rubber compounds are uniquely formulated for the performance requirements needed for each tire component. For example, the rubber compound for the inner liner component of a tire is formulated to hold air inside the tire at the correct pressure when inflated; this requires specific polymers and ingredients that are unique to that purpose. The rubber compound for the tread component of a tire contacts the road, so it is formulated to meet performance expectations such as grip, wear, wet traction, snow traction, fuel efficiency, and other tire performance needs.

3.1.1.2 Tire manufacturing processes

The tire manufacturing process begins with the selection of polymers, fillers, oils, and other ingredients such as antidegradants, that will combine into a rubber compound to provide the exact characteristics wanted for the specific tire component. A machine called a Banbury® mixer combines the various raw materials for each compound into a homogenized batch of black material with the consistency of chewing gum. The mixing process is computer-controlled to ensure batch-to-batch consistency. The compounded materials are then sent to machines for further processing into tire components such as sidewalls, belts, body plies, treads or other parts of the tire.

The various tire components then come together in a machine where the tire is built from the innermost layer to the outermost layer. The uncured tire, often referred to as a "green tire" in the tire industry, is then placed inside a hot mold and inflated to press it against the mold, forming the tread pattern and the sidewall features. The tire is then vulcanized by heating it to more than 300 degrees Fahrenheit (150 degrees Celsius) for a pre-specified time which causes chemical reactions which transform the various tire components to form a finished tire.

For additional details around each specific component and their functions please see the free National Highway Traffic Safety Administration (NHTSA) resource "The Pneumatic Tire" (US DOT, 2006).

Tire manufacturing also involves compliance with various environmental and occupational safety regulations. For example, factories typically require air and water emissions permits and must comply with federal Occupational Safety and Health Administration (OSHA) regulations. For manufacturing facilities located in California, workplace warnings must be given if facilities use chemicals listed under California's Proposition 65.

3.1.2 Different Types of Tires

3.1.2.1 Passenger car and light truck tires

Passenger and light truck tires are the predominant tires in the US (see Table 3.1, below). Passenger and light truck tires can be categorized as OE (Original Equipment) which are supplied on a vehicle at its time of purchase, or replacement tires. OE tires must meet specific, often numerous and complex performance requirements specific to the vehicle manufacturer. OE tires are designed to a specific vehicle model year/make/model/trim level combination, and any changes to the materials used to manufacture OE tires, or the tire design itself, would require approval from the vehicle manufacturer. OE tires typically do not come with treadwear warranties.

Tires designed for the replacement market ("replacement tires") are designed to perform well on a wide range of vehicles – often as many as 30 different vehicle applications are appropriate for a single tire service description (tire size/speed rating/load index combination). Passenger and light truck replacement tires can be installed by a tire dealer or other tire service professional without original equipment manufacturer (OEM) approval. In the replacement market, consumers typically demand optimized treadwear and wet traction performance. In the replacement market, tire price also is a key consideration for consumers in many cases.

According to the DTSC's Product-Chemical Profile, "'motor vehicle tire' does not mean a motor vehicle on which tires have been installed." (DTSC, 2023). Tires installed on new vehicles are not part of the Priority Product definition. OE tires are considered replacement tires due to requirements in OE contracts for OE tires to be available as replacements, customer demand for OE tires in the replacement market, and to manage excess OE tire inventory. For purposes of this Stage 1 AA, OE tires are considered to be a subset of the replacement tire market and included in the analyses.

Table 3.1 U.S. Tire Industry Shipments Summary

2023 U.S. TIRE INDUSTRY ACTIVITY SUMMARY						
Shipments (in thousands of units)						
	2022		2023		% Change 23/22	
	Total	*Radial*	Total	*Radial*	Total	*Radial*
Passenger						
Industry Original Equipment	41,616	38,817	45,657	42,723	*9.7%*	*10.1%*
Industry Replacement	213,730	213,184	219,180	218,637	*2.5%*	*2.6%*
USTMA Exports	13,962	13,932	14,462	14,412	*3.6%*	*3.7%*
Total Passenger	**269,308**	**265,933**	**279,299**	**275,771**	***3.7%***	***3.7%***
Light Truck						
Industry Original Equipment	6,260	6,250	5,856	5,846	*-6.5%*	*-6.5%*
Industry Replacement	37,241	37,082	34,253	34,162	*-8.0%*	*-7.9%*
USTMA Exports	4,349	4,349	3,842	3,842	*-11.6%*	*-11.6%*
Total Light Truck	**47,849**	**47,680**	**43,952**	**43,851**	***-8.1%***	***-8.0%***
Truck & Bus						
Industry Original Equipment	6,487	6,487	6,218	6,218	*-4.1%*	*-4.1%*
Industry Replacement	26,652	26,508	20,777	20,670	*-22.0%*	*-22.0%*
USTMA Exports	2,026	2,026	1,944	1,944	*-4.0%*	*-4.0%*
Total Truck & Bus	**35,164**	**35,021**	**28,938**	**28,831**	***-17.7%***	***-17.7%***

Notes: USTMA = U.S. Tire Manufacturers Association
Source: USTMA, 2024

Passenger and light truck replacement tires can also be divided into additional performance categories including all-season, summer, snow/winter tires, and a newer category of all-weather tires. All-season passenger and light truck tires are the most common tire type in the US and, as the name suggests, are general-purpose tires designed to perform in most climates. All-season passenger replacement tires typically come with a wear warranty from the tire manufacturer, typically in the 50,000- to 80,000-mile range. Antidegradants are a critical factor in allowing a tire to achieve these long mileage warranty periods.

Passenger and light truck tires have similar construction and utilize similar materials. However, light truck tires are designed to carry higher loads at higher inflation pressures, which requires the use of thicker rubber components, higher strength textiles and steel, and multiple body plies.

3.1.2.2 Truck and bus radial tires

Truck and bus radial tires differ in construction from passenger and light truck tires because the demands for truck and bus radial tire performance are more severe. Truck and bus radial tires contain steel cords as their body plies, instead of the textile plies found in passenger and light truck tires, and typically contain three or four steel belts rather than the two typically seen in passenger car and light truck tires. Depending on the application and type of service, truck and bus radial tires can last up to 150,000-300,000 miles on their original tread. Tires which are used for commercial purposes are designed to be retreaded, which is a process to replace the tread on the tire casing. A truck and bus radial tire body (also known as a casing or carcass) may be retreaded up to three times and may last up to a total of 750,000 miles. Because the life cycle of truck and bus radial tires is much longer than that of a passenger or light truck tire, truck and bus radial tire rubber compounds typically contain higher levels of antiozonants/antioxidants (*i.e*., 6PPD).

3.1.2.3 Motorcycle tires

Motorcycle tires differ in construction from both passenger and light truck tires and truck and bus radial tires due to the varying demands of the different types of motorcycles which are in use. A typical motorcycle tire for on-road application has a tread life ranging from 10,000-15,000 miles, depending on the motorcycle, driving style, and road surfaces encountered.

3.2 Chemical of Concern for the Priority Product

The chemical of concern for the Priority Products is N-(1,3-dimethylbutyl)-N'-phenyl-p- phenylenediamine (6PPD), Chemical Abstract Service Registry Number 793-24-8. 6PPD is within the class of PPDs and is the main antidegradant used in tires (Figure 3.3).

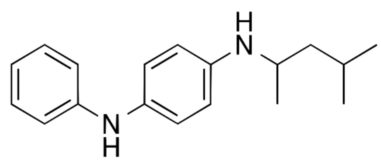

Figure 3.3 Chemical Structure of 6PPD

6PPD is used to protect tires from deterioration due to fatigue, thermo-oxidative breakdown, and from exposure to environmental degradation agents such as ozone and oxygen. These environmental degradation agents will attack the exposed tire surface and cause cracks and hardening of the rubber component throughout the tire's lifetime. In addition to the tire surface, interior portions of the tire (*i.e.,* the tire belt coat compound) can be attacked by oxygen diffusing from air inside the tire and penetrating through the grooves of the tire tread.

6PPD reacts with environmental degradants, ozone, and oxygen, faster than these degradants can react with the rubber or by quenching the reactive products of degradants and rubber, which protects the rubber products from degrading. As 6PPD reacts with the degradants, it is consumed, leaving less 6PPD in the tire. All tire compounds, except the inner liner and white rubber compounds (where used as sidewall decoration, lettering, or symbols), currently contain 6PPD as an essential antidegradant. It is important to note that 6PPD is currently used in all Consortium member passenger, light truck, truck and bus radial, and motorcycle tires. The Consortium is not aware of any motor vehicle tires available today that are 6PPD-free.

The adoption of the use of 6PPD in tires was a gradual process. Tire manufacturers began using 6PPD in tire manufacturing in the mid 1960's and early 1970's. In 1969, a British patent was published regarding the manufacturing of the 6PPD molecule (Davies and Neale, 1969). By 1975, 6PPD comprised 60% of the antiozonant used in tires (other, less effective PPDs were used previously)[6] (US EPA, 1975).

6PPD can transform into a number of reaction products when it carries out its intended function and reacts with ozone and oxygen. The reaction product of primary interest in this AA is 6PPD-quinone (6PPDQ, Figure 3.4), which was identified for the first time in December 2020 (Tian *et al*., 2021). This same paper also suggested a link between this newly discovered substance and potential impacts to coho salmon (*Oncorhynchus kisutch*) attributed to roadway stormwater runoff containing, among other things, 6PPDQ. In laboratory experiments that exposed juvenile coho salmon to 6PPDQ in water under certain conditions, Tian *et al*. (2021, 2022) observed mortality patterns similar to those previously observed in wild salmonids found near sources of urban road runoff and discharge by Scholz *et al*. (2011). However, it is notable that significant declines in the coho salmon populations in California were observed since the 1940s, pre-dating the use of 6PPD in tires by several decades (California Dept. of Fish and Game, 2002).

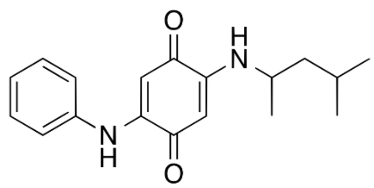

Figure 3.4 Chemical Structure of 6PPD Quinone

3.3 Function of the Chemical of Concern in the Priority Product

All tires contain antidegradants to prevent degradation of the rubber compounds caused by exposure to oxygen, ozone, fatigue and elevated operating temperatures. Antioxidants and antiozonants are two classes of antidegradant. There are in turn, two types of antioxidant and antiozonant performance that are important in tires: dynamic and static operation modes.

- Dynamic load performance: Antioxidants and antiozonants with dynamic operation modes protect the tire while it is in motion and being flexed;
- Static load performance: Antioxidants and antiozonants with static operation modes form a coating that protect the tire when it is in its resting and stationary state.

6PPD performs as an antioxidant and antiozonant in both dynamic and static operation modes. 6PPD reacts with ozone in the air to minimize the attack on the tire surface and reacts with the oxygen coming from the internal inflation pressure that degrades the belt rubber compound, thus preventing degradation of both the internal and external sides of the tire. Antidegradants are essential to ensure tire safety. Without the use of high-performing antidegradants like 6PPD, tire rubber compounds crack and degrade rapidly, creating potentially serious safety concerns (Figure 3.5).

[6] The first PPDs developed were active antiozonants but they were not as effective as 6PPD as they did not provide protection of rubber compounds for more than one and a half years. IPPD and DAPD were the first to be used in rubber compounds in the mid-1960s. DAPD reacts minimally with ozone, and IPPD reacts too fast with ozone leading to premature depletion. The final PPDs to become commercialized were 6PPD, 7PPD, and 8PPD (Kuczkowski, J. A., 1990).

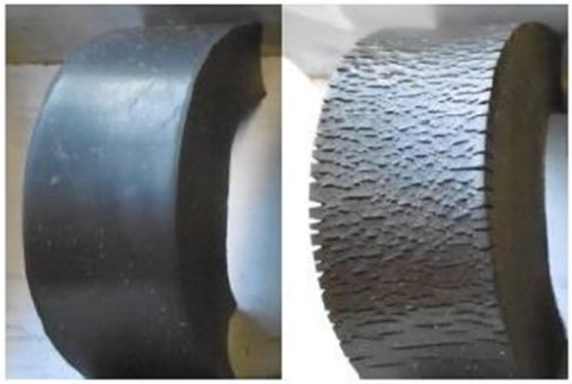

Figure 3.5 Dynamic Antiozonant Effect of 6PPD, 0.5 ppm Ozone Concentration, 40°C, 48 hours. Source: Schunk, A. 2022

The antiozonant and antioxidant properties of 6PPD are critical to creating durable tires. These properties are also important for tire longevity, leading to less demand on natural resources and energy for tire production as well as decreased tire waste. As an antidegradant reacts with degradants, its concentration in the tire is reduced; therefore, tires that are expected to last longer in the market require higher concentrations of these chemicals. 6PPD has the ability to migrate through the tire and reach the surface where it is needed to protect the tire from exposure to oxygen and ozone damage. Most importantly, the chemical migrates at the necessary rate such that the 6PPD contained in the tire can be present at the surface throughout the tire's intended lifetime. Any alternative to 6PPD would need to satisfy a similar surface availability × time profile.

In summary, antidegradants such as 6PPD must provide the following functions:

- **Protection against ozone**
    - Readily reactive with ozone to prevent crack formation on the surface of the rubber, but not too reactive in order to prevent premature depletion
- **Protection against oxygen**
    - Reactive with oxygen to prevent hardening of the rubber, loss of strength, improve tire wear, and maintain long-term durability, while not reacting so aggressively with oxygen as to cause premature depletion.
- **Protection against fatigue**
    - Reactive with the free radicals generated by breaks in rubber polymer during flexing. These free radicals can break the polymer chains and crosslinks in the rubber compound that would lead to a loss of strength for body plies, sidewall and tread.
- **Optimal migration rate/ diffusion**
    - Adequate solubility and diffusivity in rubber compounds, also referred to as migration and mobility, which allows the chemical to move to the tire surface where it is needed to react with oxygen and ozone to ensure long term protection of the tire from oxygen and ozone damage over its life
    - Available in the rubber formulation at an effective concentration over a tire's entire life cycle to ensure protection from ozone and oxygen damage
- **Be compatible with manufacturing processes**
    - No adverse effects on the rubber cure rate, tack, viscosity, *etc*.

    - Resistance to temperatures encountered during the tire vulcanization process
- **Be compatible with other aspects of tire safety and performance**
    - The chemical cannot interfere with the function of other rubber compounding ingredients needed for safety (*e.g.*, steel belt adhesion, cornering ability)

3.4 Key Performance Requirements for the Priority Product

The California Code of Regulations (CCR) §69505.5 states that an AA "shall identify the functional, performance and legal requirements of the Priority Product that must also be met by the alternatives under consideration." There are substantial requirements that tires must meet in order to be sold on the market. These requirements may be regulatory in nature (*i.e.*, safety), manufacturer-driven, or customer-driven, such as rolling resistance, wear, and other performance attributes. In addition, tires are a globally manufactured and distributed product and therefore must comply with a wide range of regulations in multiple countries.

3.4.1 Testing of Rubber Compounds Prior to Actual Tire Development

There are many steps that are needed to evaluate tire safety and performance. Before a tire is built and assessed for performance and safety, laboratory screening tests to evaluate the performance of various tire compounds must be completed with satisfactory results. These initial screening tests are essential to ensure that only viable compounds are used in development of tire products that then have to undergo more detailed and legally required testing.

All new rubber compounds using an alternative antidegradant must be tested and compared to a "control" or "witness" containing a standard material, in this case containing 6PPD, that has been produced at the same time and handled in the same manner. This is especially true for antidegradants which are reactive chemistries and can be consumed during processing and aging. Each formula contains a variety of raw materials, all of which have some level of allowable range of variation. The results can also be influenced by the environmental conditions during the processing steps and during the testing; for these reasons, it is critical to have a control made at the same time.

Any alternative antidegradant would also need to be tested in multiple rubber compounds per tire component because each tire manufacturer uses different tire compounds in their products depending on the tire's intended use. The reader can find examples in the published literature (see for example, the Vanderbilt handbook [Sheridan, MF, 2010]). Accordingly, the use of different tire compounds among manufacturers influences the types of tests that they need to perform in order to demonstrate that an alternative is acceptable.

Based on the critical functions of an antidegradant, a potential list of screening tests by rubber formula type has been established by the Consortium members which includes existing modified ASTM and ISO standard laboratory methods that can be used for all the screening tests except migration. Multiple methods are mentioned in literature for assessing chemical migration (Lederer *et al*., 1981).

Antidegradants must pass these screening tests (Table 3.2) as a first step in identifying a possible alternative.

Table 3.2 Potential Laboratory Screening Tests for Requirements by Rubber Compound

Method	Key Parameter	In Rubber Compound Testing		
		Black Sidewall	Tread	Belt Coat
ASTM D1646	Processability (viscosity and scorch)	o	o	o
ASTM D5289-19A/ASTM D2084	Cure, Reversion	o	o	o
ASTM D412-A, ASTM D573	Stress/Strain, Normal and Aged	o	o	o
ASTM D624, ASTM D573	Die C Tear, Normal and Aged	o	o	o
Lederer RCT	Migration	o	o	o
ASTM DD1149	Ozone: Static operation mode	o	o	
	Ozone: Dynamic operation mode	o		
ISO 1431-2012 (11.3)	Ozone: Intermittent Dynamic Exposure	o		
ASTM D4482-06	Fatigue to Failure	o		
ASTM D5992-96	Dynamic Properties/Viscoelastic	o	o	o
LAT100/ASTM D5963-04/DIN 53 516	Wear		o	
ASTM D430/ASTM D813	Demattia Fatigue, Normal and Aged		o	
ASTM D2229	Wire Adhesion, Normal and Aged			o
	Green aging			o
	Heat aging			o
	Oxygen aging			o
	Steam aging			o

Notes:
ASTM = American Society for Testing and Materials; ISO = International Organization for Standardization.

3.4.2 Regulatory Requirements for Motor Vehicle Tires

Tires are highly regulated to ensure their safety, quality and durability. Under the National Traffic and Motor Vehicle Safety Act of 1966 ("Vehicle Safety Act") (US Congress, 1966), automotive vehicles or motor vehicle equipment (including tires) are broadly regulated in terms of potential defects that could impact motor vehicle safety. The Vehicle Safety Act created the National Highway Traffic Safety Administration ("NHTSA"), which promulgated the Federal Motor Vehicle Safety Standards (FMVSS) as directed by Congress. All passenger, truck and bus, trailer, and motorcycle tires sold in the United States (whether OE or replacement) must meet all applicable FMVSS (49 CFR Part 571). Additionally, passenger car tires sold in the United States must conform to the Uniform Tire Quality Grading Standards (UTQGS) (49 CFR § 575.104).

The Vehicle Safety Act has been amended several times since it was enacted in 1966. Most notably, the Transportation Recall Enhancement, Accountability, and Documentation ("TREAD") Act, enacted in 2000, added several new regulatory requirements for new motor vehicle tires (US Congress, 2000).

Tire manufacturers are required by law to self-certify to the appropriate FMVSS that every tire they manufacture meets safety, durability, and other requirements or regulations prior to sale to the consumer. NHTSA conducts periodic audits of new tires subject to FMVSS to assure compliance. The Safety Act explicitly preempts any state law or regulation that conflicts with a NHTSA regulation relating to "safety." The rationale is that vehicles travel from one state to another and between countries. The absence of a uniform set of safety rules would allow one state to impose arbitrary requirements that could significantly impact interstate commerce.

3.4.2.1 Passenger and light truck tires

Pursuant to the TREAD Act, NHTSA promulgated FMVSS No. 139 (49 CFR § 571.139) in 2003, which established testing requirements for new pneumatic radial tires for light vehicles. FMVSS No. 139 applies to all new pneumatic radial tires for use on motor vehicles made after 1975 with a gross vehicle weight of 10,000 pounds or less, which includes passenger and light truck tires with a tread depth of less than 18/32 of an inch. All tires are required to have dimensions within specific limits and specified markings that notify the consumer of the dimensions of the tire, the maximum load carrying capacity, the tire identification number (TIN), and that the tire is certified to meet the applicable FMVSS. FMVSS No. 139 also imposes requirements for tread wear indicators so consumers can be aware of the need for tire replacement.

FMVSS 139 requires tire manufacturers to meet the following new tire testing requirements:

- **High speed performance:** The high speed test is run on 1.70 m (67") diameter test drums[7]. Tires must complete the 160 km/hr (100 mi/hr) step with no visual evidence of separation in the tread, sidewall, ply, cord, inner liner, belt or bead; chunking, open splices, cracking or broken cords and the tire pressure when measured within 15-25 minutes after the end of the test cannot be less than 95% of the initial inflation pressure.
- **Endurance:** The endurance test is run on 1.70 m (67") diameter test drums. All tires must complete the endurance portion, plus a 90-minute low inflation pressure step with no visual evidence of tread, sidewall, ply, cord, belt or bead separation, chunking, open splices, cracking, or broken cords, and the tire pressure, when measured within 15-25 minutes after the end of the test cannot be less than 95% of the initial inflation pressure.
- **Bead unseating resistance:** The test requires that tires retain air pressure and beads remain seated on the wheel in a test where an anvil is pressed against the tire sidewall. Wheel, tire inflation pressure, and anvil location are specified by rim diameter and tire type.
- **Tire strength (plunger energy):** The tire strength test requires that tires withstand a slow-moving plunger placed in the center area of the tread to a minimum level of calculated energy.

3.4.2.2 Uniform tire quality grading for passenger car tires

Also pursuant to Section 203 of the Vehicle Safety Act, NHTSA established the Uniform Tire Quality Grading Standards (UTQGS) as a way to assist the consumer to compare various tires (49 CFR § 575.104). This regulation pertains to passenger car, SUV, and some light truck tires. Tire types excluded from UTQGS are LT-metric light truck tires, winter-type snow tires, low-volume production passenger car tires, motorcycle tires, and tires for truck and bus applications. While the UTQGS specify treadwear, traction, and temperature grades for tires within the scope of this regulation, the threshold values within these tests are informational only and are not directly linked to safety performance of motor vehicle tires.

3.4.2.3 Regulatory Testing Requirements for Truck and Bus Radial Tires and Motorcycle Tires

All new truck and bus radial tires (as well as some light truck tires) and motorcycle tires, are required to meet the following test requirements under FMVSS No. 119:

[7] The test drum is a cylindrical structure meant to simulate the road surface. The tire is pressed against the drum and spun to simulate the effect of driving.

- **Endurance:** The test tire must complete the full endurance test with no visual evidence of tread, sidewall, ply, cord, belt or bead separation, chunking, open splices, cracking, or broken cords, and the tire pressure at the conclusion of the test cannot be less than the initial inflation pressure.
- **Tire Strength (plunger energy):** The tire strength test requires that tires withstand a slow-moving plunger placed in the center area of the tread to a minimum level of calculated energy.
- **High Speed Performance (applicable only to motorcycle tires and non-speed restricted tires with rim diameter code of 14.5 or less and load range A, B, C, or D):** The test tire must withstand testing at specified load over a series of increasing speeds for a set period of time. The test tire must complete the full test with no visual evidence of tread, sidewall, ply, cord, belt or bead separation, chunking, open splices, cracking, or broken cords, and the tire pressure at the conclusion of the test cannot be less than the initial inflation pressure.

3.4.3 Compliance with and Enforcement of NHTSA Regulations

The Vehicle Safety Act grants broad authority to NHTSA "reduce traffic accidents and deaths and injuries resulting from traffic accidents" by establishing FMVSS (US Congress, 1966). In addition, NHTSA has established regulations that address safety defects in motor vehicles and motor vehicle equipment (including tires) go beyond compliance with FMVSS.

The Vehicle Safety Act establishes a self-certification system for compliance with applicable FMVSS and UTQGS, where it is the responsibility of a manufacturer of vehicles and/or items of motor vehicle equipment, including tires, to certify that each of its regulated products is in full compliance with the performance requirements of all applicable FMVSS and consumer information regulations. This compliance burden is borne solely by the motor vehicle or equipment manufacturer.[8]

In addition to assuring that its tires meet all applicable FMVSS, a tire manufacturer designs and manufactures a tire to reduce the risks of a tire containing a safety defect. NHTSA regulations require manufacturers of vehicles and vehicle components to submit information to NHTSA about any FMVSS non-compliances or potential defects (49 CFR § 579).

As well, when a tire manufacturer designs and manufactures a tire, it considers the risk of a potential tire recall. NHTSA maintains broad authority to enforce its regulations by imposing civil and criminal penalties (49 CFR § 578) and by instituting recalls of motor vehicles and motor vehicle equipment that do not meet FMVSS or contain a safety-related defect. Coupled with the NHTSA compliance surveillance program described in the previous section, the NHTSA recall authority creates a strong interest in compliance to all NHTSA requirements due to the potential damage to a company's reputation caused by a significant recall.

3.4.4 Additional Manufacturer Test Criteria for Highway Tires

All tire manufacturers perform a combination of voluntary outdoor vehicle tests, indoor drum tests, and technical tests in addition to all required regulatory tests. In addition to the tests outlined below, tire manufacturers may have their own proprietary test methods based on their specific tire designs and according to their market experiences and needs.

[8] A manufacturer self-certifies a tire meets all applicable federal motor vehicle safety standards by molding "DOT" on the sidewall of the tire in association with the TIN, which identifies the manufacturing plant and date of manufacturer (week and year), among other information.

3.4.4.1 Indoor (drum tests) for passenger and light truck tires

Below is a list of typical indoor tests (drum tests) employed in tire development programs. Indoor laboratory tests are typically run on 1.70 m (67") diameter drums that have been an industry standard for decades. Tire manufacturers may have their own proprietary indoor drum test methods based on their specific tire designs and according to their market experiences and needs.

- **High speed performance:** Passenger tires are typically marked with a speed symbol following the maximum load rating. The tire speed symbol indicates the is the highest speed for which a tire is rated. The test method for marking a tire with a specific speed symbol is defined by UN Regulation No. 30. While most tires sold in the US contain speed symbol markings, it is an optional marking in the US from a regulatory perspective. However, most vehicles sold in the US today specify a tire fitment with a minimum tire speed symbol to meet or exceed the speed capability of the vehicle.
- **Endurance:** Tire endurance is a measurement of how long a tire can withstand severe conditions before displaying a condition that indicates the end of the test (damage to the tire).Endurance can be tested by varying the speed, load, inflation pressure, temperature, and/or number of cycles. The most typical tire endurance test varies the load. While FMVSS specifies an endurance test, tire manufacturers also conduct proprietary endurance tests in addition to the regulatory requirements. Some endurance tests are conducted on artificially aged tires, where the tire aging process is accelerated through the use of higher ambient temperatures and ozone and/or oxygen concentrations. These accelerated aging tests are intended to mimic the condition of tires which have been in service, including mileage and environmental exposure.
- **Rolling resistance:** The force necessary to keep a tire rolling is known as rolling resistance. To measure rolling resistance, a load is placed on the tire while it is being forced to turn by the drum and the resistance force which the tire generates to prevent it from turning is measured. In the US, this parameter first became important to vehicle manufacturers in the 1990s with implementation of more stringent Corporate Average Fuel Economy (CAFE) standards for new cars because lower tire rolling resistance equates to greater fuel economy (US DOT, 2006). For regulatory purposes, rolling resistance is measured according to ISO 28580:2018 and is expressed in terms of rolling resistance coefficient (RRC). Rolling resistance is regulated by UN Regulation No. 117 and other governments globally. Currently, the California Energy Commission is developing a regulatory proposal to regulate rolling resistance in California pursuant to AB 844 (California State Assembly, 2003 Chapter 645).

3.4.4.2 Outdoor (vehicle) tests for passenger and light truck tires

In addition to indoor tests, manufacturers also test tires on actual vehicles to simulate actual (sometimes worst case) driving conditions. To some extent these tests are company specific; each tire manufacturer has proprietary formulas, manufacturing processes, and tire designs and their understanding of their products in the market and how they respond to the variety of environmental and use conditions is unique and must be assessed by each company individually. Below is a list of typical outdoor vehicle performance test that passenger and light truck tires are subjected to.

- **Wear rate:** Traditionally with an outdoor test, sets of tires are driven at prescribed speeds on a known course to evaluate wear rate, usually measured in miles of travel per thousandth of an inch of tread depth loss (*i.e.*, miles per mil) or as tread loss per mileage increment (*i.e.*, mils/1000 mi).

- **Irregular wear:** During a wear test the tires are assessed for any indications of irregular wear. Uneven or abnormal wear features can significantly shorten the service life or mileage potential of tires.
- **Gravel chip/tear:** For passenger and light truck tires that are intended to be driven off road, an evaluation is conducted on vehicle on a gravel route to assess chipping and tearing of tread elements.
- **Handling- dry, wet, and snow:** Handling is a result of tire/vehicle interactions in response to various driver inputs. Handling evaluations include various road conditions such as dry, wet, and snow but also everyday driving and emergency steering situations.
- **Ride comfort:** A vehicle's perceived ride comfort, whether "sporty" or "plush," can be significantly influenced by tires. The ride comfort is assessed over a variety of road conditions and can include assessment of impacts like potholes and train tracks.
- **Noise:** Tire noise can be generated from the interaction of the tire with the road. Pass-by noise is measured from the sides of the road with a vehicle traveling at a specified speed with the engine not running.
- **Endurance:** Outdoor testing for tire endurance usually involves driving a vehicle on a closed course at a specified level of loads, inflation pressures, and speeds (US DOT, 2006 224-2581).
- **Field Testing:** Tire manufacturers may also conduct field testing to obtain performance data for tires operated under real-life conditions for an extended period of time. This testing is typically performed by a contracted fleet with routine monitoring by the tire manufacturer.
- **Traction:** Dry, and wet: Specially equipped instrumented trailers with computer-controlled braking capability are towed over known skid pad surfaces. Brakes are applied gradually to cause wheel lock-up and peak and slide friction forces are recorded.
- **Snow traction:** Snow testing is conducted as specified by ASTM F1805. Per FMVSS No. 139 (49 CFR § 571.139), to be marked with the Alpine (snow) symbol, a tire must achieve a traction index of 112 or greater as compared to the ASTM F2493 standard reference test tire.

3.4.4.3 Optional technical tests for passenger and light truck tires

In addition to the typical indoor drum and outdoor performance tests, manufacturers also often test finished tires for additional technical properties using specialized equipment, depending on customer requirements and product performance specifications. Some of these tests include the following:

- **Weight:** OE vehicle manufacturers often specify tire weight targets as part of their requirements for meeting CAFE goals since the weight of the tire is directly related to its rolling resistance and fuel efficiency.
- **Force and moment properties:** A tire's cornering capability comes from the forces generated when a tire's direction of motion is different from its heading direction, causing a slip angle. This test is an indication of how the tire will perform on vehicle handling assessments.
- **Electrical resistivity:** Moving vehicles can generate static electricity which is exacerbated by low temperature and humidity.
- **Uniformity:** Due to material and assembly variations that occur during manufacturing and curing, small deviations in tire cross section circumferentially can result in measurable spring rate or

dimensional changes, for example, an out-of-round or out of balance condition. This can have an impact on handling, noise, and ride comfort.

- **Air permeation:** Inner liner rubber compounds are formulated to minimize permeation of air through the tire carcass. The air permeation test measures the air loss over a specified time and conditions.
- **Dynamic ozone:** A indoor drum method where and the tire is exposed to ozone while it is running on a standard drum at a specified speed, temperature, and ozone concentration. This test can be used to correlate sidewall compound ozone cracking between a variety of market conditions and judge differences in performance of sidewall rubber compounds.
- **Aged tire properties:** ASTM F2838 is a method for inflating tires with a specified oxygen content, pressure, and temperature and placing them in an oven for a specific amount of time to simulate market conditions for the belt coat compound. Once a tire is aged, the belt coat compound can be cut out of the tire and tested to compare the physical properties of the compounds after aging.

3.4.4.4 Additional Manufacturer Test Criteria for Truck and Bus Radial Tires

Tire manufacturers may have their own proprietary test methods based on their specific tire designs according to their market experiences and needs.

- **High speed performance:** Not all truck and bus tires are marked with a speed rating. FMVSS 119 specifies that tires restricted to use at speeds of 55 mph (90 km/hr) or less must be marked to indicate this limitation. For tires which are marked, the tire speed rating is the highest speed that a tire can handle before it does not perform as designed. The test method for marking a tire with a specific speed symbol is defined by UN Regulation No. 54. While many tires sold in the US contain speed category markings, it is an optional marking in the US from a regulatory perspective.
- **Endurance:** Tire endurance is a measurement of how long a tire can withstand severe conditions before reaching its limit. Endurance can be tested by varying the speed, load, inflation pressure, temperature, and/or number of cycles. The most typical tire endurance test varies the load. While FMVSS specifies an endurance test, tire manufacturers also conduct proprietary endurance tests in addition to the regulatory requirements.
- **Field Testing:** Tire manufacturers may also conduct field testing to obtain performance data for truck and bus tires operated under real-life conditions for an extended period of time. This testing is typically performed by a contracted fleet with routine monitoring by the tire manufacturer.

In addition to the above, truck and bus tires are tested for many of the parameters discussed in Sections 3.4.4.2 and 3.4.4.3.

3.4.5 SmartWay Certification for Truck and Bus Radial Tires

SmartWay® Certification is a collaborative effort between the United States Environmental Protection Agency (US EPA) and the freight industry designed to help businesses move goods in the cleanest, most energy-efficiency ways possible while reducing greenhouse gases and air pollution, and protecting public health. SmartWay® is a voluntary program outside the state of California; however, within California, the California Air Resources Board (CARB) requires fleets to operate on SmartWay® verified tires. The SmartWay® program publishes a list of new and retreaded commercial vehicle tires which have been verified to demonstrate a rolling resistance coefficient at or below certain targets set by EPA (US EPA, 2012, 2022).

3.4.6 Summary of Performance Testing Requirements

The paragraphs above outline the extensive set of test requirements that are required for a new tire formulation or design before it can be placed in the market. Starting with laboratory tests as shown in Table 5.14, the successful formulation then passes through several additional stages of testing before finally being tested as manufactured tires on an actual vehicle. Based on the experience of Consortium members, the tire research and development, design, and performance testing process for a tire using existing, commercially-produced materials known to perform as necessary in tires, can take a minimum of 4 to 6.5 years. In the tire design process, each step may be repeated multiple times until an acceptable design is achieved, which can significantly extend the design process. As well, challenges encountered while conducting a step in the tire design process, may require development to go back to an earlier stage. In the case of replacing 6PPD, once a new candidate antidegradant is identified, an additional 4 years (minimum) of limited-scale field testing would be required to ensure performance as a tire ages. After satisfactory results are obtained from field testing, additional time will be needed for deployment of the new antidegradant in tires for the market, which could take months to a few years.

3.4.7 Other Regulatory Requirements for the Priority Product

In addition to performance requirements, other regulatory requirements could impact the feasibility or timeline for implementation of any alternative to 6PPD in motor vehicle tires. For example, chemicals that are used in tire manufacturing need to be registered in the various jurisdiction where tires are manufactured (*e.g*., the US, the European Union, China, South Korea). Whether or not a possible alternative is already listed on the various chemical inventories could be a significant factor in terms of the timeline for implementing an alternative. In addition, given the volumes of antidegradant that will be required for global tire production, even chemicals already present on chemical inventories may be shifted to higher production volume categories, which could trigger additional data submission requirements in terms of chemical, environmental and toxicological properties. In particular, the need for additional toxicity testing, particularly for carcinogenicity or reproductive toxicity, could add significantly to the cost and timing of implementing any alternative (*e.g.*, a standard carcinogenicity study can take up to four years to complete). Other potential regulatory requirements include California's Proposition 65, if any possible alternative is listed by the State of California as known to cause cancer or reproductive harm.

3.5 Necessity of the Function of the Chemical of Concern in the Priority Product

Under CCR §69505.5 3(A), responsible entities, in this case, Consortium members, are required to determine whether the chemical of concern or an equivalent replacement is necessary in order to meet the product's functional and legal requirements or whether the chemical of concern can simply be eliminated from the product without replacement. As discussed in prior sections, all tires require antidegradants, including antioxidants and antiozonants, for safe performance. Thus, simply removing the chemical of concern, 6PPD, from motor vehicle tires without replacement is not an option.

4 Scoping, Identification of Possible Alternatives and Relevant Factors

4.1 Purpose and Approach for this Stage 1 AA

As conceived by Gradient and the Consortium, the goal of a preliminary (Stage 1) AA under the SCP program is to answer the following question: Do potentially safer, functionally acceptable, and technically feasible alternatives to the Priority Product exist that should be given a more in-depth consideration to determine if they qualify as acceptable alternatives? If the answer to this question is yes, then a 2nd Stage AA is appropriate, where factors such as economic feasibility are considered. If the answer is no, then an Abridged AA is required. The aim of Stage 1 is not to definitively identify a final alternative but rather to identify apparently acceptable candidates alternatives for further study. We believe this philosophy is in accord with the Safer Consumer Products (SCP) regulations (CalDTSC, 2013a).

4.2 Alternatives Under the SCP Regulation

The SCP AA process requires responsible entities to identify and consider alternatives to 6PPD that meet the definition of "alternative" under section 69501.1 and potentially meet the Priority Product's requirements as outlined in section 3 of this AA (CalDTSC, 2013b SCPR section 69505.5(b)). To create the list of candidate alternatives, the Safer Consumer Products regulation requires responsible entities to "evaluate available information that identifies existing possibly viable alternatives for consideration in the AA" (CalDTSC, 2013b SCPR section 69505.5(b)).

An alternative may include any of the following:

- Removal of a Chemical of Concern from a Priority Product, with or without the use of one or more replacement chemicals.
- Reformulation or redesign of a Priority Product and/or manufacturing process to eliminate or reduce the concentration of a Chemical of Concern in the Priority Product.
- Redesign of a Priority Product and/or manufacturing process to reduce or restrict potential exposures to a Chemical of Concern in the Priority Product.
- Any other change to a Priority Product or a manufacturing process that reduces the potential adverse impacts or potential exposures associated with the Chemical of Concern in the Priority Product, or the potential adverse waste and end-of-life effects associated with the Priority Product that also meets the Priority Products function.

4.3 Inclusion of Performance as a Consideration in the Stage 1 AA

The SCP regulations do not list performance as a required consideration (*i.e.*, relevant factors) for a Stage 1 AA but rather include it as a required consideration for Stage 2. However, the SCP regulations (§ 69505.5 (e)) permit for the Consortium to include additional factors that they deem relevant to the AA at their discretion (CalDTSC, 2013a). The Consortium maintains that performance is a critical element of an AA at the initial stage because an alternative that has unacceptable performance (*i.e.*, performs poorly compared to the current product by a reasonable metric related to consumer safety or expectations) may impact tire safety, longevity, or health or environmental impacts, and will not be a viable alternative and should therefore not be considered further. Thus, performance is included as a relevant factor in this Stage 1 AA report.

4.4 Scoping: Alternatives Outside the Scope of This AA Report

The first element of an AA involves scoping, or determining the range of alternatives that will and will not be considered in the AA. Certain alternatives are being excluded from further analysis because they are too preliminary in their stage of development to meet the likely implementation schedule under the SCP regulation. These alternatives also have very limited data with which they can be evaluated and would require a revision of federal safety regulations which is something beyond the scope of the SCP program. Some alternatives also likely pose the same issues as current tires (*i.e*., by using rubber tread) and so would not constitute an alternative with a different hazard profile. Three possible technologies are not being considered as part of this AA: 1) non-pneumatic tires, including Shape Memory Alloy Radial Technology (SMART) tires; 2) electrostatic particle collectors; and 3) modified EPDM or halobutyl elastomers.

4.4.1 Non-Pneumatic Tires

As mentioned in the DTSC Technical Report, some companies are working towards non-pneumatic, or airless motor vehicle tires. These transmit the vertical load and tractive forces from the roadway to the vehicle and generate the tractive forces that provide the directional control of the vehicle without the containment of any gas or fluid for providing these functions. Examples of prototype non-pneumatic tires are shown below (Figure 4.1).

Figure 4.1 Examples of Non Pneumatic Tire Products. Sources (left to right): Michelin, 2023; Bridgestone Corp., 2013; Goodyear, 2023.

As of early 2024, there are no commercially available non-pneumatic motor vehicle tires being sold in the United States, and the FMVSS currently require all new motor vehicles to be equipped with pneumatic tires. Market introduction of a non-pneumatic tire is expected within the next several years but the FMVSS and multiple state laws would need to be amended before this can occur. Widespread adoption of non-pneumatic tires over a broad range of tire sizes, load capacities, and speed ratings is anticipated to be at least several additional years into the future. Non-pneumatic tires are incompatible with many of the current industrial processes utilized by the tire industry. Significant investment, potentially including new production facilities, will likely be required to mass-produce these types of tires.

Non-pneumatic tires for off-road applications such as agricultural equipment, construction equipment, and utility terrain vehicles (UTVs) are commercially available; however, tires for these applications are designed for significantly different operating conditions than motor vehicle tires (*e.g*., lower speeds) and are not subject to FMVSS, as NHTSA's authority only extends to vehicles and vehicle components for on-highway use.

Although non-pneumatic tires rely on a different mechanism to support a vehicle load versus conventional motor vehicle tires, many of the components in non-pneumatic tires, including the tread, are composed of rubber compounds that contain 6PPD to protect the compounds from environmental degradation and fatigue. Accordingly, 6PPD would still be present in non-pneumatic tires. Also, due to the tread compounds used, treadwear rates of any future non-pneumatic tires may not be significantly different than conventional pneumatic tires of the same size, load capacity, and speed rating. While the total amount of 6PPD in such tires may be reduced (due to the lack of a sidewall), 6PPD would still be present in the portion of the product contacting the roadway. It is also unclear whether the concentration of 6PPD in the tread rubber would have to be different (*e.g*., higher) in these tires to compensate for the reduced reservoir created by a lack of sidewall.

The DTSC report mentions nickel-titanium spring tires from the SMART Tire company as a possible alternative. The SMART tire is another concept for a non-pneumatic tire. At this time, the tire is not in production (the company website suggests it would be available for bicycle tires in 2023 but no other information is given) and the manufacturer indicates they are looking for investors. The company website indicates that the product for vehicle applications will contain a rubber tread compound, so it is not known if it will contain 6PPD. As with the other non-pneumatic tires discussed above, the concentration of 6PPD in the tread is not known.

Due to the unknown timing of widespread availability for motor vehicle use and their current materials of construction, non-pneumatic, or airless tires, are deemed to be outside the scope for this report.

4.4.2 Electrostatic Particle Collectors

Tyre Collective is a company that is working on an electrostatic collection device for TRWP (The Tyre Collective Ltd., 2024). This device is placed behind the tire on the vehicle and is not an innovation that can be applied to a tire. This technology is in the proof-of-concept phase and the most recent trial showed a 20% collection efficiency by mass. A 20% reduction in TRWP release may not be sufficient to meet the SCP requirement of a "material difference". It could also impose an additional burden on consumers if the collector has to be replaced or emptied periodically in a repair shop to function. The tire industry also has no authority to require additional products beyond tires to be installed on new vehicles or retrofitted to existing vehicles. This would be the choice and responsibility of vehicle manufacturers, who are not subject to the AA requirement. It is unknown if such a device would impact aerodynamics, fuel efficiency or vehicle clearance. Therefore, electrostatic particle collectors are also deemed to be outside the scope of this report.

4.4.3 Modified EPDM or halobutyl rubber to reduce 6PPD concentrations in sidewall

Consortium members also identified two related approaches for reducing the concentration of 6PPD in tires, which constitute a potentially viable approach under the SCP regulations. The alternatives involve using (1) a modified EPDM to formulate the sidewall rubber or (2) bromobutyl rubber to formulate the tread. Both of these materials are inherently resistant to ozone attack. While these materials normally cannot be used in tire sidewall and tread due to chemical incompatibility (*e.g*., bromobutyl rubber is used exclusively in the inner liner), the Consortium did discover patents which describe ways to use these elastomers (with modifications) to formulate sidewall (EPDM) and tread (bromobutyl) rubber.

However, there are indications of technical challenges that would need to be overcome. The modification process for EPDM involves an acid byproduct which could lead to potential corrosion of production equipment, and there may be air emissions that could require permitting for production facilities. Consortium members report that EPDM also alters the behavior of some additives (*e.g*., carbon black) relative to current tire rubber which complicates the entire manufacturing process. The bromobutyl rubber patent describes a formulation requiring an organosilane cross linking agent and "effective amounts of processing aids" whose nature is not stated. Both EPDM and bromobutyl rubber would also significantly impact the ability to recycle rubber into the process during manufacturing (rework), potentially creating more waste material. Neither material is currently available in sufficient volume to meet the needs of the global tire industry.

In addition, for the use of EPDM to remove/reduce 6PPD in tire sidewalls, the extent to which the tire sidewall contributes to the potential migration of 6PPD from tires into the environment (*via* blooming and washing off rather than from TRWP) is unknown and unquantified. Loss of 6PPD/6PPDQ from tread will occur predominantly while the vehicle is moving (by generation of TRWP), whereas sidewall loss of 6PPD/6PPDQ (by being washed off the sidewall) would occur predominantly during the parked stage of vehicle use (since, at least for passenger vehicles the vast majority of time is spent parked). Since 6PPD will still be used in other parts of the tire, the potential benefit of this alternative is unclear. The Consortium is aware of one patent that considered the potential use of modified EPDM in tread (Sandstrom, 1992), but this still required the use of antidegradants. As a result, this does not appear to be a promising option to reduce concentrations of 6PPD in tread.

For use of bromobutyl rubber in tread, although the ozone resistance of the bromobutyl rubber is mentioned, antioxidants and antiozonants are still included as ingredients in the patents so the degree of 6PPD reduction is not clear. In addition, if other rubber (requiring 6PPD) is used for the sidewall and other tire components, the 6PPD in the rest of the tire could still migrate to the tread and be put into the environment *via* TRWP.

Thus, because the potential benefit appears questionable and there are many unknowns regarding the feasibility of implementation, these two options are not evaluated further in the AA.

4.5 Possible Alternatives to 6PPD in Motor Vehicle Tires

4.5.1 Approach for Identification of Alternatives

Once the scope of the AA has been identified, the next critical step is to gather information on possible alternatives. To conduct an informative AA, one needs to consider not only those products made by the Consortium members but also other products that are available as these may be possible alternatives. As required under the SCP regulation, the Consortium must consider any candidate alternatives that are posted on the Department's website (Sandstrom, 1992). DTSC indicates that additional information sources which should be considered are journals, articles, books, references, handbooks, encyclopedias, patents, and internal company files. To identify possible alternatives, the Consortium conducted literature searches, surveyed members for literature sources, and surveyed expert industry consultants for additional literature sources. The following literature sources were evaluated by the Consortium to identify candidate alternatives:

- Technical journals, including, but not limited to
  - Rubber Division of the American Chemical Society – Rubber Chemistry and Technology
  - Rubber World
- Trade media, including, but not limited to
  - Tire Business
  - Rubber and Plastics News
  - Tire Review
  - International Tire Technology Magazine
- Reference literature and books, including, but not limited to
  - "Ozonation of Organic and Polymer Compounds" by Gennady E. Zaikov and Slavcho K. Rakovsky
  - "Ozone Risk Communication and Management" by Edward Calabrese, Charles Gilbert, and Barbara Beck
  - Vanderbilt Rubber Handbook, 14th edition
  - "Blends of Natural Rubber: Novel Techniques for blending with Specialty Polymers," edited by A. J. Tinker and K. P. Jones, Chapman & Hall, London, 1998.
  - Rubber Compounding Chemistry and Applications, 2nd Ed., Brendon Rogers, CRC Press, 2016 p. 419-459
- Online reference material, including, but not limited to
  - PubChem
  - Chemical supplier websites
- Government materials, including, but not limited to
  - Chemical Profile for Motor Vehicle Tires Containing N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) (CalDTSC, 2022)
  - Washington Department of Ecology Technical Memo (WA Ecology, 2021)
- Patent searches, including, but not limited to
  - United States Patent and Trademark Office (USPTO)
  - Google patents
- Consultation with university and government researchers, including but not limited to
  - University of California, Berkley
  - University of Washington
  - Washington State University
  - University of Massachusetts-Lowell
  - US Geological Survey (USGS)

In addition, USTMA prepared a survey concerning knowledge of research on alternatives that was sent to all Consortium members. The survey asked questions about alternatives currently under investigation as well as alternative antidegradants that had been evaluated in the past and found unsatisfactory. It also asked about company awareness of research or ideas being put forth by other entities. Responses to the survey were aggregated *via* a third party law firm to ensure confidentiality. A copy of the survey is included as Appendix D.

Over 60 suggested alternative antiozonants were identified through this process. The identified chemicals were screened for technical feasibility. Once the information was collected, the chemicals were tabulated along with their related scientific information in a spreadsheet and scored as to their perceived feasibility to function as an antiozonant in tires. The following scoring system was used:

1 = There is existing data that indicate the chemical does not work in tire rubber
2 = Feasibility data are lacking but the chemical structure indicates is it unlikely to work in tires
3 = Feasibility data are lacking but the chemical structure is promising

4 = There are some positive data indicating effective performance in tires but data are limited

Based on this scoring approach, chemicals with scores of 3 and 4 were carried forward in the AA process. However, all alternatives suggested by DTSC in the Priority Product profile and all alternatives suggested by the Washington State Department of Ecology were retained for the AA, irrespective of scoring. Overall, a total of 40 possible alternatives were carried forward into the analysis. A summary table showing the results of the literature search and the scoring of chemicals identified is included as Appendix F.

4.5.2 Possible Alternatives Identified

4.5.2.1 Possible Alternative PPDs

Based on the review process outlined above, the Consortium identified 19 potential 6PPD analogs that could potentially serve as substitutes for 6PPD. Note that these are not demonstrated to be actual alternatives to 6PPD but rather are chemicals that merit evaluation as shown in the AA to see if there is sufficient information indicating they could be possible alternatives to 6PPD. The order of the chemicals listed in Table 4.1 below does not indicate a relative level of priority.

Table 4.1 Possible PPD Derived Alternatives Meriting Further Study

Chemical Name	Acronym	CAS
N-(1,4-Dimethylpentyl)-N′-phenyl-p-phenylenediamine	7PPD	3081-01-4
N-ISopropyl-N′-phenyl-p-phenylenediamine	IPPD	101-72-4
N-Cyclohexyl-N′-phenyl-p-phenylenediamine	CPPD	101-87-1
N,N′-Diphenyl-p-phenylenediamine	DPPD	74-31-7
N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine	77PD	3081-14-9
4,4'-Dioctyldiphenylamine	DOPD	101-67-7
N,N′-Di-sec-butyl-p-phenylenediamine	44PD	101-96-2
N,N'-Ditolyl-p-phenylenediamine	Commercial DTPD	68953-84-4
N,N'-Dicyclohexyl-p-phenylenediamine	CCPD	4175-38-6
Diaryl-p-phenylene diamine	DAPD	68953-84-4
N,N'-Di-2-naphthyl-p-phenylenediamine	DNPDA	93-46-9
N' -Phenyl-N-Fluorenyl-Para-Phenylenediamine	NA	No CAS
N-(p-Phenylthiomethylphenyl)-N'-(1,3-dimethylbutyl)-p-phenylenediamine	NA	No CAS
4-(2,5-Dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	NA	No CAS
N,N - (Ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine or similar chemical 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	NA	No CAS
4-N-(2,3-Dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	NA	No CAS
RU997, Irgazone 997 Reaction product of N-phenyl-N′-(1,3-dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether	NA	No CAS
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	NA	No CAS
Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	NA	No CAS

Notes:
CAS = Chemical Abstracts Service Number; NA = Not Available; PPD = Paraphenylene Diamine.

Among these are PPDs that have been discussed in various documents as possible 6PPD replacements (*e.g.*, 7PPD, IPPD, 77PD, CPPD) and which are used to some extent commercially. The list also contains less well-known analogs, many of which lack CAS registry numbers. Lacking CAS numbers makes identifying toxicological or chemical data for these analogs challenging because all can be described by various chemicals names.

4.5.2.2 Possible non-PPD chemical alternatives

The Consortium's search process also identified 21 non-PPD possible alternatives as shown below (Table 4.2). Again, these are not demonstrated to be alternatives to 6PPD but rather are chemicals that merit evaluation in the AA to see if there is sufficient information indicating they could be potential alternatives to 6PPD. The order of the chemicals listed below does not indicate a relative level of priority.

Table 4.2 Possible Non-PPD Alternatives Meriting Further Study

Chemical Name	Acronym	CAS
N-1,3-Dimethylbutyl-N′-phenyl quinone diimine	6QDI	52870-46-9
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline	TMQ Oligomer	26780-96-1
Nickel dibutyldithiocarbamate	NBC	13927-77-0
Ethoxyquin	NA	91-53-2
Dilauryl thiodipropionate	NA	123-28-4
N,N-Diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	NA	No CAS
Mixed xylene diamines N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	NA	25790-41-4
2,4,6-tris-(N-1,4-Dimethylpentyl-para-phenylenediamino)-1,3,5-triazine	TAPDT	121246-28-4
N-Phenyl-1-naphthylamine	NA	90-30-2
N-Phenyl-2-naphthylamine	NA	135-88-6
[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520) blended with 3,9-Dicyclohex-3-enyl-2,4,8,10-tetraoxaspiro[5.5]undecane (Vulcazon AFS)	NA	110553-27-0
Specialized graphene[1]	NA	1034343-98-0
1,1' -Pentamethylenebis(2,2-di-n butylhydrazine)	NA	No CAS
α- C-4- Hydroxy- 3,5- dimethylphenyl- N-isopropyl combined with 2,2'-Methylenebis[6-(1-methylcyclohexyl)-p-cresol]	NA	77-62-3
N-(4-Methylpentan-2-yl)-10H-phenothiazin-3-amine	NA	No CAS
7-(4-Methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	NA	No CAS
2-Cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	NA	No CAS
4-(1H-Indol-2-yl)-N-(4-methylpentan-2-yl)aniline	NA	No CAS
α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	NA	No CAS
Amine functionalized lignin	NA	No CAS
Rambutan peel extract	NA	No CAS

Notes:
CAS = Chemical Abstracts Service Number; NA = Not Available; PPD = Paraphenylene Diamine.
(1) The materials referred to as graphene in this report are graphene-based materials (sometimes referred to as a graphene nano-platelet) with a surface area not greater than 180 m^2/g, and a carbon content greater than 99% and an oxygen content less than 1%. The lateral particle size of these materials is between 100 nm and 5 µm.

Notably these include a number of possible alternatives (*e.g.*, ethoxyquin, dilauryl thiodipropionate) that likely cannot replicate the functions of 6PPD but were included in the list because they were identified by DTSC or Washington Ecology as possible alternatives. As with the possible PPD alternatives, a number of these chemicals also lack CAS registry numbers making it difficult to identify potential toxicity and chemistry data.

4.6 Relevant Factors

According to the SCP regulations, each alternative must be reviewed to determine whether its use would lead to a material difference relative to the existing chemical (here 6PPD) in the various relevant factors listed in the regulation. We have considered the possibly relevant factors listed in Tables 3-1A and 3-2B of the DTSC AA Guide (2017) (which are consistent with those listed in the SCP regulation, § 69505.5 (c) (CalDTSC, 2013a). Our review occurred in stages. For some factors (*e.g.*, molecular weight) it was readily apparent that these would not be material differentiators among the different products under review. For others (notably the various toxicities specified in the SCP regulation [CalDTSC, 2013a]), we had to first tabulate data for the possible alternatives to understand if these factors differed materially among the products (the results of the tabulation are discussed in Section 5). Based on our current knowledge of the properties of the different alternatives we have identified, we have determined which factors make a material difference among the priority product and any possible alternatives such that it would inform the decision of the Stage 1 AA. The conclusions we have reached are provided in Table 4.4.

4.6.1 Information on Sales of the Priority Product in California

The SCP regulations require that product sales information be included in the AA. As indicated in Table 4.3 below, an estimated 33,332,000 passenger car/light duty truck tires were shipped to California in 2022 and an estimated 3,160,000 heavy duty truck and bus tires were shipped to California in that year, for an estimated total number of tires shipped to California in 2022 at 36,492,000 units. Further details regarding the derivation of this number are provided in Appendix E.

Table 4.3 Estimated Annual Shipments of the Priority Product in California

Vehicle Category	USTMA Tire Shipments in 2022	
	U.S.	CA (est.)
Passenger/Light Duty Truck	298,847,000	33,332,000
Heavy Duty Truck/Bus	33,139,000	3,160,000
Total	331,986,000	36,492,000

Notes:
CA = California; est. = Estimated; U.S. = United States.

4.6.2 Relevant Exposure Pathways

We have considered the exposure pathway-related factors listed in Table 3-2C of the DTSC AA Guide (2017) (which are consistent with those listed in the SCP regulation, § 69505.5 (c) (3)) (CalDTSC, 2013a). Based on our current knowledge of the properties of the different possible alternatives we have identified, we have determined which exposure pathway-related factors make a material difference among the priority product and any possible alternatives. The conclusions we have reached are described in Table 4.5.

4.6.3 Conceptual Model for Product Life Cycle

Figures 4.2 and 4.3 show the conceptual exposure models for the life cycle of the Priority Products (*i.e.*, 6PPD-containing tires), and the potential non-6PPD-based tires, respectively. Both types of products are assumed to have the same life cycle stages, although end of life process may vary depending on the alternative.

Across the various life cycle stages (*e.g.*, raw materials extraction, manufacturing, distribution, use, disposal) of the Priority Products, exposure to 6PPD (or its possible alternatives) for raw material production workers, tire manufacturing workers, consumers, or the general public *via* the inhalation and/or dermal contact exposure routes is possible. For the chemical production and tire manufacturing workers, the main routes of concern are inhalation and dermal. 6PPD and many of the possible alternatives are known dermal sensitizers (phenylene diamines alternatives, Durazone 37, and Irgazone 997 and see hazard Table 5.1 for more details), there is potential dermal exposure concern for chemical production and tire manufacturing workers if individuals do not wear appropriate PPE or if PPE is worn incorrectly or malfunctions. For a subset of possible alternatives, no dermal sensitization data are available. Once a tire is cured, there would be no dermal sensitization risk from 6PPD in tires. We assume the same can be said for non-6PPD possible alternatives in a cured tire, however, no data are available to confirm. During the use phase of the life cycle, there are some emerging exposure pathways relating potential inhalation exposures to airborne TRWP for the general public (Cao *et al*., 2022; Johannessen *et al*., 2022). More data are needed in order to confirm these findings.

As for effects to the aquatic environment, some studies have stated that 6PPD and many of the possible alternatives are harmful to some aquatic species following acute or chronic exposure (see aquatic hazard table 5.3 for more details). Recent studies concerning the 6PPD transformation product 6PPDQ reported that 6PPDQ is more toxic to coho salmon compared to 6PPD (see hazard table 5.4 for more details), however, the lack of information on the exact mechanism of why 6PPDQ causes such effects limits this analysis. No data are available for the transformation products of the possible alternatives, other than 77PD. For 77PD, the single available study concluded that 77PD is toxic to coho salmon, but the transformation product, 77PDQ, is not toxic to coho salmon at the highest tested concentration (Chapelet *et al*., 2023).

In California, the current industry metrics for end of life tire processing estimate that 45%, 16%, and 35% of end of life tires enter into landfills, tire derived fuel, and recycling (*e.g.*, retreaded as tires for buses and heavy-duty trucks, crumb rubber), respectively, in 2021 (CalRecycle, 2023). As for environmental exposures relating to the end of life processing of 6PPD-containing tires, more data are needed in order to assess potential concerns because migration of 6PPD, and the degradation product 6PPDQ, from recycled tires in products such as crumb rubber is not well characterized.

For chemical ingredients generated during waste production, if wastes were properly disposed of, there is low risk to human and ecological receptors.

However, if the waste products are improperly handled or disposed, there could be concerns relating to the potential for acute and chronic aquatic toxicity to be exerted by the products as a result of entering waterways either directly or through surface runoff during storm events. The same pathways and concerns are anticipated relating to possible alternatives.

4.7 Life Cycle Segments

Consistent with the requirements of the Stage 1 AA, we approached life cycle considerations from the perspective of what is readily known or understood about the possible alternatives without engaging in extensive analysis. The Stage 2 AA would involve a more detailed effort at substantiating and potentially quantifying life cycle differences among the different products under review. The information presented below is intended to be complimentary to the life cycle information provided in Tables 4.4 and 4.5. We note that several life cycle assessments (LCAs) have been developed for tires (BLIC, 2001; Piotrowska *et al*., 2019; Dong *et al*., 2021; Michelin, 2021), however none of these are granular enough to discuss the life cycle impacts of using 6PPD in tires. Thus, these LCAs provide very limited information for evaluating the life cycle impacts of tires containing 6PPD *versus* those that contain a possible alternative.

4.7.1 Raw Materials Extraction

To better understand the impacts of 6PPD and the possible alternatives, we compiled information on chemical production for the 6PPD and the other alternatives by consulting the National Library of Medicines PubChem database, which provides data on chemical manufacturing processes including the raw ingredients (Table 4.6). We used the database to sequentially trace back the processes and ingredients used to produce 6PPD and the possible alternatives until we reached an apparent starting material (*e.g.*, simple hydrocarbons that are extracted from fossil fuels or mineral salts obtained from mining). Information was available for most but not all possible alternatives; for some specific PPDs information was lacking but could be inferred from information provided for other members of this family. Based on our review, it is expected that 6PPD and most of its possible alternatives will ultimately be produced from fossil fuel sources or from mining activities (*e.g.*, graphene, sulfur). Both amine functionalized lignin and rambutan peel extract involve agriculturally produced materials. It is unclear whether current agricultural production of these materials is sufficient to support the antioxidant/antiozonant needs of tire production, especially for rambutan peel extract. If the active ingredients in rambutan peel extract are produced synthetically, they may well involve fossil fuel precursors.

While information on raw materials extraction is limited, we believe it indicates it is unlikely that there will be material differences among the possible alternatives, as all involve inputs involving fossil fuels and/or mined materials of various types (*e.g.*, metals). There are multiple methods for producing graphene but the most common involve either processing of mined graphite or deposition of methane (typically fossil fuel derived) onto a substrate. Thus, the overall impact on raw materials extraction is unlikely to be materially different for any of the possible alternatives under consideration based on information that is currently available.

4.7.2 Resource Inputs and Other Resource Consumption

This aspect of the life cycle describes raw ingredients and energy required to produce the antidegradant as well as other materials that might be impacted by the production processes (*e.g.*, water used for cooling). This information would likely be found in LCAs and those available for tires do quantify resource inputs (water, energy) for tire manufacturing. However, as noted above, there is no LCA available that quantifies the aspects of the life cycle specific to 6PPD and thus quantitative comparisons to the impacts of the possible alternatives is not feasible. None of the alternatives under consideration would require a wholesale change in the resource inputs to components which make up the majority of a tire; it is expected that tires will still be comprised of elastomers, fabrics, steel, silica, carbon black, *etc*. 6PPD (or a possible alternative) comprises only a small percentage of the mass of a tire, so even if the resource inputs required for an alternative were to be significantly different from 6PPD, the overall impact on the resource inputs for the tire would be small. It seems likely that production of alternate PPDs would involve similar resource inputs and consumption as 6PPD. Many of the non-PPD inputs also involve some of the same raw ingredients (*e.g.*, aniline) so their production pathways should not be materially different in terms of their impact on resources. Some of the possible alternatives are at least partially mineral in nature (*e.g.*, graphene, nickel dibutyldithiocarbamate) and so their processes is likely to be different but data are lacking to allow for comparisons to 6PPD. Lignin is a waste product of wood product manufacture but the production of amine functionalized lignin would introduce energy and chemical inputs. Rambutan peel extract similarly involves a waste product as a starting ingredient with further chemical processing. Details about production processes are limited based on internet searches for their producers or the processes involved. It is also conceivable that some possible alternatives would be produced at different locations which could have different impacts in terms of raw material and chemical intermediate transportation (both in terms of distance and transportation mode). However, data are lacking to assess such effects and moreover, transportation networks would likely change significantly to increase efficiency due to the large volume of antidegradant involved. Overall, whether resource inputs and consumption during production would be materially different between 6PPD and the possible alternatives is unknown at this time.

4.7.3 Intermediate Materials Processes

Intermediate materials processes refers to chemicals that are produced in the synthesis pathways of 6PPD and its possible alternatives. If an alternative involves a particularly hazardous (or non-hazardous) component during its production, that could constitute a material difference relative to 6PPD. On the other hand, an alternative that eliminates a hazardous chemical used during the production process would be preferable. Review of information on the chemical precursors of the functional ingredients in the Priority Product and possible alternatives (as summarized in Table 4.6) suggests that the PPD-related alternatives have essentially equivalent intermediate materials and processes as 6PPD. The non-PPD materials (*e.g.*, TMQ, ethoxyquin, NBC, DLTDP, graphene) involve different chemistries but all appear to involve industrial chemicals with some significant hazard. The hazards of graphene depends on the structure (*i.e.*, thickness) and stage of the production process. As shown in Table 4.6, amine functionalized lignin may involve some hazardous chemistries in lignin extraction (*e.g.*, methanol) or amine functionalization but details are lacking. Rambutan peel extract may similarly involve hazardous chemicals in extraction (*e.g.*, ethanol, methanol); less hazardous extraction solvents (*e.g.*, hydrochlorid acid) appear possible but all extraction process data appears related to small scale production; the chemistries appropriate for large scale production are unclear. Overall, it appears unlikely that intermediate materials processes are materially different among 6PPD and the various possible alternatives.

4.7.4 Manufacture

We interpret this life cycle stage as relating to the manufacturing of the tire itself (*i.e.*, the priority product) as earlier steps in the life cycle (*e.g.*, manufacturing of tire ingredients) are discussed in sections 4.7.2 and 4.7.3). The basic process of tire manufacturing described earlier (*i.e.*, mixing the individual compound, assembling each component and then building the tire from the inner side outwards in a tire assembly machine) will likely remain the same for the foreseeable future. As indicated in Tables 5.1 to 5.3, all the possible alternatives pose some hazards which could be relevant for workers during exposure. 6PPD and a number of the possible alternatives (44PD, DTPD, CCPD, ethoxyquin, Irgazone 997, N-Phenyl naphthalenes) are category 1 skin sensitizers; as already mentioned, this could expose workers who do not wear appropriate PPE (in violation of employer instructions). Other possible alternatives (Vulcazone, graphene, DLTP, NBC) do not have this hazard and would present less risk. Many of the latter do have other hazards (*e.g.*, NBC is a carcinogen, ethoxyquin has systemic toxicity) so this may not constitute a material difference. In addition, there are many toxicity data gaps for a number of the possible alternatives so the potential hazards for workers from these chemicals is hard to judge.[9] Overall, 6PPD and all of the possible alternatives have some hazardous properties involved in their manufacture (Table 4.6). These range from aniline and its precursors for the PPD alternatives to nickel, quinoline, ethoxyaniline, and various mineral acids. It should be noted that 6PPD (or a possible alternative) comprises a small percentage of the mass of the tire and it is assumed that all other ingredients (*e.g.*, elastomers, fabric belts, steel, carbon black, silica, other additives) will largely remain the same and contribute the same level of hazard. The extent to which some additives may change with a new antidegradant is also not currently known.

[9] It should be noted that for chemicals to be used in large volumes such as would be required for an antidegradant in tires, these toxicity data gaps would have to be filled under various global chemical registration programs. This would allow for a better understanding of these hazards; however, the data are not currently available.

Moreover, tires will still require vulcanization which constitutes the major source of energy required during the production process. Thus overall, it appears unlikely that changing the antidegradant will not have a material difference on the impacts of the manufacturing stage but data are too limited to be certain.

4.7.5 Packaging

There appears to be no material difference among the priority product and the possible alternatives under consideration in terms of the type of packaging that would be used. Tires are shipped in shipping containers, on pallets or individually, depending on the needs of the commercial customer. Any alternative would likely have the same general weight and dimensions as an existing tire so the method of packaging would not be expected to be different. Regarding the antidegradant itself, it is also anticipated that a chemical alternative to 6PPD would likely have a similar volume and density as 6PPD, therefore no significant change in raw material packaging would occur as a result of substitution of an alternative, unless higher quantities were required to offset any difference in mobility or reactivity *vs.* 6PPD. Overall, there is no expectation that switching to an alternative product would require either more or less packaging.

4.7.6 Transportation/Distribution

Transportation/distribution of the priority product and/or chemical of concern is considered to be an insignificant pathway in terms of 6PPD migration to the environment because the tires on the vehicles used for this purpose generate a very small fraction of the total TRWP generated on an annual basis in California and, as a result, pose minimal potential for significant exposure. Additionally, the tires being transported do not emit the chemical of concern during transport for distribution or sale. There is no evidence that transportation impacts (*e.g.*, from chemical suppliers to formulators; from formulators to retail outlets) would be different among the priority product or any of the possible alternatives under consideration. For example, 6PPD and its possible alternatives do not constitute the bulk of the product weight, so shipping tonnage would not be expected to be different. Depending on the production of the alternative (*e.g.*, at locations more or less distant from tire manufacturing facilities) there could be an impact on the transportation/distribution portion of the life cycle. However, no data are available to assess this potential impact since an alternative has not been definitively identified. It is also likely that cost would incentivize minimizing transportation of raw ingredients to tire production facilities so transportation impacts (*e.g.*, CO_2 emissions, TRWP generated from transport trucks) from the antidegradant production facility to tire production locations may not significantly change but this is unclear at the present time.

4.7.7 Use

Use is one area where the possible alternatives may have materially relevant differences to 6PPD, because the use phase of the product involves generation of TRWP and washing off of the antidegradant present on the tire surface. In addition, if a new alternative changes the abrasion rate of a tire, that would have an impact on TRWP generation. If the alternative also has differential hazards *versus* 6PPD (as some appear to do) this could be a materially relevant difference. If alternatives can reduce the release of 6PPD (or another chemical with similar toxicity to susceptible species) to the environment, then there would be a material difference in this parameter. Beyond the reported effect of 6PPD on certain salmon species, there are other aspects of the use phase which will need to be considered. One important consideration would be whether an alternative results in greater or lesser tire wear, potentially resulting in different environmental impact. However, TRWP generation rate likely depends more on driving conditions (*e.g.*, vehicle, load, speed, drive cycle, road surface type) than the antidegradant. Any alternative that could be implemented in a reasonable timeframe would still be rubber-based. Given the potential for a reduction in impact of the antidegradant, this does appear to be a factor that will be materially relevant to alternative selection.

4.7.8 Operation and Maintenance

Tires require little maintenance while in actual use. The maintenance that is required (*e.g*., maintaining tire pressure, tire rotation, balancing) would not be expected to change with any of the possible alternatives. This phase of the product lifecycle is also not associated with release of 6PPD from the tire and exposure of any potential receptor. Consortium members cannot conceive of a mechanism by which this would be different for any of the possible alternatives given that the basic nature of a tire will remain the same. Thus, operation and maintenance is unlikely to be a relevant factor among 6PPD and the possible alternatives.

4.7.9 Waste Generation and Management

We interpret this stage of the lifecycle to refer to production waste during tire production. TRWP are a wear product generated during the use phase but the impact of these are discussed in Section 4.7.7. Manufacturers cycle excess formulated compound back into the manufacturing process (called rework); this substantially minimizes waste generated during tire production. The ability to continue the rework process is critical for minimizing production waste and will need to be considered for any alternative. For example, as noted, earlier Consortium members' experience suggests it may be difficult to use modified EPDM or bromobutyl rubber as rework in production due to issues of behavior with other tire additives (*e.g*., carbon black) and is one of the reasons why they were not included in the AA. Any alternative antidegradant that impacts processing time or temperature stability could significantly impact the potential for rework. Thus this stage of the life cycle has the potential to be substantially different among the possible alternatives.

4.7.10 Reuse and Recycling

As shown in the conceptual model for tires (Figures 4.1 and 4.2), most tires are reused or recycled at the end of their useful life. Significant portions of the spent tire stream is re-used as fill material (road paving or crumb rubber infill), as structural materials (*i.e*., sea walls) or burned for energy (*e.g*., in cement kilns). If possible alternatives alter this situation, there could be a material difference in terms of end-of-life tire management potential. For example, NBC contains the carcinogen nickel which could impact air emissions from cement kilns or use as fill in artificial turf. Data currently suggest that 6PPD is well absorbed onto soil particles so its migration from sites where spent tires are used as fill is likely limited (WA Ecology, 2022); there are no data to indicate whether the same is true for any of the possible alternatives. A number of possible alternatives have higher vapor pressures and so may therefore present a greater inhalation risk.

One particular consideration for truck and bus tires is retread. An alternative that interferes with the retreading process could substantially increase tire waste because new truck and bus tires would need to be purchased and discarded more frequently. Depending on the possible alternative there could also be potential for exposure of retread facility workers. Overall, the reuse and recycling stage of the life cycle has the potential to be substantially different among the possible alternatives.

4.7.11 End-of-life Disposal

A relatively small portion of the tire waste stream is currently disposed of in landfills or incinerated. If tires with alternative antidegradants have a different lifespan this could impact the amount of post-manufacturing tire waste generated and could exceed reuse and recycling capacity. It is also possible that chemicals can leach out of tires and impact the environment from improperly designed or operated disposal facilities. Overall, the end-of-life stage of the life cycle has the potential to be substantially different among the possible alternatives.

5 Comparison of Alternatives

5.1 Hazard

5.1.1 Hazard Evaluation Approach

According to the SCP Regulation (CalDTSC, 2013a), a hazard evaluation comparing 6PPD and possible alternatives must include hazard endpoints from the Green Chemistry Hazard Traits defined in the California Code Of Regulations, Title 22, Division 4.5, Chapter 54.[10] Gradient organized the human health hazard endpoints into two groupings (*i.e.*, Group A and Group B). Group A hazard endpoints have corresponding GHS hazard endpoints (*e.g.*, acute toxicity, dermal sensitization, carcinogenicity), which allowed for transfer of existing hazard assignments according to each chemical's European Chemicals Agency (ECHA) Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) dossiers and GreenScreen assessments, if available.

Group B hazard endpoints are those that do not have corresponding GHS hazard endpoints (*e.g.*, ototoxicity, hematotoxicity, cardiovascular toxicity). To a large extent, these types of specific toxicity are subsumed in the larger category of "systemic toxicity," which *is* addressed in ECHA dossiers and GreenScreen assessments under Systemic Target Organ Toxicity – Repeated Exposure. Nonetheless, to comply with the SCP regulations, we addressed these remaining health endpoints (*i.e.*, discussed herein after as "Group B" endpoints) by reviewing ECHA dossiers, supplemented by GreenScreen assessments, for data on these particular health effects.

5.1.1.1 Hazard *versus* Risk

The California SCP regulations (and AA in general) do not allow Consortium members to incorporate a quantitative estimate of health risk (*i.e.*, combining estimates of dose and exposure to determine the likelihood of an adverse exposure) in making decisions about whether alternatives should be selected (CalDTSC, 2013a). It is important to stress that while chemical-specific hazards are presented in this section, chemical-specific hazards do not necessarily reflect the hazards of the actual final product (*i.e.*, a tire). Thus, when reviewing chemical-specific hazard data, the indication of a hazard does not necessarily equate to an actual human or ecological health risk caused by using the chemical in the tire. Risk and hazard are different concepts.

5.1.1.2 Group A Endpoints

For the Group A human health hazard endpoints (*e.g.*, dermal sensitization, carcinogenicity, target organ toxicity following repeated exposure) (summarized in Table 5.1), we reviewed the hazard properties of 6PPD and the possible alternatives for hazard properties using mainly ECHA REACH dossiers (ECHA, 2023) and existing GreenScreen assessments, if available.

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[10] This evaluation is based on a literature review of the available studies and did not involve an independent verification of the results of any study.

There are a number of additional potential hazard concerns required by the SCP regulations that are not classified in the ECHA dossiers. These were addressed as follows:

- **Endocrine Disruption and California Proposition 65.** The European Union's (EU) Endocrine Disruptor Priority List and the California Proposition 65 list were used to inform these endpoints (UL LLC, 2023).
- **Terrestrial Toxicity.** Pharos (Healthy Building Network, 2019) was used to inform this endpoint.
- **Bioaccumulative Potential.** Chemicals are considered bioaccumulative if the bioconcentration factor (BCF) is >1,000 according to California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5 (CalOEHHA, 2012).
- **Persistence.** Based on the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (UN, 2019), possible alternatives are considered persistent if 0 to <20% of the chemical degrades within 28 days, inherently biodegradable if 20 to <60% of the chemical degrades within 28 days, and readily biodegradable if 60 to 100% of the chemical degrades within 28 days.
- **Global Warming Potential (GWP).** We compared the possible alternatives to the greenhouse gases listed in Table 8.a.1 of the "Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)" (IPCC, 2013). Chemicals that are neither gases or chlorinated/fluorinated were considered to have negligible GWP.
- **Ozone-Depleting Potential (ODP).** US EPA's list of ozone-depleting substances (US EPA, 2018b) was used to evaluate this endpoint. Chemicals that are neither gases or chlorinated/brominated were considered to have negligible ODP.
- **Clean Air Act VOC Contributing to Smog Formation.** We assessed whether each possible alternative is a volatile organic compound (VOC); a chemical was considered to be a VOC if it had a vapor pressure equal to or greater than 0.1 mm mercury (Hg) based on criteria in CARB (2009). Additionally, we noted whether the chemical is listed as a substance exempted under 40 CFR § 51.100 (as per CARB, 2009).

To meet the SCP regulations' requirement for an easily understood matrix of hazards, we adapted the color-coding system used by various hazard evaluation tools, such as the GreenScreen hazard evaluation system (Clean Production Action, 2019). This employs a red/orange/yellow/green "heat map"-type color coding to allow the reader to easily compare the hazards of different chemicals at a high level. In addition, we added light grey shading to the endpoints for which no data were found (*i.e.*, data gaps). It should be noted that data gaps do not indicate a lack of toxicity; they merely indicate that no information was found.

5.1.1.3 Group B Endpoints

For group B endpoints (*e.g.*, ototoxicity, cardiovascular toxicity), we qualitatively summarized the reported findings concerning these adverse effects or the lack of relevant adverse effects, as well as any data gaps (Table 5.2). In conducting our review, we focused primarily on repeated-dose studies, because these typically have the most detailed evaluation of potential health effects, whereas acute dosing studies often only examine a limited number of health effects using gross measures (*e.g.*, clinical signs, organ weight changes). This is a qualitative approach, but we believe that the alternative approach (creating an arbitrary and novel GHS-like scoring rubric for all of the additional SCP hazard endpoints that lack recognized classifications like the GHS) would be unreasonably burdensome and problematic, because, as noted above, many of these health effects are already addressed in the larger category of systemic toxicity. Lastly, the SCP regulations do not define each Group B endpoint. While some endpoints are straightforward, such as respiratory, cardiovascular, and digestive system toxicity, others are not. As a result, we took the following approaches for certain vague Group B endpoints:

- **Epigenetic Toxicity.** We noted from our review whether possible alternative were or were not genotoxic. Genotoxicity generally implies changes in the DNA sequence, which is outside the scope of epigenetic toxicity, but genotoxicity also implies a potential for interaction with DNA, so it is evaluated given that more direct data on epigenetic effects are lacking. In addition, we looked for other relevant information in our data sources regarding other types of DNA activity (*i.e.*, altered methylation).
- **Reactive in Biological Systems.** In their Priority Product profile, DTSC cited this as a factor of concern. We acknowledged this fact but were unable to make a determination about this relevant factor for possible alternatives due to a lack of definition for this endpoint under the SCP regulations; thus, data gaps were assigned for all chemicals evaluated. All chemicals (*i.e.*, water, oxygen) are reactive in biological systems.
- **Immunotoxicity.** We included respiratory and dermal sensitization as relevant under this endpoint, as these are immune system-mediated effects.

Again, it should be noted that the chemical-specific hazards presented in Tables 5.1-5.4 do not represent the potential hazards or risk of finished tires, because the finished tire limits the ability of 6PPD to migrate (*i.e.,* relative to the exposed surface area of the tire, concentration and accessibility of 6PPD is low).

5.1.1.4 Salmonid Acute Toxicity

While not specifically required under the SCP regulation, potential acute toxicity to salmonid species is part of the rationale for DTSC listing the priority product. To be responsive to DTSC's action, we included acute salmonid toxicity as a hazard consideration in the AA. For each possible alternative, we conducted a comprehensive literature search to identify relevant lethal concentration 50 (LC_{50}) data for the parent chemical and quinone product if applicable (*i.e*., phenylene diamines). We focused specifically on data reported in the peer-reviewed literature and as summarized in scientific and regulatory agency reports (such as DTSC and WA DOE) for organisms in the Salmonidae family (*e.g*., genuses Salmo, Salvelinus, Oncorhynchus), based on phylogenetic relationship to coho salmon. Species in genus Salmo include Atlantic salmon (*Salmo salra*) and brown trout (*Salmo trutta*). Species in genus Salvelinus include Arctic char (*Salvelinus alpinus*), brook trout (*Salvelinus fontinalis*), and white-spotted char (*Salvelinus leucomaenis pluvius*). Species in genus Oncorhynchus (other than coho salmon, *Oncorhynchus kisutch*) include Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). We conducted searches of the scientific literature in the PubMed, Scopus, and US EPA ECOTOX databases, agency reports (*e.g*., DTSC, WA DOE), and, as mentioned, ECHA REACH dossiers. For PubMed[11] and Scopus[12] literature searches, we searched the common name and CASRN of each chemical in a search

[11] As an example PubMed search, the search string for IPPD was as follows: (101-72-4[EC/RN Number]) OR ("N-isopropyl-N′-phenyl-p-phenylenediamine"[tiab:~0] OR IPPD) AND (oncorhynchus OR ecotox*[Title/Abstract] OR aquatic[Title/Abstract] OR ecolog*[Title/Abstract] OR ecosystem*[Title/Abstract] OR fish[Title/Abstract] OR salmon[Title/Abstract] OR trout[Title/Abstract] OR "marine organisms"[Title/Abstract] OR "aquatic organisms"[Title/Abstract] OR "freshwater"[Title/Abstract] OR wildlife[Title/Abstract] OR fauna[Title/Abstract] OR "Ecotoxicology"[Mesh] OR "Aquatic Organisms"[Mesh] OR "Ecosystem"[Mesh] OR "Fishes"[Mesh] OR "Animals, Wild"[Mesh] OR "Ecology"[Mesh] OR "Salmon"[MeSH] OR "Trout"[Mesh]) NOT (zebrafish OR Human OR mice).

[12] As an example Scopus search, the search string for IPPD was as follows: (CASREGNUMBER (101-72-4) OR TITLE-ABS-KEY ("IPPD" OR "N-isopropyl-N'-phenyl-p-phenylenediamine")) AND TITLE-ABS-KEY (ecotox* OR aquatic OR fish OR salmon OR trout OR "marine organisms" OR "aquatic organisms" OR "freshwater" OR wildlife OR invertebrates OR oncorhynchus) AND NOT TITLE-ABS-KEY (zebrafish OR human OR mice).

string to identify aquatic toxicity data in salmonids. In order to provide the most conservative evaluation in the current AA, we identified the lowest reported LC_{50}s for each possible alternative for both the parent chemical itself and its quinone product if applicable and available. Other studies may have reported higher LC_{50} values. We also reported the duration of exposure (*e.g.*, 24 hrs, 96 hrs), experimental flow conditions (*e.g.*, flow-through, static) and whether the exposure concentrations were nominal or verified by experimental measurement. Results of the salmonid acute toxicity evaluation are presented in Table 5.4.

5.1.1.5 USGS studies of alternatives involving cell lines

Although the SCP program does not require generation of additional data, under sponsorship from USTMA, the US Geological Survey (USGS) have conducted initial studies on a subset of PPD-related possible alternatives, specifically, CCPD, 77PD, and DPPD, with 6PPD studied for comparison. These three phenylene diamines were selected because they have slightly different chemical structures (alkyl alkyl or aryl aryl substitutions) compared to 6PPD (alkyl aryl substitution), or they were selected because they were mentioned as possible alternatives by documents published by California DTSC (CalDTSC, 2022) and/or Washington Department of Ecology (WA Ecology, 2021). The USGS authors had previously published a study demonstrating that the *in vitro*, Pacific salmon cell system was able to partially replicate the species-specific differences in susceptibility to 6PPDQ reported in whole animal studies (Greer *et al*., 2023). The current studies used cell lines derived from two Pacific salmon species, coho and Chinook. The goal of these cell-based studies was to determine whether the selected alternatives produced toxicity in salmonid cells in a manner similar to 6PPD. Given the difficulty in conducting screening studies in whole salmon (*e.g*., time, cost, availability, low throughput) and the need for new approach methodologies that limit the use of live animal screening, these studies were also intended as proof-of-concept investigations to determine whether a cell-based screening approach would provide a rational basis for identifying a subset of possible alternatives to 6PPD.

The studies conducted in collaboration with the USGS focused on the selected possible alternatives as well as their ozonation products. Rather than isolated chemical solutions, the studies involved extracts of tire rubber that had been formulated with the different antiozonants at a standard concentration. Strips of the rubber were subjected to ozone at three different concentrations (0, 10, and 40 parts per hundred million (pphm)). Strips were then eluted in 100% ethanol overnight. A portion of each extract was sent to an analytical laboratory for quantification of parent compounds and associated quinones. The rubber extracts were then tested at different concentrations in both the coho-derived cell line (CSE-119) and Chinook cell line (CHSE-214). Because the research is being conducted under a Cooperative Research and Development Agreement (CRADA) with USGS, which intends to publish the results in a peer reviewed journal, full details of the methods cannot be provided here but may be able to be shared with DTSC by USTMA as confidential business information. A brief, preliminary overview of the results of these studies is provided below in Section 5.1.3.5.

5.1.1.6 Transformation Products

As required by the SCP regulations, we also identified the main transformation products of the possible alternatives and reviewed their chemical properties and potential toxicity (Table 5.10). We identified potential transformation pathways and products mainly *via* ECHA REACH dossiers (ECHA, 2023). We then reported the classified GHS hazards of the potential transformation products *via* the ECHA dossiers of the transformation products. Additionally, we noted if any transformation product is on the EU Persistent, Bioaccumulative, and Toxic (PBT) list, the California Toxic Air Contaminant (TAC) list, and/or the California Proposition 65 list, using Underwriters Laboratories Inc.'s (UL) List of Lists (LOLI) (UL LLC, 2023). In Table 5.10, possible alternatives that were present on any of these lists or which had significant toxicity under GHS classification (*e.g*., carcinogenicity category 1, acute or chronic toxicity category 1, mutagen) were flagged with orange shading.

Prior to reliance on information in ECHA dossiers, we evaluated the potential to conduct analyses with OPERA and the OECD QSAR Toolbox. Overall, neither program yielded useful information and in fact, while OPERA can predict physical-chemical properties, environmental fate parameters, and toxicity endpoints (Mansouri *et al*., 2018), it does not have a module to predict transformation products. Our methodology and findings are discussed briefly below.

Regarding hydrolysis, we used the OECD QSAR Toolbox hydrolysis simulator at pH neutral, acidic, and basic. Under these conditions, none of the hydrolysis simulators predicted transformation products for any PPD-based alternatives, most likely because the p-phenylenediamine moiety (present in 6PPD and similar PPDs) may not be included in the software's hydrolysis model training set. In contrast, for two non-PPD alternatives, 6QDI and dilauryldithiopropionate, hydrolysis transformation products could be modeled based on hydrolysis at their imine and ester bonds, respectively. The modeled hydrolysis products were identical to those reported in the ECHA REACH dossiers for the possible alternatives (described below).

Regarding ozonation and oxidation, we looked for tools that could address these transformation pathways. We did not find programs that could model transformation products through the ozonation pathway. The QSAR Toolbox does not contain an ozonation simulator, but does contain an autoxidation simulator. Autoxidation is a free radical reaction of a chemical with molecular oxygen that results in the formation of oxidation products of 6PPD (OECD, 2017). The QSAR Toolbox autoxidation simulator did not predict 6PPDQ as one of the oxidation products. We note that although 6PPD can react with ozone or potentially ozone-related secondary oxidants (*e.g*., hydroxyl radical), no significant degradation of 6PPD in zero-grade (ozone-free) air was observed experimentally after 6 hours of exposure, as reported by Hu *et al*. (2022).

As mentioned, due to the lack of utility using QSAR modeling approaches to evaluate transformation products of the alternatives, we identified potential transformation pathways and products mainly *via* ECHA REACH dossiers (ECHA, 2023). ECHA REACH dossiers provide some information on potential transformation products but are incomplete in terms of the range of possible transformation products covered. Data on potential transformation products was available for 6PPD and seven of the 40 possible alternatives (Table 5.10). The seven possible alternatives were: six PPD derived chemicals (7PPD, 44PD, 77PD, IPPD, commercial DTPD, and DAPD) and the non-PPD alternative 6QDI. These seven possible alternatives had hydrolysis studies reported in the ECHA dossier. The 33 remaining possible alternatives did not have ECHA REACH dossiers or did not identify transformation products in their hydrolysis studies.

Among the seven possible alternatives with data, 18 potential hydrolysis products were identified. According to ECHA, most PPDs have similar transformation pathways for hydrolysis where the first step is the cleavage of the alkyl chain resulting in a phenolic chemical (*e.g*., 4-hydroxydiphenylamine for 6PPD, 7PPD, and IPPD) and an alkylamine (ECHA, 2023). The structure of the alkylamine will vary due to PPDs having different alkyl chain lengths. For example, for 6PPD the alkylamine formed is 1,3-dimethylbutylamine, whereas for 7PPD the alkylamine formed is 1,4-dimethylpentylamine. Most PPDs are currently understood to form a quinone-imine transformation product which may be from the oxidation of the phenolic chemical. The secondary hydrolysis products are usually p-benzoquinone and p-hydroquinone, and in some cases, an amine due to the cleavage of the second amino group. For PPDs linked to phenyl groups (*e.g*., 6PPD, 7PPD), the amine formed is aniline. Most PPDs are expected to follow a similar transformation pathway and produce similar transformation products. Quinones were not listed as a transformation product in any of the ECHA dossiers of any of the examined chemicals.

5.1.2 Hazard Scoring Approach

We quantitatively scored hazards of 6PPD and possible alternatives using an adaptation of the Chemical Scoring Index (CSI). The CSI is a largely GHS-based tool for ranking the hazards of chemicals in oil and gas products (Verslycke *et al*., 2014). The CSI has been used in prior AAs that have been accepted by DTSC. The CSI considers not only the hazard but also the percentage of each chemical in the product formulation. These two pieces of information are combined using a scoring matrix to arrive at a total hazard score for the chemicals in the product. The original form of the CSI is heavily focused on acute toxicity hazards and did not have all the endpoints required under the SCP regulations (Verslycke *et al*., 2014), so some modifications to the CSI were required for this assessment. The modifications to the original CSI approach consisted of the following, and are also described in Tables 5.5-5.7:

- **No data substances.** Gradient did not attempt to score chemicals that have no data, since doing so would result in low scores, which could be interpreted as less hazardous compared to chemicals with higher scores based on data. We also did not use predictive toxicity modeling software to fill endpoints such as aquatic toxicity or dermal sensitization because doing so would unfairly give data-poor compounds a scoring advantage compared to data-rich compounds. The majority of the data-gap endpoints cannot be modeled, thus data-gap penalty scores, which are always lower than the score of the most severe classification, would be applied. For example, DOPD CAS 101-67-7 is a complete data-gap chemical. If we were to score DOPD using the data-gap penalty scores, its total score would be 220, which would make DOPD appear as a less toxic alternative than 6PPD, a data-rich chemical, that has a total score of 275. However, DOPD should not be considered a less toxic alternative to 6PPD because DOPD lacks toxicity information.
- **Assigning a penalty for endpoint-specific data gaps for data-poor chemicals.** The original CSI approach does not penalize data gaps on an *endpoint by endpoint* basis. It only penalized a product if <30% of its composition is accounted for by components with no data, with a maximum penalty score of 100 for the environmental categories, 100 for the human health categories, and 50 for the physical categories (if ≥30% of a product's composition is accounted for by components with no data, it would not be evaluated [see above]). Thus, the CSI lacks granularity in terms of how many or which health endpoints have missing data. For this AA, we added endpoint by endpoint penalty scores for data gaps, which is more conservative than the CSI's approach. These data gap scores were assigned based on hazard severity (*i.e.*, the maximum carcinogenicity and mutagenicity data gaps are scored 50 *versus* 10 for endocrine disruption). Also, in general, data gap penalty scores are lower than the Category 1 hazard scores for the same endpoint, and data gap penalty scores generally decrease with decreasing chemical concentrations, except for some categories of particular concern (*e.g*., Category 1 carcinogens).
- **Chronic aquatic toxicity.** The CSI does not have scores for chronic aquatic toxicity; thus, the CSI's scoring system for acute aquatic toxicity was used.
- **Terrestrial toxicity and GWP.** The CSI does not have scores for terrestrial toxicity or GWP; thus, scores for these metrics were created.
- **Mutagenicity, reproductive/developmental toxicity, and systemic toxicity single- and repeated-dose toxicity.** Under the original CSI approach, scores did not differ between the GHS subcategories for mutagenicity, reproductive/developmental toxicity, and systemic toxicity single- and repeated-dose toxicity. To provide more granularity in the scoring, for this AA, we adopted the maximum CSI score for Category 1 for all of the abovementioned hazard endpoints, but scaled down to a lower score for subsequent subcategories (approximately 50% of the Category 1 score for Category 2, and so on). This approach is in line with the spirit of the GHS and CSI. Note that

the CSI implemented lower scores for Categories 2 and below for carcinogenicity, corrosivity, and acute mammalian and aquatic toxicity, but not for the four abovementioned endpoints.

- **Endocrine.** We moved the endocrine hazard endpoint from ecological toxicity to human health toxicity. Additionally, we used a score of 25, instead of the original 50 in the CSI, for endocrine disruptors, because the EU's Endocrine Disruptor Priority List, which we used for this assessment, is a listing of chemicals with endocrine *concern* that should be explored *via* testing, rather than a list based on studies showing actual effects. In contrast, the maximum score for mutagenicity is 50 and is based on positive findings of a mutagenic effect.
- **Skin and respiratory sensitization.** We created separate skin and respiratory sensitization categories from the original CSI's "sensitizer" category, to be consistent with the SCP regulations' toxicity categories. Additionally, we used a maximum score of 50, instead of the original 25 in the CSI, for skin and respiratory sensitization. This is because the original CSI approach was developed for oil and gas applications, in which sensitization was less of an issue.
- **VOCs contributing to tropospheric ozone formation.** We used a maximum score of 75, instead of the original 50 in the CSI, for this endpoint. Because smog formation is a particular concern for California cities, we increased the maximum score for this endpoint.
- **Eye and skin irritation.** We created separate categories for eye and skin irritation from the "irritant" category in the original CSI to be more consistent with the required SCP regulations' toxicity categories. We assigned a maximum data gap penalty score of 25 for products in which components with no data account for more than 30% of the composition, matching the score of 25 for Category 1 skin or eye irritants, because these are common hazards.

When the original CSI approach provided numerical scoring values for an endpoint, we used those scores, other than the abovementioned deviations for endocrine disruption, skin and respiratory sensitization, and VOCs contribution to tropospheric ozone formation. When scores for endpoints were created, we employed scores that were consistent with similar endpoints (*e.g.*, we used the same scoring used for "irritation" in the original CSI approach for the new eye and skin irritation scores). In our scoring approach, we did not score Group B endpoints (Table 5.2) or acute toxicity in salmonids, because any adverse effects that rise to the level of GHS classification would already be captured under the single target organ toxicity – repeated exposure endpoint and acute aquatic toxicity, respectively, and we wanted to avoid "double counting." We also did not attempt to score chemicals that have no data, since doing so would result in low scores, which could be interpreted as less hazardous compared to chemicals with higher scores based on data.

Lastly, Greenscreen assessments classified 6PPD and several possible alternatives as respiratory sensitizers based on dermal sensitization hazard, a respiratory sensitization structural alert (phenylenediamine alert from OECD QSAR Toolbox), and/or professional judgement (ToxServices, 2021a,b,c,f,g,h). Gradient listed ToxService's hazard assignments in the relevant hazard table (Table 5.1 Group A), however, Gradient did not score the endpoint based on respiratory sensitization assignment. Instead, a data gap score was assigned because there are very few recognized respiratory sensitizers relative to the large number of skin sensitizers (Kimber *et al.*, 2018; North *et al.*, 2016).

According to the United Kingdom government agency, Health and Safety Executive, there are only approximately 45 substances or chemical groups that are recognized respiratory sensitizers, mostly made up of enzymes, dusts, and low-molecule-weight chemicals (United Kingdom, Health and Safety Executive, 2021). Comparatively, there are many thousands of known or suspected dermal sensitizers (Kimber *et al.*, 2018). Additionally, many chemical allergens are exclusively dermal sensitizers (Kimber *et al.*, 2018). In other words, a substance's ability to elicit a dermal sensitization response is not a good predictor of its ability to elicit a respiratory sensitization response.

It is also important to recognize that the mechanisms in which dermal sensitization occurs (*i.e.,* adverse outcome pathway) is well understood, however, very little is known about the adverse outcome pathway leading to respiratory sensitization (North *et al.*, 2016). Respiratory sensitizers tend to induce a predominantly T helper cell type 2 (Th2) response involving IgE antibodies, whereas dermal sensitizers tend to induce a predominantly T helper cell type 1 (Th1) response (North *et al.*, 2016).

5.1.3 Hazard Scoring Results

5.1.3.1 Hazards of 6PPD and Possible Alternatives

Tables 5.1 and 5.3 summarize hazard scoring for the human health (Group A endpoints only), and environmental and physical evaluation parameters, respectively. The total hazard scores for each possible alternative are summarized in Table 5.8.

When interpreting the hazard scores, the higher the score, the greater the potential concern. However, while we quantitatively scored hazards of 6PPD and possible alternatives, it should be stressed that the hazard scores should be treated as approximations of hazards (*i.e*., ballparks) because of the underlying uncertainties. A score of 100 would be considered less toxic than a score of 400, however, a score of 275 should be considered more or less the same compared to a score of 300.

6PPD and all 40 alternatives exhibited a lack of global warming or ozone depletion potential, contribution to smog formation, and flammability. That is, all 40 possible alternatives were essentially equal to 6PPD with respect to physical hazards and received scores of 0. Accordingly, total hazard scores were only affected by the human health and environmental hazard parameters. For example, 6PPD received a total hazard score of 275 based on scores of 125, 150, and 0 for human health, environmental, and physical hazards, respectively.

Human health and environmental hazard data were available for 19 of the 40 possible alternatives. Total hazard scores for these 19 alternatives ranged from 40 to 325. The only possible alternative that received a total hazard score higher than 6PPD was 6QDI, a non-PPD possible alternative, with a score of 325. 6QDI was concluded to have many data gaps and relied on surrogate data from 6PPD for most hazard endpoints, and thus the higher hazard score for 6QDI was due to data gap penalites (*i.e*., penalites of 25 each for data gaps for carcinogenicity and germ cell mutagenicity). Therefore, 6QDI may not necessarily need to be excluded from consideration as a possible alternative until relevant hazard endpoints are experimentally determined for 6QDI itself (rather than reliance on 6PPD as a surrogate).

For a number of alternatives, no hazard data were available to develop a hazard score (*i.e*., rambutan peel extract, lignin, DNPDA). Graphene (CAS 1034343-98-0), it is an engineered nanomaterial made completely from carbon. Not all graphenes are the same. The form of graphene evaluated in this report, due to positive performance, is a specialized form of graphene nanoplatelets. Even within this category of graphene, there could be differences (*e.g.*, size, number of layers, surface area, surface chemistry) that could contribute to differences in toxicity (Fadeel *et al.,* 2018; Achawi, *et al.*, 2021). Additionally, from a worker safety perspective, graphene nanomaterials must be handled with proper engineering controls and PPE to prevent inhalation exposure (The Graphene Council and Barkan, 2023). The form of graphene (CAS 1034343-98-0) reported in the toxicology studies of the ECHA dossier (reported in Tables 5.1, 5.2, 5.3, and 5.8 of this report) consists of sets of graphene nanoplatelets (The Graphene Council and Barkan, 2023; ECHA, 2023). It is not known if the toxicology studies cited in the ECHA dossier would apply to the form of graphene under study in this AA. In addition, the manufacturer of one form of this material

(Prophene™, Akron Polymer Solutions), is not listed as one of the joint registrants of graphene in the ECHA dossier (ECHA, 2023).

5.1.3.2 Group B Human Health Hazard Endpoints

Table 5.2 summarizes results for each possible alternative with respect to Group B human health hazard endpoints (*i.e.*, those that do not have corresponding GHS hazard endpoints such as ototoxicity or cardiovascular toxicity). As discussed, quantitative hazard scoring was not performed for Group B hazard endpoints and these endpoints are subsumed in the larger category of "systemic target organ toxicity" addressed in ECHA dossiers and GreenScreen assessments. Nevertheless, we qualitatively summarized Group B hazard information for each possible alternative in accordance with SCP guidelines.

Liver effects (*e.g.,* changes in liver organ weight and changes in liver functions) and hematological changes (*e.g.,* macrocystic anemia) were observed for 6PPD and some of the possible alternatives. However, the effects were either considered adaptive and/or not clinically significant by the respective ECHA dossier registrants (ECHA, 2023). Kidney effects, such as increased kidney organ weight and histopathological changes, were found for some of the possible alternatives; however, none of the respective ECHA dossier registrants considered the effects to classifiable either (ECHA, 2023). In addition, many of the possible alternatives and 6PPD are dermal sensitizers, but this information was already captured under Group A endpoints.

5.1.3.3 Salmonid Acute Toxicity – Parent Chemicals

Table 5.4 summarizes salmonid acute toxicity data (*i.e.*, LC_{50}) for the possible alternative parent chemical. As mentioned, we identified LC_{50}s for the parent chemicals themselves, and for their quinone products when appropriate and available. This section discusses results for the parent chemicals. For 6PPD, the lowest reported LC_{50} in coho salmon was 250 µg/L in juveniles exposed for 24 hrs (Tian *et al*., 2021), however, the lowest reported LC_{50} in a salmonid was 140 µg/L in rainbow trout exposed for 96 hrs (Monsanto Co., 1977, as cited in the EcoTox database).

Nine of the 40 possible alternatives (as the parent chemicals) had LC_{50} data available in a salmonid. The nine possible alternatives were five PPD derived chemicals (77PD, 44PD, commercial DTPD, CCPD, and DAPD) and four non-PPD chemicals (6QDI, NBC, ethoxyquin, and N-Phenyl-1-naphthylamine). The lowest reported LC_{50}s of the nine possible alternatives ranged from 24 to >100,000 µg/L. The LC_{50}s were all determined in rainbow trout, with the exception of 77PD for which an LC_{50} of 24 µg/L was determined in juvenile coho salmon exposed for 96 hrs (Chapelet *et al*., 2023).

Three of the nine possible alternatives had LC_{50}s lower than 6PPD: 77PD, 44PD, and CCPD, for which LC_{50}s of 24, 130, and 130 µg/L were reported after 96 hr exposures. As discussed, for 77PD the LC_{50} data was reported in coho salmon (Chapelet *et al*., 2023). For 44PD, the LC_{50} (130 µg/L) was reported in rainbow trout (Dionne, 1995 as cited in ECHA, 2023). For CCPD, the available LC_{50} value was based on the LC_{50} for 44PD as a surrogate (*i.e*., 130 µg/L as reported by Dionne [1995 as cited in ECHA, 2023]). In contrast, the remaining six possible alternatives had LC_{50}s higher than 6PPD, ranging from 440 to >100,000 µg/L. Two of these six chemicals had LC_{50}s at least two orders of magnitude greater than that of 6PPD, the non-PPD chemicals ethoxyquin and NBC for which LC_{50}s of 18,000 and >100,000 µg/L, respectively, were reported in rainbow trout after 96 hr exposures.

Overall, among the 40 possible alternatives, LC_{50} data in coho salmon was only available for 77PD. As mentioned, all other LC_{50}s were reported in rainbow trout, and although the majority were on the same order of magnitude as 6PPD, two non-PPD chemicals had LC_{50}s at least two orders of magnitude greater than that of 6PPD.

Ultimately, as discussed, any potential acute aquatic toxicity hazards reported in salmonids may not represent potential hazards or risk associated with their presence in a final vehicle tire product, as any potential hazard of these chemicals is dependent upon their potential migration from vehicle tires and TRWP, which if any, remains unclear.

5.1.3.4 Salmonid Acute Toxicity – Quinone Products

Table 5.4 summarizes the lowest reported salmonid acute toxicity data (*i.e.*, LC_{50}) for 6PPDQ and quinone products of the potential PPD derived alternatives. For 6PPDQ, the lowest reported LC_{50} in coho salmon was 0.041 µg/L as measured in juveniles exposed for 24 hrs (Lo *et al*., 2023). In addition, Nair *et al*. (2023) reported an LC_{50} of 0.64 µg/L in juvenile rainbow trout exposed to 6PPDQ for 96 hrs.

For potential PPD derived alternatives, LC_{50} data for a quinone product was only available for five possible alternatives, 77PDQ, CPPDQ, DPPDQ, DTPDQ, and IPPDQ. Chapelet *et al*. (2023) reported an LC_{50} > 226 µg/L in juvenile coho salmon exposed to 77PDQ for 96 hrs. In addition, Nair *et al*. (2023) reported LC_{50}s > 50 µg/L (the highest tested concentrations) in juvenile rainbow exposed to 77PDQ, CPPDQ, DPPDQ, DTPDQ, and IPPDQ for 96 hrs.

Overall, data regarding potential acute toxicity of the quinone products of the potential PPD derived alternatives is limited only to two studies involving 77PDQ (Chapelet *et al*., 2023; Nair *et al*., 2023), and CPPDQ, DPPDQ, DTPDQ, and IPPDQ (Nair *et al*., 2023). These studies suggest there may be lower acute toxicity of 77PDQ, CPPDQ, DPPDQ, DTPDQ, and IPPDQ relative to 6PPDQ, however, these results will require validation by other laboratories and further studies. Hence, there is inadequate evidence to assess the potential acute toxicity hazard of quinone products of the potential PPD derived alternatives in salmonids.

5.1.3.5 USGS Predecisional Summary

Rubber samples containing 6PPD or one of three potential alternatives (77PD, CCPD, or DPPD) were used to address potential toxicity using cell Pacific cell-line toxicity assays established in Greer *et al*. (2023). Studies conducted by USGS demonstrated the utility of cell-line-based approaches for initial screening of potential 6PPD alternatives. Ozonation of rubber containing 6PPD led to significant toxicity for coho cells in comparison with the Chinook salmon line. All rubber samples reacted with ozone resulting in production of quinone transformation products. Representatives of all three classes of PPDs (77PD, CCPD, or DPPD) and their quinones showed differential toxicity relative to 6PPD, providing a preliminary indication that not all PPDs pose the same degree of hazard to coho as 6PPD.

Although preliminary, the Consortium believes this supports the consideration of other PPDs as part of the Stage 2 AA. As noted above, the USGS work is being conducted under a CRADA, and under the terms of that agreement, the results cannot be publicly released prior to publication by USGS. A confidential version of the results is being provided to DTSC separately as confidential business information. It is hoped that publication will allow for public release of the information during Stage 2.

5.1.3.6 Hazards of environmental degradation products

As shown in Table 5.10, hazard data were available for 6PPDQ and four of the 18 potential hydrolysis products identified: 1) p-benzoquinone, 2) p-hydroquinone, 3) aniline, and 4) 1-methyl-propylamine. None of the potential breakdown products are listed on the EU PBT list. In addition, of the potential breakdown products, only aniline is present on the California Proposition 65. All of the identified breakdown products are present on the California TAC list, except for 6PPDQ and 1-methyl-propylamine.

All 4 of the ahydrolysis breakdown products mentioned above are classified under GHS as Category 1 for acute aquatic toxicity, however, the classifications are not necessarily based on evidence in salmonids. Two of the breakdown products (p-hydroquinone and aniline) were also classified as Category 2 for carcinogenicity. A number of the breakdown products are also classified as skin sensitizers.

Overall, several of the possible PPD based alternatives (*i.e.*, 7PPD, 77PD, 44PD, and 6QDI) have breakdown products in common with 6PPD (*i.e.*, aniline and p-benzoquinone) and thus have the potential for similar health hazards (*i.e.*, shaded orange in Table 5.10). For the majority of possible alternatives, breakdown products were not described in the ECHA dossiers and no conclusions about their potential hazards can be reached. This was notably the case for many of the possible non-PPD based alternatives (*e.g.*, NBC, DLTP, ethoxyquin, graphene). This constitutes an important source of uncertainty in the AA. Further research into the potential breakdown products of these possible alternatives is required.

It should also be noted that any chemical-hazards summarized above based on studies of pure chemical do not necessarily reflect actual hazards or risks associated with vehicle tires because the extent to which the antidegradant will be released from the TRWP and be subject to breakdown is currently unknown.

5.2 Performance

To organize performance information available for the possible alternatives we considered three groupings: information available from studies published pre-2020 (the date the Tian *et al*. 2021 study was published on-line); data from testing on a select set of PPD alternatives conducted by Flexsys in conjunction with the USGS toxicity studies; and data from performance studies published post 2020. Each of these is discussed below.

5.2.1 Performance Data from Studies Pre-2020

Table 5.11 summarizes data for 26 alternatives that was published in patents, journal publications or other sources prior to 2020. This table lists the class of compound, the chemical name and CAS registry number, the results of the screening-level performance test and the conclusion as to whether the tests suggest additional study of the chemical's performance is warranted. The references for where the test information can be found is also included. It should be noted that in these older studies, not all comparisons of performance were made against 6PPD. For example, some were compared to ethoxyquin or other PPDs, and in such cases, Consortium technical experts inferred whether this indicated similar or better performance compared to 6PPD was possible (generally we leaned towards including rather than excluding such compounds from further study). In addition, since the data comes from different sources, the test for ozone protection is not consistent across the chemicals evaluated, making interpretation challenging. In some cases, data were not provided for ozone effectiveness (*e.g.*, if the chemical was discussed as an antioxidant only) or no comparison compound was included. Such chemicals were generally not recommended for further study. This evaluation also considered the speed at which the chemical is likely to migrate through the tire rubber, typically based on molecular size. As noted in Section 3.3, migration and/or diffusion through tire rubber is important for maintaining an effective concentration of antioxidant on the tire surface. Chemicals that, based on their molecular size, would be expected to migrate too quickly or too slowly through tire rubber compound were not included as candidates for further study.

In addition, other considerations such as staining and solubility in rubber vary by compounds and need to be considered. For example, ethoxyquin and IPPD are highly staining antioxidants and are unsuitable for use in parts where water may drip from the part onto a painted body surface, such as externally mounted spare tires.

Table 5.11 Performance Data on Possible Alternatives From Sources Prior to 2020

Class of Compound	Chemicals	CAS	Performance Test Results	Results Support Further Consideration?	Reference
Phenylene Diamine	N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD)	3081-01-4	Comparable to 6PPD in Tier 2 type dynamic ozone test in SBR	Yes	G. Wilder, US 3,839,275 "Preserving rubber with N-(1,4 dimethylamyl) - N'-para-phenylenediamine"
Phenylene Diamine	N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD)	101-72-4	Comparable to 6PPD in Tier 2 type dynamic ozone test in SBR	Yes	G. Wilder, US 3,839,275 "Preserving rubber with N-(1,4 dimethylamyl) - N'-para-phenylenediamine"
Phenylene Diamine	N-cyclohexyl-N'-phenyl-p-phenylenediamine (CPPD)	101-87-1	5% improvement over "commercial control" in Tier 2 type dynamic ozone test in NR; 17% improvement in SBR. Control not identified	No	US 3,511,805, M. Kosmin *et al.*, "Rubber preserved with alicyclicmethyl phenylenediamines"
Phenylene Diamine related	N-1,3-dimethylbutyl-N'-phenyl quinone diimine (6QDI)	52870-46-9	Shows approximately the same stabilizing effect as 6PPD in outdoor aging studies - Tier 2 testing but ozone level not provided	No - produces 6PPD on mixing with rubber	F. Ignatz-Hoover *et al.*, "Chemical additives migration in rubber" Rubber Chemistry and Technology (2003) 76 (3): 747–768
Dihydroquinoline	Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	60% of activity of ethoxyquin in Tier 2 type testing	No - Not as active as ethoxyquin which is much less active than 6PPD	H. Kilbourne, "Chemical inhibition of ozone degradation of SBR", Rubber Chemistry and Technology (1959) 32 (4): 1155–1163
Diphenyl amine	4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	15% better ozone resistance than ethoxyquin and 15% better than DTPD in a Tier 1 type test	No - Migration rate is unsuitable based on expert judgment	H. W. Kilbourne, *et al.* "Chemical inhibition of ozone degradation of SBR", Rubber Chemistry and Technology, Vol. 32, p. 1155 (1959).
Phenylene Diamine	N,N'-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	Limited ozone data shows it acts as an antiozonant, but no comparison with other materials	No - Material would migrate too rapidly based on expert judgment	J. Amberlang, *et al.*, "Antioxidants and Antiozonants for General Purpose Elastomers" Rubber Chemistry and Technology (1963) 36 (5): 1497–1541.
Phenylene diamine	N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	Equivalent to Ethoxyquin in a Tier 1 type test	No - based on 2023 Flexsys study	H. W. Kilbourne, *et al.* "Chemical inhibition of ozone degradation of SBR", Rubber Chemistry and Technology, Vol. 32, p. 1155 (1959).

Class of Compound	Chemicals	CAS	Performance Test Results	Results Support Further Consideration?	Reference
Phenylene diamine	N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	No data - Listed only as an antioxidant in two separate articles	No	J. Amberlang, *et al.*, "Antioxidants and Antiozonants for General Purpose Elastomers" Rubber Chemistry and Technology (1963) 36 (5): 1497–1541.
Metal dithiocarbamate	Nickel dibutyldithiocarbamate (NBC)	13927-77-0	Shown to be an antiozonant but cures too fast, which affects compound processability	No	C. Pinazzi *et al.*, "Protection of natural rubber against atmospheric agents. I. The effects of nickel dibutyldithiocarbamate alone and in combination with protective agents. "Rubber Chemistry and Technology (1955) 28 (2): 438–456
Dihydroquinoline	Ethoxyquin	91-53-2	Early antiozonant used in tires but not as effective as CCPD	No	H. W. Kilbourne, *et al.* "Chemical inhibition of ozone degradation of SBR", Rubber Chemistry and Technology, Vol. 32, p. 1155 (1959).
Sulfur compound	Dilauryl thiodipropionate	123-28-4	No Data. No reference to the material as an antiozonant	No	Not available
Phenylene Diamine	N' -Phenyl-N-Fluorenyl-Para-Phenylenediamine	No CAS	Shown to be equivalent to 77PD in SBR/NR in static ozone testing	Yes	J. Hunt, US 3,625,913 "N'-Alkyl and N'-Aryl-N-Fluorenyl-p-phenylene=diamines as antiozonants in natural and synthetic diene rubbers",
Phenylene Diamine	N-(p-phenylthiomethylphenyl)-N'-(1,3-dimethylbutyl)-p-phenylenediamine	No CAS	Material provided good antiozonant protection but is expected to be too slow to migrate for long term protection based on expert judgment	No	J. Kuczkowski, US 4,124,565, "N,N' -DISUBSTITUTED-P-PHENYLENEDIAMINES"
Phenylene Diamine	4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	Original physical properties are equal to that of 6PPD and ozone testing shows excellent performance	No - Although the literature data is positive, several members have tested the molecule and found that the protection is insufficient	김영주, KR20090100673A, "Tire sidewall rubber composition"

Class of Compound	Chemicals	CAS	Performance Test Results	Results Support Further Consideration?	Reference
Phenylene Diamine	N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	Tier 1 testing showed antiozonant activity is as good as 6PPD and Tier 2 testing showed better antifatigue activity	No - Molecular weight of compounds probably too high to effectively migrate based on expert judgment	M. Boone *et al.*, US Patent US 10,428,009 B2 METHODS OF MAKING COMPOUNDS AND MIXTURES HAVING ANTIDEGRADANT AND ANTIFATIGUE EFFICACY 2019
Phenylene Diamine (Kruger)	RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3-dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5	No ozone data. Shown to migrate much faster than 6PPD	No	R. H. Kruger, C. Boissiere, K. Klein-Hartwig & H. J. Kretzschmar (2005) "New phenylenediamine antiozonants for commodities based on natural and synthetic rubber", Food Additives and Contaminants, 22:10, 968-974
Dihydroquinoline	N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	Shown to be a better antiozonant than ethoxyquin in Tier 2 lab tests	Yes - but heavy staining may be an issue based on expert judgment	D. Beaver, *et al.* US Patent 2,713,047 6-diethylamino-1,2-dihydroquinolines
Hindered amine	N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	Approximately 400% better than IPPD in time to cracking in NR and SBR compounds-Tier 2 testing but non-black compound	Yes	E. Masatomo, *et al.*, US 3,634,316 "Sulfur vulcanizable natural and synthetic rubbery polymers containing xylene diamines as antiozonants"
Triazine	2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5 triazine (Durazone 37 or TAPDT)	121246-28-4	Good solubility in NR but limited solubility in BR and SBR. Works as antiozonant at low levels in sidewall with phenolic resin as well as Durazone. No comparison to 6PPD. In EPDM sidewall ozone protection is equivalent to sample with no antiozonant. Overall no good data for antiozonant potential for tire compounds	No	M. Pender, US 8,329,788 B2 "Tire having enhanced ozone resistance"

Class of Compound	Chemicals	CAS	Performance Test Results	Results Support Further Consideration?	Reference
Phenylnaphthyl amines	N-Phenyl-1-naphthylamine	90-30-2	Listed as an antioxidant - poor performance in chloroprene	No	R. Murray, Factors Influencing the Ozone Resistance of Neoprene Vulcanizates under Flexure, RCT (1959) 32 (4):1117
Phenylnaphthyl amines	N-Phenyl-2-naphthylamine	135-88-6	Listed only as an antioxidant; no information regarding antiozonant potential	No	Ambelang, J. C., *et al.* "Antioxidants and antiozonants for general purpose elastomers." Rubber Chemistry and Technology 36.5 (1963): 1497-1541.
Ether + Phenol	[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)	110553-27-0	Samples containing very high levels of phenolic compound had good dynamic ozone performance in sidewall. At these levels probably causes oxidation based on expert judgment	No	D Dall'abaco, V. Formaggio, *et al.*, WO 2018/163041 A2, "TYRE FOR VEHICLE WHEELS "
Hydrazine	1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	Shown to be an antiozonant in dynamic testing of rubber but not compared to conventional antiozonants	No	H. Stewart, US 3,157,616, Antiozonant rubber compositions containing alkylene bis-hydrazines
Nitrone + Phenolic AO	α- C-4- hydroxy- 3,5-dimethylphenyl - N-isopropyl and Lowinox WSP	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	Nitrone plus a phenolic antioxidant provided superior static ozone resistance to IPPD	Yes	G. Scott, UK Patent application 2137619 A-1984, "Nitrone compounds and stabilised rubber compositions containing them"
Nitrone	α- C-4- Hydroxy- 3,5-dimethylphenyl-N-tert. butyl nitrone	No CAS	Compared to IPPD - reasonable ozone performance, some antifatigue activity, synergistic with phenolic antioxidants	Yes	G. Scott, L. Nethsinghe, 1984 UK patent application 2137619A for "Nitrone compounds and stabilised rubber compositions containing them"

Notes:
BR = Butadiene Rubber; CAS = Chemical Abstracts Service Number; EPDM = Ethylene Propylene Diene Monomer; NR = Natural Rubber; SBR = Styrene Butadiene Rubber.

5.2.2 Performance Testing at Flexsys of Possible Alternatives also Tested by USGS

As noted earlier, several PPDs (*i.e.*, CCPD, 77PD, DTPD, and 7PPD with 6PPD studied for comparison) were formulated into a model sidewall rubber compound, which was extracted and tested by USGS for potential toxicity using cell-based methods. To understand the potential performance of these formulated rubber materials, samples of the rubber were also tested for cure and dynamic ozone performance. Samples were exposed to ozone at concentrations of 10 pphm and 40 pphm for 24, 48, and 96 hours at 15% strain. Another series of samples were exposed to 40 pphm of ozone for 96 hours at 15% strain. Compounded properties showed that the CCPD and 77PD samples were scorchier (tended to cure too fast) than 6PPD. All other materials were acceptable. Ozone performance was evaluated visually by estimating the size and number of cracks under the different conditions. The results of these tests are shown in Table 5.12. Compounds showing adequate ozone performance included 77PD, CCPD, and 7PPD. Only 7PPD had performance equivalent to 6PPD; 77PD, and CCPD appeared to be less effective at higher ozone concentrations but showed at least some antiozonant activity that warranted further study. DPPD and DTPD both failed the dynamic ozone testing (*e.g.*, had many more cracks than 6PPD). Table 5.12 also lists a few earlier studies from Table 5.11 that corroborated the results of the Flexsys testing.

Table 5.12 Performance Testing at Flexsys of Possible Alternative also Tested by USGS

Chemical	CAS	Test Results	Results Support Further Consideration?	References
N,N'-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	One of two samples failed in max ozone exposure where neither of two 6PPD samples failed	Yes	Antiozonant study conducted at Flexsys in 2023
N,N'-diphenyl-p-phenylenediamine (DPPD)	74-31-7	Many more cracks than 6PPD at all ozone exposure conditions	No	Antiozonant study conducted at Flexsys in 2023
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	Appearance was good at lower ozone exposure but at maximum ozone exposure only one of the two samples survived	Yes	Antiozonant study conducted at Flexsys in 2023
N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	Both test samples failed at maximum ozone concentration.	No	Antiozonant study conducted at Flexsys in 2023
N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD)	3081-01-4	Both test samples looked equivalent to 6PPD at all ozone levels.	Yes	Antiozonant study conducted at Flexsys in 2023

Notes:
CAS = Chemical Abstracts Service Number; USGS = United States Geological Survey.

5.2.3 Recent Performance Data at Other Laboratories (Post-2020)

Table 5.13 lists the performance results for a number of chemicals with published performance data since 2020. Several provide clear comparisons to 6PPD in terms of ozone protection, although again these may not involve tire compounds but other types of rubber where 6PPD is used (*e.g.*, nitrile rubber). Five chemicals were found to have performance data indicating they would be appropriate for further study:

N,N-(ethane-1,2-diyl) bi(N-phenylbenzene-1,4-diamine), 4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine, graphene, 4-((4-dimethylamino)phenyl)amino)phenol, and 4-[4-(4-methylpentan-2-ylamine)anilino]phenol. As shown in Table 5.13, the last chemical was found not be effective against ozone in one patent but was found to be effective in another. Again, in the interest of not excluding possible alternatives, that last chemical was suggested for further study based on the positive patent finding.

Table 5.13 Performance Data for Possible Alternative from 2020 to Jan 2024

Class of Compound	Chemical	CAS	Results from Non-standard Tests/Calculation	Results Support Further Consideration?	References
Phenylene Diamine	N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	Material is more effective in ozone protection of liquid nitrile rubber than 6PPD	Yes	M. Boone *et al.*, EP3394028, “Compounds with antidegradant and antifatigue efficacy and compositions including said compounds”
Phenylene Diamine	4-[4-(4-Methylpentan-2-ylamino)anilino] phenol	No CAS	Material has equivalent ozone protection to 6PPD in natural rubber/carbon black compounds	Yes	X. Yang, WO 2022/146441, “Rubber composition with longer lasting antiozonation”
Inorganic	Graphene	1034343-98-0	In sidewall compounds, it may be possible to reduce 6PPD if graphene is added to the rubber compound. However, Consortium members noted migration and diffusion across other tire components would need to be considered in assessing potential impacts.	Yes	Doug Paschall *et al.*, “Tire Compounding with Prophene (sidewall)” Paper presented at Rubber Division Technical Meeting April 2022

Class of Compound	Chemical	CAS	Results from Non-standard Tests/Calculation	Results Support Further Consideration?	References
Phenothiazine	N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	No ozone data, but based on calculations the authors predict good ozone performance. It is an effective antioxidant	Yes	C. Recker *et al.*,WO2022069001A1, “Phenothiazine compound, its preparation and use in rubber blends and vehicle tires, as ageing protectant, antioxidant, antiozonant and colorant”
Polymeric amine functionalized lignin	Amine functionalized lignin	No CAS	Ozone testing was static, but comparable to 6PPD. Fatigue was similar to 6PPD. Since there is no blooming or reservoir, it is unlikely to provide long term protection	Yes	J. Chung, U. Hwang, J. Kim, N. Kim, J. Nam, J. Jung, S. Kim, J. Cho, B. Lee, I. Park, J. Suhr, D. Nam, "Amine-functionalized lignin as an eco-friendly antioxidant for rubber compounds" ACS Sustainable Chemistry and Engineering 2023, 11 (6), 2303-2313
Gallate related	Rambutan peel extract	No CAS	Ozone testing showed comparable crack resistance to 6PPD	Yes	Sukatta U, Rugthaworn P, Seangyen W, Tantaterdtam R, Smitthipong W, Chollakup R. Prospects for rambutan peel extract as natural antioxidant on the aging properties of vulcanized natural rubber. SPE Polymers. 2021;2:199-209. https://doi.org/10. L 1002/pls2.10042

Notes:
CAS = Chemical Abstracts Service Number.

5.2.4 Future Testing Required

In the sections above, possible alternatives were identified that produced positive results in initial screening tests of ozone protection. It must be stressed that such tests are the first step in evaluating an alternative and they cannot be assumed to indicate actual effectiveness in a manufactured tire. To place the above results in context, we provide below a discussion of further testing that may be required prior to selecting a final alternative.

As mentioned in Section 3.4, all new passenger, light truck, truck and bus, trailer, and motorcycle tires sold in the United States must meet rigorous FMVSS (49 CFR Part 571). However, well before a possible alternative is incorporated into a tire, it must pass many feasibility tests to assess its suitability in a tire.

To assess the feasibility of any new chemical or material in tires, chemical manufacturers, researchers, and tire manufacturers may conduct the Tier 1a screening tests listed in Table 5.14 below. Tire manufacturers may conduct the Tier 1b laboratory-scale screening tests noted in Table 5.14 to evaluate the performance of the candidate chemicals or materials in green (non-cured) and cured rubber compounds. A primary purpose of the Tier 1 laboratory-scale tests is to disqualify chemicals or materials that do not perform as required. Once a candidate chemical or material achieves the required outcome in laboratory tests, a tire manufacturer then typically conducts pilot, or intermediate-scale (Tier 2) tests, involving tens to a few hundred kilograms of rubber compounds. A limited number of test tires may be produced using rubber compounds from the pilot-scale mixing tests and used for preliminary tire testing before resources are committed to conducting manufacturing-scale tests. Tier 2 tire compound testing usually requires several iterations to determine if acceptable properties can be obtained. Only once the material achieves the required outcome in Tier 2 tests, will the new material be evaluated in factory-scale processing trials, followed by tire builds, and finally long-term tire testing (Tier 3). These factory-scale tests are also used as a means to ensure consistent batch-to-batch properties of the rubber compounds, consistent industrial performance, and consistent in-tire performance.

In order to assess the performance feasibility of 6PPD alternatives in tires, Consortium members would take the same approach as described above. Table 5.14 below is a non-exhaustive listing of tests which may be conducted by chemical manufacturers, researchers, and/or tire producers to screen and ultimately test candidate alternative antidegradants. Tire manufacturers will rely on properties listed in the Tier 1b, 2, and 3 sections of Table 5.14 and may also conduct additional testing, beyond what is listed in this table.

All tires sold in the US are required to comply with the requirements in all applicable FMVSS, so no possible alternatives would advance on to long-term tire testing if Tier 1 and 2 testing results are not favorable In addition, regardless of how well a 6PPD alternative performs in laboratory-scale and pilot-scale testing, the performance of the alternative in a long-term, field, tire testing is the deciding factor regarding the suitability of the material for safe commercial scale use.

Table 5.14 Non-Exhaustive List of Performance Testing for Candidate Antidegradant Chemicals or Materials in Tires

Tiered Approach		Test Legally Required in the US?	Properties Tested	Description	Test Method
Tier 1a	**Laboratory Testing for Screening of Chemicals for Inherent Antiozonant Activity**	**No.** Chemical manufacturers, researchers, and/or Consortium members may utilize Tier 1a tests to screen chemicals before moving on to Tier 1b tests.	Reaction with Ozone	Test measures the ability to protect polymer in solution. Quick and easy to run.	Layer, R. 1966. *Rubber Chemistry and Technology* 39(5):1584-1592
			Migration	Tests ability of chemical to migrate to the surface	Ignatz-Hoover, F. 2003. *Rubber Chemistry and Technology* 76(3):747-768 (and references therein)
Tier 1b	**Laboratory (Small-Scale) Testing of Candidate Alternatives in Green and Cured Rubber Compounds**	**No.** Consortium members utilize Tier 1b tests to screen chemicals before moving on to Tier 2 tests.	Viscosity (Processability)	Rheological properties of green (uncured) rubber compounds	ASTM D6146
			Cure/Reversion	Speed of vulcanization / indicator of potential for reversion in a cured compound	ASTM D5289 ASTM D2084
			Stress-Strain	Mechanical properties of compound	ASTM D412-A
			Tear Strength	Ability to remove tire from mold	Die B Tear Strength: ASTM D624
			Ozone: Static	Ozone resistance	ASTM D1149
			Ozone: Dynamic	Ozone resistance in service	ASTM D1149
			Ozone: Intermittent Dynamic/Static	Best overall test – Reflects all states of tire	ISO 1431-2012
			Fatigue to failure	Effect of flexing on compound life	ASTM D4482
			Wire adhesion testing (belt and body ply compounds)	Adhesion of steel reinforcement to rubber compounds	ASTM D2229
			Viscoelastic Properties	Tire performance predictors (traction & rolling resistance)	ASTM D5992

<table>
<tr><th colspan="2">Tiered Approach</th><th>Legally Required to Pass in the US?</th><th>Properties Tested</th><th>Description</th><th>Testing Method</th></tr>
<tr><td rowspan="9">Tier 2</td><td rowspan="9">Pilot-Scale Testing of Tire Compounds[1] / Testing of Tires[2]</td><td rowspan="9">No, but all manufacturers would need alternatives to demonstrate acceptable performance for all Tier 2 tests before moving onto to Tier 3 tests.</td><td colspan="3">Initial evaluation of performance in industrial processes</td></tr>
<tr><td colspan="3">Green & cured properties listed in Tier 1b</td></tr>
<tr><td>Wear Test
(Tread Compounds)</td><td>Tread lifetime</td><td>Various:
LAT 100, ISO 23233:2009;
DIN ASTM D5963</td></tr>
<tr><td>Aged Endurance</td><td rowspan="3">Machine (drum) testing of tires</td><td>Methods set by individual Consortium members</td></tr>
<tr><td>High Speed Performance</td><td>SAE J1561</td></tr>
<tr><td>Rolling Resistance</td><td>ISO 17025, 28580
SAE J1269, J1270, J2452</td></tr>
<tr><td>Traction</td><td>Wet & dry traction (and perhaps snow for some applications)</td><td>Wet: ASTM F1649
Dry: ASTM F1650
Snow: ASTM F2493</td></tr>
<tr><td rowspan="6">Tier 3</td><td rowspan="6">Manufacturing-Scale Testing of Tire Compounds[1] / Testing of Tires[2]</td><td rowspan="6">Yes</td><td>Processability</td><td>Consistency of handling of rubber compound on tire plant equipment</td><td>ASTM D1646</td></tr>
<tr><td colspan="3">All green & cured rubber properties listed in Tier 1b.</td></tr>
<tr><td>Endurance</td><td>Evaluates tire's ability to perform over extend lab test, including low pressure conditions for FMVSS No. 139 tires</td><td>FMVSS 119/139 (tire type dependent)</td></tr>
<tr><td>High Speed Performance</td><td>Evaluates tire performance at high test speeds</td><td>FMVSS 119/139 (tire type dependent)</td></tr>
<tr><td>Bead Unseat</td><td>Evaluates tire resistance to force applied to sidewall under lab test conditions</td><td>FMVSS 139
(passenger/some LT)</td></tr>
<tr><td>Tire Strength</td><td>Evaluates performance of tire under plunger force applied to tread</td><td>FMVSS 119/139</td></tr>
</table>

Tiered Approach		Legally Required to Pass in the US?	Properties Tested	Description	Testing Method
			Field performance	Long-term evaluation of tires on vehicles in a limited-scale, monitored, evaluation	Methods set by individual Consortium members

Notes:

6PPD = N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine; ASTM = American Society for Testing and Materials; FMVSS = Federal Motor Vehicle Safety Standards; ISO = International Organization for Standardization; UTQGS = Uniform Tire Quality Grading Standards.

Sources: FMVSS 139 (https://www.nhtsa.gov/sites/nhtsa.gov/files/tp-139-02.pdf); UTQG (https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-575/subpart-B/section-575.104).

(1) Several of these tests are run on both the original sample and aged samples. There are a number of additional tests that are run on specific compounds. For example, ply-to-ply adhesion strength, wire adhesion to wirecoat compound (wire coverage and pullout force), filler performance on cure (agglomeration), and other tests.

(2) In addition to these tests, each individual company will run proprietary tests to evaluate noise, handling, wet performance, wear, cut/chip resistance, performance on ice, performance in snow, and ride comfort.

5.3 Relative Exposure Potential

5.3.1 Relative Exposure Potential of 6PPD and Possible Alternatives

For Table 5.9, we consulted experimental, modelled, and estimated data from a variety of sources, including study reports, mainly from ECHA REACH dossiers (ECHA, 2024) and US EPA's EPI Suite software (US EPA, 2019a). In Table 5.9, all experimental values are bolded to differentiate between experimental and modeled or estimated data. Similar to the hazard information, there are many data gaps regarding information on the physical-chemical properties of the possible alternatives' ingredients, particularly those that do not have ECHA REACH dossiers or are polymers, mixtures, or unknown or variable compositions, complex reaction products, and biological materials (UVCBs). Polymers, mixtures and UVCBs cannot be modeled in programs such as EPI Suite, due to a lack of a Simplified Molecular Input Line Entry System (SMILES) and a reliable underlying dataset. In addition, Gradient did not color-code this table, because no color-coding was provided by the various data sources and because it would be difficult to assign relative preferences for many of the relevant factors.

Many of the physical-chemical parameters are not materially relevant given how vehicle tires are used (*e.g.*, melting and boiling point are not relevant because the TRWP are not likely to reach temperatures in which the chemical state of 6PPD in the tire will be altered, and volatility is addressed *via* the vapor pressure parameter). For those endpoints that would be materially relevant for vehicle tires (*e.g.*, log octanol-water partition coefficient [K_{ow}], log organic carbon partition coefficient [K_{oc}], vapor pressure, and water solubility), we used the following criteria from US EPA's "Interpretive Assistance Document for Assessment of Discrete Organic Chemicals" (US EPA, 2013) for the evaluation of possible alternatives' exposure potential in air, water, soil, sediment, and groundwater *via* soil and sediment:

- **Vapor Pressure – Estimated by MPBPWIN:**
  - $\geq 10^{-4}$ = Chemical mostly in the vapor (gas) phase.
  - 10^{-5} to 10^{-7} = Chemical in the vapor and particulate phase.
  - $\leq 10^{-8}$ = Chemical mostly in the solid phase.
  - For chemicals with a vapor pressure < 10^{-6}, there is low concern for inhalation exposure.
- **Water Solubility (mg/L) – Estimated by WSKOWWIN:**
  - >10,000 = Very soluble.
  - >1,000-10,000 = Soluble.
  - >100-1,000 = Moderate solubility.
  - >0.1-100 = Slightly soluble.
  - <0.1 = Negligible solubility.
- **Log K_{ow} – Estimated by KOWWIN:**
  - <1 = Highly soluble in water (hydrophilic).
  - >4 = Not very soluble in water (hydrophobic).
  - >8 = Not readily bioavailable.

- >10 = Not bioavailable – difficult to measure experimentally.

- **Log K_{oc} – Estimated by PCKOCWIN:**
    - >4.5 = Very strong sorption to soil and sediment; negligible migration potential to groundwater.
    - 3.5-4.4 = Strong sorption to soil and sediment; negligible to slow migration potential to groundwater.
    - 2.5-3.4 = Moderate sorption to soil and sediment; slow migration potential to groundwater.
    - 1.5-2.4 = Low sorption to soil and sediment; moderate migration potential to groundwater.
    - <1.5 = Negligible sorption to soil and sediment; rapid migration potential to groundwater.

The physical-chemical data in Table 5.9 were examined in the context of the abovementioned US EPA criteria to look for differences among the possible alternatives. The results of the comparison are included in Table 5.9.

For 6PPD, low exposure potential *via* air is expected (based on a value of 4.93×10^{-6} mm Hg at 25°C). Low exposure potential *via* air is also expected for the majority of alternatives (*i.e.*, 30 of 40 possible alternatives). Twenty-two chemicals had vapor pressures at least one order of magnitude lower than 6PPD (ranging from 1.57×10^{-19} to 5.47×10^{-7} mm Hg at 25°C), and eight chemicals were on the same order of magnitude as 6PPD (ranging from 1.24×10^{-6} to 8.22×10^{-6} mm Hg at 25°C). No vapor pressure was found for graphene. However, vapor pressure for graphene would be negligible since graphene is an inorganic with melting point above 4,000°C. In contrast, three of the eight remaining chemicals may have some air exposure potential due to vapor pressures greater than 0.0001 mm Hg (one PPD derived alternative, 44PD, and two non-PPD alternatives NBC and ethoxyquin).

Regarding exposure potential *via* water for 6PPD, we identified a water solubility of 2.83 mg/L at 25°C and log K_{ow} of 4.68 at 20°C, suggesting that 6PPD is relatively insoluble in water and hydrophobic. The majority of possible alternatives are expected to have similar exposure potential *via* water. Briefly, 30 of the 40 possible alternatives had water solubility on the same order of magnitude (nine possible alternatives ranging from 1.26 to 51 mg/L) or at least one order of magnitude lower than 6PPD (21 compounds ranging from 0.719 to 3.94×10^{-7} mg/L). In addition, 33 of the 40 possible alternatives had log K_{ow} values greater than 3.5 (ranging from 3.5 to 11.9), suggesting they are relatively hydrophobic. Based on water solubility greater than 100 mg/L, only two possible alternatives, the possible non-PPD alternatives 1,1'-pentamethylenebis(2,2-di-n-butylhydrazine) and representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol), are expected to be soluble or moderately soluble in water, respectively. However, all of the possible alternatives have log K_{ow} values greater than 1, suggesting that none of the alternatives may be considered hydrophilic. For example, 1,1'-pentamethylenebis(2,2-di-n-butylhydrazine) and representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol) have log K_{ow} values of 2.64 and 5.57, respectively.

Regarding exposure potential *via* sediment for 6PPD, we identified a log K_{oc} of 4.363 suggesting that the candidate chemical may sorb strongly to soil and sediment and have negligible to slow potential for migration to groundwater. All alternatives had log $K_{oc} \geq 3$ (ranging from 2.992 to 11.407), suggesting at least moderate potential to sorb to soil and sediment and slow migration potential to groundwater. No log K_{oc} was identified for graphene.

Some of the possible alternatives have substantially less water solubility than 6PPD (*e.g*., DOPD, DLTP, RU997, and TAPDT) which could affect their environmental partitioning. Similarly, some have substantially higher log K_{ow} values (an indication of partitioning into organic materials) than 6PPD (*e.g*., DLTP, Ru997/Irgazone 997 blend, TAPDT, and DOPD) which again could result in different environmental behavior. Some also have substantially different vapor pressures (some higher, some lower) which could affect workplace exposures. While this evaluation provided some insight into the ingredient-level exposure potential of the possible alternatives, ideally, we would compare the product-level exposure data, because the ingredients are meant to react and create a structure that is distinctly different from the individual ingredients. Unfortunately, no product-level exposure information is available at this time for any alternative.

5.3.2 Relative Exposure Potential of Potential Breakdown Products

As summarized in Table 5.10, 6PPDQ did not have an ECHA dossier and therefore did not report information regarding physical-chemical parameters of interest (*i.e*., vapor pressure, water solubility, log K_{ow}, and log K_{oc}). Data regarding relevant physical-chemical parameters was available for seven of the 18 potential hydrolysis products (4-hydroxydiphenylamine, 1,3-dimethylbutylamine, p-benzoquinone, p-hydroquinone, aniline, 6QDI, and 1-methyl-propylamine). In general, these hydrolysis products may have some exposure potential *via* air and water, but low to moderate exposure potential *via* sediment.

Briefly, based on reported vapor pressures ranging from 7.5×10^{-6} to 178 mm Hg at 25°C, the hydrolysis products may have potential to be in the vapor phase and therefore may exhibit some exposure potential *via* air. Based on water solubility ranging from 7.9 to 7,200 mg/L, the hydrolysis products are generally expected to be slightly soluble to soluble in water. Only one of the hydrolysis products, the non-PPD 6QDI (a reported hydrolysis product of 6PPD), has a log K_{ow} greater than 4, suggesting relative hydrophobicity. In contrast, log K_{ow} of the other hydrolysis products range from 0.1 to 2.82, suggesting relative hydrophilicity. Finally, available log K_{oc} values for the hydrolysis products range from 1.57 to 2.6, suggesting low to moderate potential to sorb to soil and sediment, and slow to moderate migration potential to groundwater.

As discussed, while this evaluation provided some insight into the exposure potential of the breakdown products (*via* hydrolysis only) of possible alternatives that could be used as ingredients, ideally, we would compare breakdown products resulting from completed vehicle tire. No such exposure information is available at this time.

6 Conclusions of Stage 1 AA

6.1 Selecting Possible Alternatives to the Priority Product

Using the data gathered related to hazard exposure potential and performance, as discussed in Section 5, we then used the information in aggregate to draw conclusions about whether there were possible alternatives that should be considered in greater depth in a Stage 2 AA. There are various methods for selecting alternatives in an AA, ranging from purely qualitative and narrative approaches to sophisticated approaches such as multi-criteria decision analysis (MCDA) (Beaudrie *et al*., 2020). Although we used a modified CSI approach to score toxicological hazards (with the exception of group B endpoints and salmonid toxicity), we were unable to develop quantitative scores for relative exposure potential or performance. Relative exposure potential was scored as better, similar, or worse than 6PPD, and performance was simply scored as whether the available information suggested a chemical might be suitable for further testing (*i.e*., the data were suggestive of ozone reactivity but not informative of performance in a tire). Thus, our approach was both quantitative (with the modified CSI scoring) and qualitative (for group B endpoints, salmonid toxicity, relative exposure potential and performance). Given this combination of quantitative and qualitative information, a flexible narrative approach is the best method for considering the data and reaching a conclusion about a possible alternative's merits.

In our narrative analysis we considered the following:

- Whether the hazard score was preferable, similar, or less preferable than 6PPD. Preferable and less preferable were based on a chemical being 30 percent above or below the 6PPD CSI scores for human health, environmental hazards, and physical hazards.
- Whether any of the Group B endpoints suggested a form of toxicity not found for 6PPD or more substantial than that reported for 6PPD. We found no convincing evidence of such a difference, so this did not figure in the consideration.
- Whether data on toxicity to salmonids suggested lower toxicity than 6PPD and 6PPDQ. If an alternative had an LC_{50} value more than one order of magnitude greater or lower than that reported for 6PPD and 6PPDQ – that was considered to be an important difference.
- Whether key data on exposure potential (*e.g*., water solubility, vapor pressure, log K_{ow}, log K_{oc}) suggested differential migration in the environment and therefore different exposure potential relative to 6PPD. This was a difficult consideration to assess because various potential exposure pathways are being considered, and a factor that was beneficial for one pathway could be detrimental to another (*e.g*., reduced water solubility could mean less exposure *via* water but more exposure *via* sediment).
- Whether preliminary data from bench scale tests regarding performance of the chemical as an antidegradant (particularly protection against ozone) suggested further testing would be warranted. This was a yes/no metric.

Regarding the relevant factors listed in Tables 4.4 and 4.5 and rated as "yes" or "potentially" as to their relevance for reaching an AA conclusion, most of the health hazard and environmental hazard (*e.g.*, aquatic toxicity, effects on aquatic organisms, persistence) factors are already covered by the CSI hazard scoring approach and the salmonid data described above. Among the Group B human health endpoints, there were no differences among alternatives (considering data gaps and study limitations) that appeared to constitute a "material" difference. Among the environmental fate/physical and chemical properties described in Table 4.4, the most critical (*e.g.*, water solubility, vapor pressure, lipid, and carbon solubility) are also covered in the decision making process, as noted above. Other potentially relevant factors that are physical/chemical properties – such as molecular weight, boiling point, *etc*. – are related to these critical properties (*e.g.,* chemicals with high boiling points also have high vapor pressures) and so were not explicitly considered separately. Flash point, a factor added by the Consortium members due to concerns about safety during manufacture, was not a relevant consideration in the end because most possible alternatives were not flammable according to GHS (*i.e.*, flashpoint higher than 93°C or chemical is a solid) or lacked data. A number of life cycle stages (*e.g.,* use, waste generation and management, reuse/recycling, and end-of-life) were all scored as potentially relevant; more information about how the possible alternatives would affect these stages of the tire life cycle is needed in order to determine their potential impact.

Overall, the decision to retain a chemical for further consideration in Stage 2 was based primarily on a chemical having sufficient hazard data, which gave an indication a chemical was not more hazardous than 6PPD and preliminary performance data indicating a chemical should be considered for further testing. Whether a chemical and its quinone transformation product had lower toxicity to salmonids was considered but was not a determinant for exclusion since data exist for so few chemicals. As noted above, relative exposure potential also appeared to not be clearly differentiated among alternatives. Some alternatives appeared more likely to migrate through certain environmental media more than others, but whether this results in a significant difference in risk to all receptors of concern was not clear.

6.2 Possible Alternatives to Priority Product to Consider in Stage 2

The results of the Stage 1 AA are summarized in Table 5.15 where existing data on hazard, relative exposure potential, and performance are shown for each possible alternative. It should be noted that performance data are limited to simple screens where such information is available. As detailed earlier in this Stage 1 AA report, much more extensive testing would be required before any actual alternative could be implemented.

Of the 40 alternatives considered in the Stage 1 AA, only a few had similar or reduced hazard scores relative to 6PPD, and had screening level performance data indicating a potential to perform in tires as an antiozonant. The chemicals that met these criteria and would be further evaluated in Stage 2 are the following:

7PPD. This chemical has similar overall hazard score relative to 6PPD. It also has similar exposure potential. In screening level tests conducted by Flexsys it showed effective performance against ozone.

IPPD. This chemical has similar overall hazard score relative to 6PPD (slightly lower environmental hazard). Results of one study suggests the quinone metabolite is less toxic than 6PPDQ in rainbow trout. It is slightly more likely to migrate to water. In a screening level test reported in a 1970 patent, IPPD showed effective performance against ozone; however, Consortium members have questions regarding the long-term protection ability of IPPD. IPPD is not a persistent molecule in a rubber compound. One Consortium member’s observation is that IPPD rapidly loses its effectiveness in tires. In most cases, this antiozonant would be ineffective before the tread is depleted, resulting in failure to meet consumer expectations.

77PD. This chemical has somewhat lower hazard scores than 6PPD. One study (Chapelet *et al*., 2023) showed that while the parent chemical is somewhat more toxic to coho salmon (and other species) than 6PPD, the quinone metabolite is far less toxic to coho salmon than 6PPDQ, meaning that the overall impact on coho would likely be less. In addition, based on limited data from cell-based studies conducted by USGS, it appears that the parent chemical and its corresponding quinone may have a slightly improved toxicity profile for coho salmon relative to 6PPD, a finding the requires confirmation. 77PD has similar exposure potential relative to 6PPD. In screening level tests conducted by Flexsys it showed effective performance against ozone.

CCPD. This chemical has similar overall hazard to 6PPD and, based on limited data from cell-based studies conducted by USGS, it appears that the parent chemical and its corresponding quinone may have an improved toxicity profile for coho salmon relative to 6PPD; a finding that requires confirmation. It also has similar exposure potential. In screening level tests conducted by Flexsys it showed effective performance against ozone.

Specialized graphene. Graphene nanoplatelets (as discussed previously) are graphene-based materials with a surface area not greater than 180 m^2/g, and a carbon content greater than 99% and an oxygen content less than 1%. The lateral particle size of these materials is between 100 nm and 5 µm. This particular material has superior hazard scores relative to 6PPD, although potential differences in the structure of the graphene tested in performance studies and the form of graphene reported in ECHA dossiers may be important to consider in Stage 2 since differences in size, number of layers, surface area, and/or surface chemistry could contribute to differences in toxicity (Fadeel *et al*., 2018; Achawi, *et al*., 2021). There are no data indicating its toxicity to salmon and while potential toxicity seems unlikely, it should be verified. Graphene is likely to remain part of the rubber matrix, and it is non-volatile and non-water soluble. In terms of performance, graphene may not completely eliminate the need for 6PPD or another antiozonant in tread, since it does not migrate in rubber. However, it could constitute a potential method for reducing 6PPD concentrations without compromising important criteria such as the potential for rubber rework during the tire manufacturing process.

6.3 Alternatives to be Eliminated from Further Consideration

As shown in Table 5.15, 35 of the 40 alternatives evaluated were eliminated from further consideration in Stage 2. Some alternatives were eliminated because they have so many data gaps in terms of toxicological hazard that they could not be confidently evaluated. This was the case for the following alternatives:

- N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)
- 4,4'-Dioctyldiphenylamine (DOPD)
- N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)
- N' -Phenyl-N-Fluorenyl-Para-Phenylenediamine
- N-(p-phenylthiomethylphenyl)-N'-(1,3-dimethylbutyl)-p-phenylenediamine
- 4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline
- N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]
- 4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl
- 4-[4-(4-Methylpentan-2-ylamino)anilino]phenol
- Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)
- N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2
- N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-
- 1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)

- α- C-4- hydroxy- 3,5- dimethylphenyl- N-isopropyl combined with 2,2'-Methylenebis[6-(1-methylcyclohexyl)-p-cresol]
- N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine
- 7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one
- 2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine
- 4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline
- α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone
- Amine functionalized lignin
- Rambutan peel extract

Some possible alternatives that passed the initial screen described in Section 3 were subsequently eliminated from further evaluation in Stage 2 due to a lack of performance data or because available data indicated they would not perform well against ozone. Note that some of these eliminated chemistries were also dropped due to lack of toxicity data as noted above. These eliminated possible alternatives due to lack of performance data were:

- N,N′-Diphenyl-p-phenylenediamine (DPPD)
- N-1,3-Dimethylbutyl-N′-phenyl quinone diimine (6QDI) (also had a worse human health score than 6PPD)
- Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ) (also had a worse human health score than 6PPD)
- 4,4'-Dioctyldiphenylamine (DOPD)
- N,N'-Di-sec-butyl-p-phenylenediamine (44PD)
- N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)
- N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)
- Nickel dibutyldithiocarbamate (NBC) (also had a worse human health score than 6PPD)
- Ethoxyquin
- Dilauryl thiodipropionate
- N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethylbutyl)-p-phenylenediamine
- 4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline
- RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3-dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)
- 2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)
- N-Phenyl-1-naphthylamine
- N-Phenyl-2-naphthylamine
- [2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520) blended with 3,9-Dicyclohex-3-enyl-2,4,8,10-tetraoxaspiro[5.5]undecane (Vulcazon AFS)
- 1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)
- N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine
- 7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one
- 2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine
- 4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline

No possible alternatives were excluded based on relative exposure potential. Although some chemicals had different properties relevant for environmental mobility compared to 6PPD, it is not clear whether a chemical that is less water soluble but more fat soluble, or less water soluble but more volatile, would be a preferred alternative.

As noted earlier, investigation of possible alternatives to 6PPD is a highly active area of research. One of the first tasks for the Stage 2 AA will be to review the recent scientific literature to determine if new data are available which could affect the decision to drop some alternatives from consideration. This may be more likely to affect possible alternatives dropped due to a lack of performance data rather than possible alternatives dropped from having too many toxicological data gaps, given the costs and time frames for most toxicological studies.

6.4 Decision Concerning Abridged AA or Stage 2 AA

As noted in Section 6.1, a number of possible alternative antiozonants to replace 6PPD in motor vehicle tires were identified in the Stage 1 AA. Consequently, it is appropriate to carry these alternatives forward into the Stage 2 AA process where they will be examined in further detail consistent with the requirements of the SCP regulations.

7 Work Plan For Stage 2 AA

7.1 Tasks for Stage 2 AA and Final AA Report

The procedure for completing Stage 2 is outlined in the SCP regulations. The specific tasks we would undertake would be the following:

- Obtain DTSC approval on Stage 1 AA report (including resolving any comments received);
- Confirm that no new candidate alternatives have become available since the time of the Stage 1 submission; if these are available, we will determine their suitability for including in the analysis (*e.g*., adding them to the Section 5 table to see if they are suitable);
- Update the hazard, performance and exposure potential information for the 40 already identified possible alternatives based on new study data that becomes available after submission of the Stage 1 AA;
- Re-screen the available alternatives to understand which have sufficient data to support a Stage 2 AA;
- Revisit relevant factors for possible alternatives carried forward, as these could change;
- Perform a more in-depth evaluation of hazard and exposure potential (*e.g*., looking more deeply into potential transformation products including their likelihood of being formed and their potential to migrate in the environment);
- Revisit the conceptual model to see if it requires revision for the revised set of possible alternatives;
- Update the literature search to be sure the most current information is available on product performance;
- Work with an economist to quantify the economic impacts of the priority product and possible alternatives;
- Use the sequential, simultaneous, or hybrid decision framework to evaluate possible alternatives and come to a decision;
- Prepare Stage 2 AA report;
- Include self-evaluation described in chapter 11 of DTSC's AA Guide (2017);
- Schedule a call with DTSC at the 6-month time point to discuss any issues that arise; and
- Give DTSC 2 months' notice if we require an extension or expect to complete the Stage 2 AA on time.

At the end of the Stage 2 AA, we are optimistic that we will have identified one or more possible alternatives that hold promise to replace or materially reduce 6PPD in motor vehicle tires, subject to future performance testing to ensure comparable tire safety and performance. Additional toxicity testing may need to be performed to satisfy regulatory requirements and to fill important data gaps.

7.2 Proposed Stage 2 AA Completion Schedule

The SCP regulation requires an implementation schedule be submitted as part of the Stage 1 report. The following schedule is offered to comply with that requirement. Given the rapidly changing situation with research related to 6PPD alternatives, we reserve the right to adjust and modify this schedule as needs arise. The only required timing is that the Stage 2 AA report be submitted one year after DTSC approval of the Stage 1 AA report, subject to any potential approved extension request.

Table 7.1 Proposed Stage 2 AA Completion Schedule

Action Item	Potential Completion Date
DTSC indicates acceptance of Stage 1	60 days from March 29, 2024, if no clarification/modification required
	All times below are after DTSC acceptance of Stage 1
Update possible alternatives search Revisit conceptual model Initiate more in-depth hazard and exposure factor review	Weeks 1 to 8
Engage with economist, begin assessment of economic impacts	Weeks 3 to 12
Meeting with DTSC to discuss issues expected in Stage 2	Week 4 to 6
Update performance database, determine if newer data are available	Weeks 8 to 48
Determine if newer hazard data on identified possible alternatives are available	Weeks 8 to 48
Revisit relevant factors for Stage 2 in light of reduced possible alternative set	Week 8
Data review/tabulation for hazard, exposure, performance, life cycle, and economics impact phase	Weeks 20 to 30
Discuss progress/outstanding questions with DTSC	Week 30
Explore decision frameworks	Weeks 30 to 32
Initial decision using appropriate decision framework	Week 33
Internal review of initial decision, QC by larger group	Week 34
Prepare final AA report	Weeks 34 to 40
Report review by Working Group	Weeks 41 to 43
Report review by full Consortium	Weeks 46 to 48
Revise final AA report, final edits	Weeks 48 to 51
Submit final AA report to DTSC	Week 52[1]

Notes:
AA = Alternatives Analysis; DTSC = Department of Toxic Substances Control; QC = Quality Control.
(1) Subject to any potential approved extension request.

8 Uncertainty Analysis

A number of possible sources of uncertainty were encountered in the course of conducting this Stage 1 AA. The key sources are summarized below.

Identification of Possible Alternatives. Alternatives were identified based on patent searches, journal article searches, general Internet searches, and surveys and conversations with Consortium members. It is possible that other alternative formulations exist and were not identified, but this is considered unlikely given that the AA was directed by a large Consortium with great familiarity with the industry and that the searches involved the major sources of information available about tire manufacturing. For any alternative that could have been missed (*e.g.*, an obscure patent, possibly not in English), it is doubtful whether it would have data on chemical composition, hazards, exposure, and performance and yet be unknown to the Consortium. Lacking such data, it would not likely affect the conclusions of the AA. Thus, the conclusions of this Stage 1 AA would not change.

Evaluation of Relevant Factors. For some of the relevant factors, the existence of material differences or lack thereof is fairly apparent. For example, it is clear from chemical manufacturing data that HFC or other high potency global warming gases are not used in the manufacturing process. Similarly, we can be fairly confident that while neither 6PPD nor any of the alternatives are listed under Proposition 65, many of the alternatives do contain components in their lifecycle that are listed (*e.g.*, benzene, toluene, nickel). On the other hand, data for particular toxic modalities are lacking for many of the alternatives, many of which do not even have CAS numbers. In addition, while data are available on the physical chemical properties from data sources such as Episuite, the exposure potential of the alternatives when formulated as part of a tire may be different from that of the pure chemical.

Hazard Evaluation. To evaluate the hazards of the alternatives, we primarily relied on ECHA REACH dossiers and GreenScreens. These two sources sometimes differed in terms of their assignment of particular hazard scores and we typically used the more conservative score in our CSI scoring process. However, GreenScreens were only available for a small subset of alternatives so not all alternatives had the same level of data. Due to the large number of alternatives examined, we also did not conduct an exhaustive literature review on each chemical of interest. Had we done so, we may have uncovered additional hazard data that could conflict with the data in the aforementioned sources or that could fill in data gaps. This more detailed evaluation of health hazard data will be conducted during Stage 2 of the AA process. Moreover, as noted above, the composition information we had on some of the patent-identified alternatives is for example formulations, which may not reflect the composition of any actual commercial product.

Use of CSI-Like Hazard Scoring Approach and Penalizing for Data Gaps. We adapted the CSI approach to provide quantitative scores of hazard endpoints (Section 5 hazard tables), but note that these scores should only be used as approximations of hazards, due to the underlying uncertainties. Although we largely retained the scoring values provided in the original CSI method, which was published in a peer-reviewed journal (Verslycke *et al.*, 2014), we also needed to make certain modifications to the approach meet the requirements of the SCP regulations. See Section 5.1.2 for a full description of these modifications. As a sensitivity analysis, we reperformed the scoring analysis using two hypothetical scenarios: (1) assigning the maximum penalty score for data gaps regardless of what percentage of the product composition was accounted for by chemicals with data gaps, and (2) using no penalty scores for data gaps. In both cases, we always evaluated products in which >30% of the composition was accounted for by chemicals with no data (this will need to be done).

Rejection of Alternatives with Extensive Data Gaps for Toxicity. Although we made reasonable efforts to evaluate the hazards of possible alternatives, for some chemicals the number of data gaps was so extensive that we felt we could not reliably evaluate their hazard in a way that would allow consistent comparison across possible alternatives. Read across approaches could have been applied but these involve some uncertainties.[13] In addition, the fact that these chemicals lack substantial amounts of toxicological data suggests they would require a very substantial testing program before they could be adopted as a replacement for 6PPD, which could add multiple years to adoption of a potential alternative. Finally, many of the chemicals with very limited data for toxicity also lacked data for performance.

Environmental Transformation Products. Due to the release of antidegradant into the environment *via* TRWP, the potential for transformation or breakdown of the antidegradant into other chemicals is an important consideration in the AA. Unfortunately, information on potential environmental breakdown products for the possible alternatives is very limited. Aside from studies of 6PPD, we were unable to locate any studies examining the potential breakdown products of possible alternatives from reaction with ozone. For the PPDs, formation of quinones seems likely but the degree to which it occurs and the quinone persists in the environment is unknown. Information on ozone related breakdown products of the non-PPD alternatives was not located. We also could not find any modeling programs that would describe transformation with ozone. More generally, information on environmental breakdown products by other processes (*e.g.*, hydrolysis) was not present in the ECHA dossiers we consulted. A deeper examination using additional sources will be required in Stage 2 for the smaller number of alternatives considered viable based on hazard and initial screens of performance for the parent chemicals.

Performance. As discussed in Section 4, evaluation of the performance of an antidegradant in tires will involve a very large battery of tests, ranging from bench scale studies to field tests of manufactured tires placed on vehicles. The whole range of tests is likely to take several years to complete. Consequently, for this Stage 1 AA, we only had preliminary bench scale testing results available for a subset of possible alternatives. It is conceivable that alternatives that performed well in bench scale studies could fail to perform adequately in subsequent, more sophisticated tests. While this might not disqualify that alternative completely (because modifications may be possible to address the issues), it would impact the conclusions of the AA. In addition, the data we had available only covered a few of the alternatives. Although these were the ones that appeared most promising from a chemical structure basis, it is possible that if such data were available for other alternatives, we could have reached different conclusions. It is hoped that additional data will be available for review in Stage 2.

Cost. We did not assess costs of the possible alternatives considered in Stage 1. Data on the bulk prices of specialty chemicals is particularly difficult to obtain. We did examine some chemical supplier websites (*e.g.*, Alibaba) but found that the ranges supplied from different suppliers were so broad that they were both of questionable accuracy and not likely to be useful. We did not consider cost of the possible alternatives in Stage 1. This will be done in Stage 2 where it is hoped that an economist on the team will provide guidance on this issue.

[13] For example, one of the Consortium members disagreed with ToxService's use of 6PPD as a read across for IPPD (ToxServices, 2021c).

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Tables and Figures

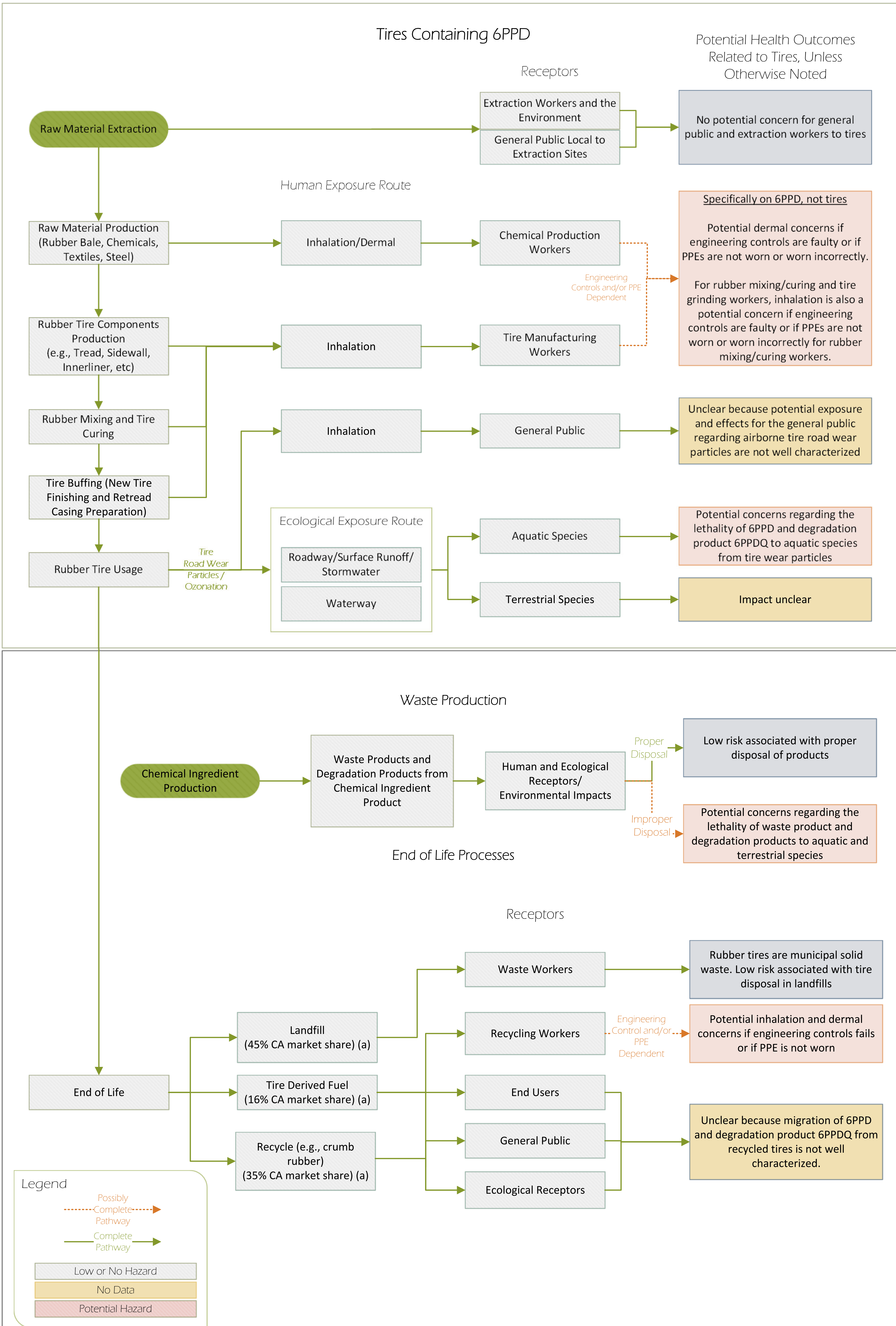


Figure 4.2 Conceptual Exposure Model: Tires Containing 6PPD

(a) Of the 35% of recycled tires in California, 13% are recycled as crumb rubber, 10% are retreaded as tires for buses and heavy-duty trucks, 8% are sold as used tires, 1% are used as tire-derived aggregate, and 3% are recycled *via* other means. Source: CalRecycle, 2023

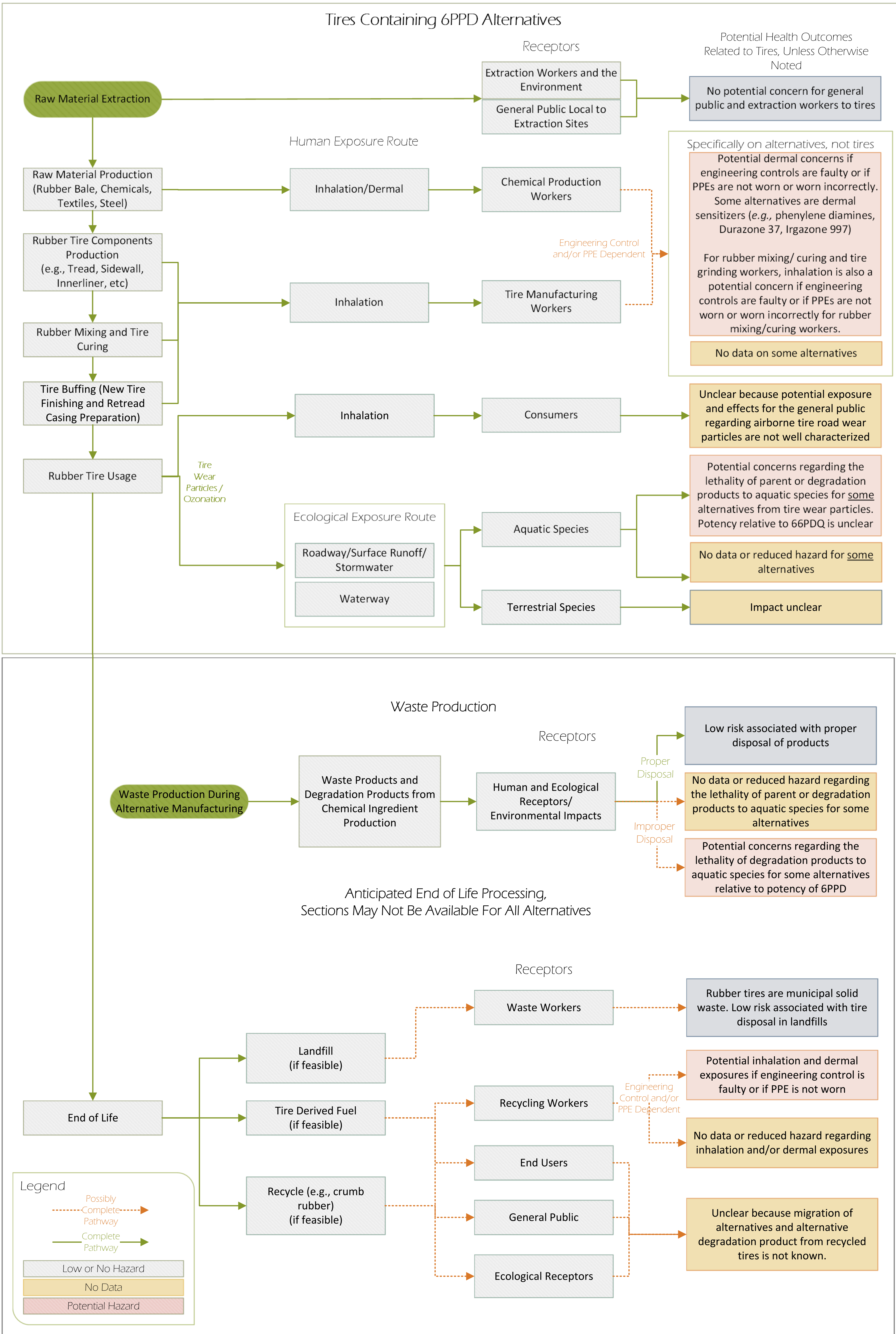


Figure 4.3 Conceptual Exposure Model: Tire Containing Possible Alternatives to 6PPD

Table 4.4 Consideration of Potentially Relevant Factors Identified in the SCP Regulations

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
Life Cycle Segments	Raw materials extraction	Unlikely for most alternatives, but data are limited. Potentially for amine treated lignin and rambutan peel extract.	While there are multiple LCAs for tires that characterize resource inputs such as energy, water, and other material requirements (Michelin, 2021; Dong *et al*., 2021; Piotrowska *et al*., 2019), there are no LCAs which focus specifically on the impacts associated with having 6PPD in tires nor is there an LCA available for any of the possible alternatives if present in a tire. A review of general information on chemical production for the functional ingredients in the products (Table 4.6) suggests that, qualitatively, there are unlikely to be material differences between them, as most involve inputs involving fossil fuels and/or mined materials of various types (*e.g.*, metals). There are multiple methods for producing graphene but the most common involve either processing of mined graphite or deposition of methane (typically fossil fuel derived) onto a substrate. For amine functionalized lignin, the base material, lignin, is a byproduct of wood processing so might involve no new materials extraction, assuming lignin from wood processing could meet the needs of tire production. Rambutan peel extract is an agricultural product and its production at the scale needed for tire production could have adverse impacts on land use. If the active antiozonant(s) are identified these could be produced industrially, likely from fossil fuel-based materials.
	Resource inputs and other resource consumption	Unclear	We define this life cycle segment as involving the resources used and consumed to produce the ingredients used as input for tire manufacturing, but not tire manufacturing itself, which is addressed below. There is no LCA available that specifically addresses the resource inputs or consumption associated with producing 6PPD or the possible alternatives for use in tires. Data on the inputs (other than chemical inputs discussed in Table 4.6) required to produce 6PPD and the possible alternatives are lacking. Production of graphene appears to be a highly energy intensive process (*i.e.*, high temperatures) but again, no data are available to allow comparison to other possible alternatives. Information is lacking regarding production of amine functionalized lignin or rambutan peel extract in terms of the reagents or other inputs required because these specific materials are listed in patents and do not appear to be produced at scale commercially (although for rambutan peel extract the processing could be limited). It is also conceivable that some possible alternatives would be produced at different locations which could have different impacts in terms of raw material and chemical intermediate transportation (both in terms of distance and transportation mode). However, data are lacking to assess such effects; it is unclear how production of an alternative antiozonant could change in terms of suppliers and their locations in order to meet demand and moreover, transportation networks would likely change significantly to increase efficiency due to the large volume of antidegradant involved. Analyzing the potential suppliers and their geographic locations for the possible alternatives under consideration was considered outside the scope of the Stage 1 AA.
	Intermediate materials production processes	Unlikely, but data are limited	A review of information on the chemical precursors of the functional ingredients in the Priority Product and possible alternatives (as summarized in Table 4.6) suggests that the PPD-related alternatives have essentially equivalent intermediate materials and processes as 6PPD. Most of the non-PPD materials (*e.g.*, TMQ, ethoxyquin, NBC, DLTDP, graphene) involve different chemistries but all involve industrial chemicals

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
			with significant hazard (*e.g.*, nickel for NBC, ethoxyquin and DLTDP involve various acids). The details (and therefore hazards) of producing amine functionalized lignin are unknown as this material is proposed in a patent. Various internet searches for companies producing amine functionalized lignin (of any type) were not informative. Some hazardous chemicals may be associated with lignin extraction such as formaldehyde or methanol (see Table 4.6). Likewise, some hazardous chemicals may be involved in production of rambutan peel extract (*e.g.*, methanol, hydrochloric acid) although details related to large scale extraction are lacking. The active ingredients in rambutan peel extract may also need to be produced synthetically and various searches for rambutan peel extract synthesis did not uncover any data for this. The hazards of graphene depend on the structure (*i.e.*, thickness) and stage of the production process.
	Product manufacture	Unlikely, but data are limited	As noted above, this lifecycle segment pertains to the hazards and impacts of producing the Priority Product and possible alternatives (*i.e.*, tires). As indicated in Tables 5.1 to 5.3, all the antidegradants pose some hazards which could be relevant for workers during exposure. It should be noted that the antidegradant comprises a small percentage of the mass of the tire and it is assumed that all other ingredients (*e.g.*, rubbers, fabric belts, steel, carbon black, silica, other additives) will largely remain the same. The extent to which some additives may change with a new antidegradant is not currently known. Moreover, tires will still require vulcanization which constitutes the major source of energy required during the production process. Thus overall, it appears that changing the antidegradant will not have a material difference on the impacts of the manufacturing stage but data are too limited to be certain. How the manufacturing process would change with a new antidegradant is unknown because it may require changes in tire formulation or production. We are unaware of any studies of potential worker exposure to any of the chemicals under study. This will need to be further explored in Stage 2.
	Packaging	Unlikely	This lifecycle segment pertains to the hazards and impacts of packaging the Priority Product and possible alternatives (*i.e.*, tires). Tires are packaged as either single units or on pallets. A change in the antidegradant appears unlikely to affect how the priority product is packaged.
	Distribution	Unclear	This lifecycle segment pertains to the hazards and impacts of transporting the Priority Product and possible alternatives (*i.e.*, tires) to various sales sites. It is unlikely that the location of tire factories would change significantly if one of the possible alternatives was implemented in lieu of the priority product, so transportation impacts (CO_2 emissions, road wear particles) from the production facility to sales locations should not change.
Life Cycle Segments	Use	Potentially	If alternatives can eliminate or reduce the release of 6PPD or another chemical with similar toxicity to susceptible species to the environment, then there would be a material difference in this life cycle segment. Beyond the reported effect of 6PPD on certain salmon species, there are other aspects of the use phase which will need to be considered. One important consideration would be whether an alternative results in greater or lesser tire wear, potentially resulting in different environmental impact. However, tire wear particle generation likely depends more on driving conditions (*i.e.*, speed, road surface type), than the

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
			antidegradant. Any alternative that could be implemented in a reasonable timeframe would still be rubber-based.
	Operation and maintenance	Unlikely	Tires require little maintenance while in actual use. The maintenance that is required (*e.g.*, maintaining proper inflation, periodic tire rotation and balancing) would not be expected to change with any of the possible alternatives.
	Waste generation and management	Potentially	This lifecycle segment pertains to manufacturing of the tire. During manufacturing manufacturers cycle excess formulated compound back into the manufacturing process (called rework); this substantially minimizes waste generated during tire production. The ability to continue the rework process is critical for minimizing production waste and will need to be considered for any of the possible alternatives. An alternative antidegradant that impacts processing time or temperature stability could significantly impact the potential for rework.
	Reuse and recycling	Potentially	A significant portion of tires are re-used as fill material or burned for energy (*e.g.*, in cement kilns) (See Figures 4.1 and 4.2). If possible alternatives alter this situation, there could be a material difference in terms of waste minimization potential. For example, NBC contains the carcinogen nickel which could impact air emissions from cement kilns or use as fill in artificial turf. Possible alternatives that have different environmental mobility (*e.g.*, greater water solubility) might also lead to a material difference in impact during reuse. One particular consideration for truck and bus tires is retread. An alternative that interferes with the retreading process could substantially increase tire waste because whole truck and bus tires would need to be purchased and discarded more frequently.
	End-of-life disposal	Potentially	As noted above, most tires are recycled to energy or other uses (*e.g.*, crumb rubber infill). If tires with alternative antidegradants have a different lifespan this could impact the amount of post-manufacturing tire waste generated and could exceed reuse and recycling capacity. However, consumers will only accept a limited decrease in product lifespan and so an alternative that substantially reduces product lifespan will be rejected.
Adverse Air Quality Impacts**	Would the product bring any changes to emissions of California Toxic Air Contaminants (*e.g.*, benzene, Cr[VI])?	Unclear	Based on a review of the California Toxic Air Contaminant list (CARB, 2020), neither 6PPD nor any of the possible alternatives are Toxic Air Contaminants. As shown in Table 4.6, nearly all of the possible alternatives have chemicals in their production stream (*e.g.*, benzene, nickel) that are Toxic Air Contaminants but the extent to which emissions would increase from increased production of the alternatives is not known.
	CO_2 emissions	Unclear	LCA exist for tires that describes carbon dioxide (CO_2) emissions (Dong *et al*., 2021; Piotrowska *et al*., 2019). However, details related to the contribution of 6PPD or any possible alternative to overall product CO_2 emissions are lacking. Thus, no data on this factor are available for a comparison.
	HFC emissions	No	As indicated in Table 4.6, HFCs do not appear to be used in production of 6PPD or any of the possible alternatives.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Methane emissions	Unlikely, but data are limited	Methane is released during fossil fuel extraction and most of the possible alternatives have fossil fuels (oil, natural gas) as part of their production life cycle. Graphene can be produced using methane *via* vapor deposition. Methane is known to be an input in production of NBC but is presumably consumed and not released to the environment. It is unknown whether methane is associated with the production of amine functionalized lignin or rambutan peel extract, but this seems unlikely.
	Nitrogen fluoride emissions Perfluorocarbon emissions Sulfur hexafluoride emissions	No	Based on the available production process information for 6PPD and the possible alternatives (Table 4.6), emissions of these chemicals are not expected to be part of the life cycle of the Priority Product or any of the possible alternatives. However, the available data on production process are limited.
	Other global warming gas emissions	No	All the ingredients of the Priority Product and possible alternatives are produced (or harvested in the case of rambutan peel) industrially so each involves some CO_2 emissions. No other greenhouse gases are known to be produced in the product life cycles. Methane is known to be an input in production of NBC but is presumably consumed and not released to the environment.
	Particulate matter emissions	Potentially, in part	Use of tires produces TRWP. TRWP will still be produced if any of the possible alternatives are used in lieu of the Priority Product. Whether the absolute amount of TRWP generated will change is not known although since particles are generated by tires gripping the road and this is an important factor for safety, a large change in particle number seems unlikely. That being said, the reported impact of TRWP, given the appropriate conditions, on certain sensitive species (*e.g.*, coho salmon, as reported in laboratory studies) potentially would be reduced if 6PPD is replaced with an alternative without such a reported effect on sensitive species. However, other potential impacts of TRWP (*e.g.*, other additives) would likely be the same. Thus, the relevance is considered to be "potentially, in part" because, while the emissions themselves are unlikely to change significantly, the impact could be materially different.
	Nitrogen oxide emissions Ozone-depleting substances emissions Sulfur dioxide emissions	No	Based on the known production process for 6PPD and the possible alternatives (Table 4.6), emissions of these chemicals are not expected to be part of the life cycle of the Priority Product or possible alternatives. None of the functional ingredients in the Priority Products and alternatives are ozone-depleting substances. A few of the possible alternatives (DOPD, DLTP) have production processes that involve sulfuric acid, which may be produced using sulfur dioxide, but this is not the only method of production and release of sulfur dioxide may not be part of the production process.
	Would the product bring any changes to emissions of compounds that might lead to tropospheric ozone production?	Unclear	Tropospheric ozone is formed by the reaction of solar energy with hydrocarbons and nitrogen oxides. 6PPD and all of the possible alternatives have hydrocarbons in their production chain, and several have nitrogen compounds (nitric acid). Whether compounds contributing to tropospheric ozone formation are emitted during production and whether production occurs in California is unclear.
Adverse Ecological Impacts*	Would the product, its constituents, or its likely breakdown products have any acute or chronic	Yes	Recent laboratory studies have reported that 6PPD's transformation product 6PPDQ, in certain concentrations, exhibits acute toxicity to certain fish species such as coho salmon. Although toxicity of quinone products of the alternatives is not known with certainty, preliminary data suggests that the

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	toxicity to impact aquatic, avian, or terrestrial animal or plant organisms or microbes?		quinones of certain other PPDs do not possess the same degree of toxicity to such species. These data were collected in *in vitro* systems, however and would need to be verified. In terms of other environmental breakdown products of 6PPD and the possible alternatives, data are limited. To the extent that information was found in the ECHA dossiers we examine, as shown in Table 5.10, 6PPD and many possible alternatives have similar breakdown products which do have acute aquatic toxicity (GHS category 1), including p-benzoquinone, p-hydroquinone and aniline. Data on environmental transformation products for many of the possible alternatives (TMQ, ethoxyquin, DLPTP) are lacking. Graphene would presumably have no transformation products in the environment but could release nano materials which could have an environmental impact.
	Would the product bring changes in population size, reduction in biodiversity, or changes in ecological communities?	Yes	Recent laboratory studies have reported that 6PPD's transformation product 6PPDQ can cause symptoms associated with pre-spawn mortality in certain salmonid species which, among other factors, has the potential to impact the population size of this species. Moreover, reductions in the population size of these salmon species could affect biodiversity. As noted earlier, there is preliminary information suggesting that other PPD antidegradants do not possess this property. It appears unlikely that non-PPD alternatives (*e.g.*, TMQ, ethoxyquin) can produce these or equivalent effects although this has not been studied.
	Would the product bring changes to the abilities of an endangered or threatened species to survive or reproduce?	Yes	See discussion above.
	Would the product bring changes to deterioration or the loss of environmentally sensitive habitats?	Unclear	6PPD is not known to directly cause habitat deterioration or loss. Along with other factors, laboratory studies have indicated that 6PPDQ can potentially impact populations of coho salmon and other sensitive species. The salmon spawning process is known to be important in transporting nutrients to riverine ecosystems. Thus, while 6PPD and 6PPDQ are not known to directly cause habitat loss or deterioration, there may be an indirect effect. It is unknown whether any of the possible alternatives could impact sensitive habitats since they are not currently used in a manner similar to 6PPD. Alternatives that do not cause pre-spawn mortality of coho salmon or other sensitive species (or which are less potent in this regard) would seem to be preferred alternatives with respect to this relevant factor. If additional agricultural land is required to produce lignin or rambutan peel extract (assuming these are not synthesized chemically), there could be associated habitat loss.
	Would the product bring changes that contribute to or cause vegetation contamination or damage?	Unclear	6PPD is not known to directly cause habitat deterioration or loss. This is not stated to be a property of the possible alternatives but these have not been used in as widespread a product as motor vehicle tires. If additional agricultural land is required to produce lignin or rambutan peel extract (assuming these are not synthesized chemically), there could be associated habitat loss.
	Would it bring adverse effects on environments that have been designated as impaired by a California State or federal regulatory agency?	Unclear	6PPD is not known to directly cause habitat deterioration or loss. Along with other factors, laboratory studies have indicated that 6PPDQ can potentially impact populations of coho salmon and other sensitive species. The salmon spawning process is known to be important in transporting nutrients to riverine

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
			ecosystems. Thus, while 6PPD and 6PPDQ are not known to directly cause habitat loss or deterioration, there may be an indirect effect. It is unknown whether any of the possible alternatives could impact sensitive habitats since they are not currently used in a manner similar to 6PPD. Alternatives that do not cause pre-spawn mortality of coho salmon or other sensitive species (or which are less potent in this regard) would seem to be preferred alternatives with respect to this relevant factor. If additional agricultural land is required to produce lignin or rambutan peel extract (assuming these are not synthesized chemically), there could be associated habitat loss.
	Would it result in biological or chemical contamination of soils?	Unclear	6PPD does not appear to affect soils during its use in tires; tire wear particles generally enter the aquatic environment or remain on roadways. The extent to which 6PPD/6PPDQ can migrate to soils from use of tire rubber as fill (*e.g.*, in artificial turf) is not well studied. Any alternative would presumably have the same potential if tires containing it were used in a similar manner. As noted earlier, any alternative to 6PPD would have to migrate through tire rubber which would seem to indicate a similar ability to migrate from rubber infill to soil.
	Any other adverse effects, as defined in Section 69401.2(a) (CalDTSC, 2012a), for environmental hazard traits and endpoints specified in Article 4 of Chapter 54, as follows: ▪ Domesticated animal toxicity ▪ Eutrophication ▪ Impairment of waste management organisms ▪ Loss of genetic diversity (including biodiversity) ▪ Phytotoxicity ▪ Wildlife developmental impairment ▪ Wildlife growth impairment ▪ Wildlife reproductive impairment ▪ Wildlife survival impairment Evidence for environmental hazard traits (*i.e.*, from standard aquatic and terrestrial toxicity testing, research-based investigations, mechanistic	Unclear	Because of the reported phenomenon of pre-spawn mortality (Scholz *et al.*, 2011), 6PPDQ has the potential to affect coho reproductive success. There is also information suggesting it may affect coho development. These could have an impact on genetic diversity. Preliminary *in vitro* data suggest some of the possible alternatives do not have this effect. However, data are incomplete on the potential for these possible alternatives to have other adverse ecological impacts.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	evidence from cell-based or whole organism-based assays showing perturbations of known physiological, biochemical or other pathways, or evidence from quantitative structure activity relationship programs).		
Adverse Soil Quality Impacts*	Would the product impact soil compaction or other soil structure changes?	No	Given the primary use of the product (driving on engineered roadways) it would not be expected that effects on the soil physical characteristics listed would be materially different among possible alternatives.
	Would the product impact soil erosion?		
	Would the product cause loss of organic matter in soil?		
	Would the product cause soil sealing?		
	Would the product be expected to directly enter the municipal storm sewer systems (*e.g.*, car wash detergents)?	No	6PPD and its possible alternatives would all be expected to be present in tire road wear particles and enter stormwater sewers during precipitation events. Since 6PPD and all of the alternatives are similar in this regard, the factor would not be materially different and is therefore considered not relevant.
	Would the product bring any increase in biological oxygen demand within the water system?	No	Neither 6PPD nor any of the possible alternatives have been demonstrated to have the potential to affect the growth of biological organisms in a way that would alter biological oxygen demand.
	Would the product bring any increase in chemical oxygen demand within the water system?	Unlikely	As antioxidants, it can be expected that all alternatives would have the *potential* to affect chemical oxygen demand. Whether such effects are materially relevant (given the relatively low concentrations of these chemicals detected in surface water bodies) has not been investigated. It seems logical to expect that other chemicals, present at higher concentrations, would be more likely to impact chemical oxygen demand.
	Would the product bring any increase in the temperature of water systems?	No	Neither 6PPD nor any of the possible alternatives have the potential to alter the temperature of water systems. Key determinants of water temperature in streams are the source of incoming waters, the speed and depth of the water, and the degree of vegetative cover affecting sunlight. None of these would be affected by 6PPD or its possible alternatives.
	Would the product bring any increase in total dissolved solids in water systems?	Potentially	Total dissolved solids (TDS) indicates the amount of inorganic and organic chemicals present as molecular, ionized, or colloidal particles in water. Some of the possible alternatives are inorganic and the alternatives vary in their water solubility. It is possible that this property could differ among the possible alternatives although whether it would be materially different is unclear.
	Increase in California CWA priority pollutants	No	Based on a review of the California Clean Water Act (CWA) Hazardous Substances, Priority Pollutants, and Toxic Pollutants lists (UL LLC, 2020) neither 6PPD nor any of its possible alternatives are present on these lists. The same applies to the main transformation products, to the extent that these are known.
	Increase in California CWA pollutants		

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
Adverse Water Quality Impacts*	Increase in chemicals with drinking water MCLs	No	Based on a review of the relevant regulations (22 CCR § 64431, § 64444, and § 64449) neither 6PPD nor any of its possible alternatives have drinking water MCLs. The same applies to the main transformation products of 6PPD and the possible alternatives, to the extent that such transformation products are known.
	Increase in chemicals with drinking water notification levels	No	Based on a review of the California guidance (CalSWRCB, 2020) neither 6PPD nor any of its possible alternatives have drinking water notification levels. The same applies to the main transformation products of 6PPD and the possible alternatives to the extent that such are known.
	Increase in chemicals with drinking water public health goals	No	Based on a review of the relevant regulation (CalOEHHA, 2019b) neither 6PPD nor its possible alternatives have drinking water public health goals (PHG).
	Exceedance of a standard relating to the protection of the environment	No	The consortium members are not aware of any material difference between 6PPD and any of the possible alternatives with respect to this relevant factor.
Public Health Impacts*§	Acute mammalian toxicity [Not included as a SCP hazard trait but included at preparer's discretion]	No	As shown in Table 5.1, there are slight differences in acute toxicity across the possible alternatives. Some possible alternatives (*e.g.*, 44PD) have a higher acute toxicity than 6PPD (GHS category 3 *versus* 4) and many (*e.g.*, 7PPD, DPPD, 6QDI, Durazone 37, graphene) are not classified under GHS nor classified for acute mammalian toxicity. These differences are not likely to have a significant bearing on the choice of alternative (*i.e.*, there are no GHS acute toxicity category 1 or 2 alternatives) There are also many alternatives with data gaps for this factor.
	Carcinogenicity	Potentially	As shown in Table 5.1, 6PPD is GHS not classified for carcinogenicity. A number of possible alternatives are similarly not classified (7PPD, DTPD, DLTP, Durazone 37). Several possible alternatives (*i.e.*, TMQ oligomer, N-phenyl-2-naphthylamine, NBC) are classified as GHS category 2 for carcinogenicity. There are many possible alternatives with data gaps for this factor.
	Developmental toxicity Reproductive toxicity	Yes	As shown in Table 5.1, 6PPD is has a high hazard classification (category 1B) for reproductive and developmental toxicity. A number of PPDs have similar classification (although some of these are based on using 6PPD as a surrogate). A few possible alternatives have low potential for reproductive and developmental toxicity (*i.e.*, GHS not classified). There are many possible alternatives with data gaps for this factor.
	Cardiovascular toxicity	Potentially	As shown in Table 5.2, 6PPDQ has been suggested to affect the cardiovascular system in coho salmon by affecting vascular permeability, however, there are many data gaps and no relevant observations have been made in mammalian species. A few possible alternatives (*e.g.*, NBC, DLTP) have been reported to affect the cardiovascular system.
	Dermatotoxicity	Potentially	As shown in Table 5.1, 6PPD is not classified for skin irritation or corrosion (*i.e.*, low hazard). Most possible alternatives are either similarly not classified or have a data gap for this factor. Three possible alternatives score worse than 6PPD for this factor (44PD, CCPD and N-phenyl-2-naphthylamine).
	Ocular toxicity	Yes	As shown in Table 5.1, 6PPD is not classified for eye irritation (ECHA) or classified as category 3 (Ecology GreenScreen). A number of possible alternatives are GHS category 2 for eye irritation (*e.g.*, 6QDI, CCPD,

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
			NBC, 44PD, and N-phenyl-2-naphthylamine). A number of possible alternatives (*e.g.*, 77PD, DTPD, TMQ oligomer, Durazone 37, graphene) score more favorably. There are many possible alternatives with data gaps for this factor.
	Respiratory sensitization	Yes	6PPD and several other PPDs are classified in the Ecology GreenScreens as respiratory sensitizers based primarily on a structural alert (Table 5.1). There are many chemicals with data gaps, although a few possible alternatives are not classified for respiratory sensitization (*i.e.*, low hazard) such as Durazone 37.
	Skin sensitization	Yes	6PPD and several other PPDs (*e.g.*, 7PPD, 44PD, Durazone 37) are classified as category 1 skin sensitizers (Table 5.1). Several non-PPD alternatives are GHS not classified for skin sensitization (TMQ oligomer, NBC, graphene, Vulcazone AFS blend). There are many chemicals with data gaps.
	Organ toxicity	Yes	As shown in Table 5.1, 6PPD is classified as category 2, moderate hazard, for repeated dose systemic toxicity (which encompasses organ toxicity) as evaluated by ToxServices. However, in the EU ECHA dossier, it is "not classified." A number of the 6PPD alternatives (7PPD, NBC, ethoxyquin, N-phenyl-2-naphthylamine) have similar or worse scores. A number are GHS not classified for this factor and so appears to have lower hazard than 6PPD (*e.g.*, DPPD, DTPD, DLTP, Durazone 37, graphene). There are a number of data gaps.
	Endocrine toxicity	Potentially	As shown in Table 5.1, the picture is mixed. None of the possible alternatives are listed as endocrine disrupters in the EU. 6PPD and a few possible alternatives (7PPD, IPPD, 6QDI and ethoxyquin) were listed as having moderate evidence of endocrine activity in the Ecology GreenScreens. Many possible alternatives have data gaps for this factor.
	Epigenetic toxicity	No	Epigenetic toxicity refers to the ability to alter gene expression without necessarily changing gene structure. In reviewing toxicity summaries for the possible alternatives, we found no indication that any of the possible alternatives exerted epigenetic effects. However, such effects are not often studied.
	Genotoxicity	Potentially	As shown in Table 5.1, 6PPD is not classified for genotoxicity/mutagenicity. All possible alternatives but one are either similarly not classified or have a data gap for this factor. DPPD is reported to be GHS category 2 (moderate hazard) for this factor.
	Hematotoxicity	Potentially	As shown in Table 5.2, 6PPD has been found to exert hematotoxicity at high doses in rats in some studies. A number of other PPDs (44PD, IPPD, DPPD, DAPD) and non PPDs (NBC, ethoxyquin, DLTP) have also shown hematotoxic effects. Data for a number of chemicals (*e.g.*, TMQ, graphene) are lacking.
	Hepatotoxicity and digestive system toxicity	Potentially	As shown in Table 5.2, 6PPD has given some evidence of adverse effects in the liver in rodents. A few of the possible alternatives (*e.g.*, polymerized TMQ, ethoxyquin) have also shown adverse effects on the liver. Note that effects on liver weight alone are not considered adverse but may be considered adaptive.
	Immunotoxicity	Unclear	Other than being a dermal sensitizer, 6PPD is not known to be an immunotoxicant. Data gaps exist for most of the possible alternatives. A few (NBC, DAPD) have reports of changes in the weight or size of immune system related organs but no more direct indications of adverse effects.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Musculoskeletal toxicity	Potentially	6PPD is not noted to cause musculoskeletal toxicity. No relevant information was found for any of the possible alternatives except NBC, which was noted to cause degeneration of skeletal muscle in rats. Effects on skeletal development during gestation are addressed under Developmental Toxicity.
	Nephrotoxicity and other toxicity to the urinary system	Potentially	6PPD is not reported to cause adverse effects on the kidney. Most possible alternatives similarly were not reported to cause adverse kidney effects. Ethoxyquin and N-phenyl-1-naphthylamine have been reported to cause kidney degeneration in rats.
	Neurodevelopmental toxicity Neurotoxicity	Potentially	6PPD is not reported to cause adverse neurological effects either in adults or juvenile animals. Most possible alternatives have data gaps for this factor. NBC and ethoxyquin and are reported to have caused adverse neurological effects in experimental animals.
	Ototoxicity	No	No data were located which indicated ototoxic (hearing related) effects for 6PPD or any of the possible alternatives.
	Reactivity in biological systems	Potentially	DTSC has stated that 6PPDQ is reactive in biological systems as part of the Agency's Priority Product Profile. We believe that the effects of 6PPDQ reported by some researchers are more appropriately and precisely described by other relevant factors (*e.g.*, those related to aquatic toxicity). That being said, preliminary data discussed in section 5 suggests that at least some other PPDs and their quinone transformation products may have differential toxicity to coho salmon. While all molecules are reactive at some dose in biological systems, it appears likely that the toxicity will differ. More data are needed to fully evaluate this endpoint.
	Respiratory toxicity	No	No data were located which indicated specific adverse respiratory effects for 6PPD or any of the possible alternatives. The apparent effects of 6PPDQ on cellular respiration are noted under hematoxicity because this appears to be an issue with oxygen transport in the blood.
	Evidence for other toxicological hazard traits	No	In our review of hazard data, we did not discover evidence for other toxicological hazard traits.
	Exceedance of an enforceable California or federal standard related to public health	No	To the best of our knowledge, use of the Priority Product or any of the possible alternatives will not involve intentional exceedance of such a standard, other than the ones already addressed elsewhere in this table.
Waste and End-of-Life Effects*	Would the product bring any change to the volume or mass of the waste materials and byproducts generated during the life cycle?	Unclear	Because the possible alternatives are all replacements for 6PPD in vehicle tires and represent only a small fraction of the mass of a tire, a materially relevant impact on the amount of waste or byproducts produced is not foreseen. However, as noted above, tire manufacturers rely on reusing some production waste (re-work) in the tire manufacturing process to minimize waste generation. An alternative that alters that ability could result in more waste generation but the extent to which that might occur is not currently known.
	Would the product need any special handling to mitigate adverse impacts resulting from the waste materials generated during the life cycle?	Unclear	At this time, it is not expected that there will be any different requirements for waste material handling from any of the possible alternatives. However, as noted above, their production process (certainly at scale) is not well understood. This will be explored in the Stage 2 AA.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Effects on solid waste or wastewater disposal or treatment	Unclear	At this time, it is not expected that there will be any different requirements for waste material handling from any of the possible alternatives as it related to waste disposal. However, as noted above, their production process (certainly at scale) is not well understood. This will be explored in the Stage 2 AA.
	Effects on discharge(s) or disposal(s) to storm drains or sewers adversely affecting wastewater or storm water treatment facilities	Unclear	At this time, it is not expected that there will be any different impacts on wastewater or stormwater treatment facilities. It is expected that all production facilities operate with water discharge permits which might need to be modified to address production of tires with a new antidegradant.
	Release to the environment	Unclear	Consortium members are not aware of any other factors associated with releases to the environment that would be associated with any of the possible alternatives.
Environmental Fate*	Aerobic and anaerobic half-lives of the product, its constituents, or its likely breakdown products	Unclear	No information on the aerobic or anaerobic half-lives could be found in EpiSuite or ECHA dossiers for 6PPD and the possible alternatives. Although we are aware of specific studies related to the aerobic and anaerobic half-lives of 6PPDQ, we are unaware of any data that exists for the potential alternatives, making comparisons impossible. This relates to the factor of persistence, discussed below.
	Aqueous hydrolysis half-life of the product, its constituents, or its likely breakdown products	Unclear	No information on hydrolysis rate constant could be found in EpiSuite or ECHA dossiers.
	Atmospheric oxidation rate	Unclear	No information on hydrolysis rate constant could be found in EpiSuite or ECHA dossiers. However, see Table 5.9 regarding the environmental half-life in air which is influenced by atmospheric oxidation rate. Although there are differences among 6PPD and possible alternatives for this property, they are not considered materially relevant since the primary concern is migration of 6PPD to surface water. All values are less than 1.0. 6PPD and most possible alternatives have very low vapor pressures suggesting limited impacts on air. While 6PPD associated with dust has been measured in air it is unclear how this would be affected by atmospheric processes since the chemical is contained within the particle substrate.
	Bioaccumulation of the product, its constituents, or its likely breakdown products	Yes	As shown in Figure 5.11, neither 6PPD nor any of the possible alternatives are listed as persistent, bioaccumulative or toxic. 6PPD and the possible alternatives do vary substantially in terms of the bioaccumulation potential. For example, as shown in table 5.3, while 6PPD, DPPD, 7PPD, DTPD are considered bioaccumulative based on California criteria, other possible alternatives (IPPD, TMQ oligomer, 44PD, ethoxyquin, and DLTP) are not. There are a number of chemicals with data gaps. Given that 6PPD and 6PPDQ are of concern for toxicity to certain fish species, bioaccumulation potential should be considered a relevant criterion if there is a difference among possible alternatives.
	Mobility in environmental media	Yes	See below regarding water solubility, lipid solubility, log k_{ow}, *etc*. There is a difference in ability to move through environmental media across the possible alternatives. Given that the key concerns regarding 6PPD are effects on certain fish species, environmental mobility is a relevant factor if there are differences among the possible alternatives.
	Persistence	Yes	6PPD and the PPD related alternatives are either considered persistent or have data gaps. NBC, TMQ oligomer, and ethoxyquin are considered persistent although DLTP is not.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Photodegradation	Unclear	Data for the photolysis rate constant is lacking for most of the possible alternatives. Moreover, given the low vapor pressure of the possible alternatives, it does not appear that free chemicals will be present in the air. Whether photolysis is a relevant mechanism for chemicals in tire wear particles is unknown.
Materials and Resource Consumption	Impacts on consumption of renewable resources, including energy and raw materials, throughout the product life cycle	Potentially	Very few inputs to the production of 6PPD and its possible alternatives as renewable resources. Tires do contain some renewable resource content (natural rubber) and whether this would change with different antidegradants (particularly non PPD antiozonants) is unclear. It is unknown how renewable energy requirements might differ for the possible alternatives. For electric vehicles, which have an increasing share of the vehicle market in California, consumption of renewable energy is important, and this could be affected by rolling resistance and vehicle energy efficiency per mile traveled. This could be affected by the possible alternatives if they affect rolling resistance.
	Impacts on consumption of non-renewable resources, including petroleum, coal, metals, minerals, and other finite resources, throughout the product life cycle	Potentially	As shown in Table 4.5, all of the possible alternatives appear to have some fossil fuel or otherwise non-renewable ingredients. Whether there is a quantitative difference among possible alternatives that is materially different is unclear. As noted above, possible alternatives that could affect the rolling resistance could impact consumption of non-renewable energy sources.
Physicochemical Properties*	Do the product or the alternatives exhibit oxidizing properties that facilitate combustion?	No	6PPD and all of the possible alternatives are being used as antidegradants, and ideally have both antioxidant and antiozonant properties. Therefore, the alternatives would likely inhibit rather than facilitate combustion.
	Do the product or the alternatives exhibit explosivity?	Unlikely	Based on the available ECHA REACH dossiers of the chemicals, none of the products exhibit this property (ECHA, 2020). However, for a number of possible alternatives, information on explosivity is not available.
	Do the product or the alternatives exhibit flammability?	Unlikely	Based on the available ECHA REACH dossiers of the chemicals, none of the products exhibit this property (ECHA, 2020). However, for a number of possible alternatives, information on flammability is not available.
	Do the product and alternatives have different physical states?	Potentially	Some alternatives, like 6PPD, are solids whereas others are viscous liquids. However, this difference is not expected to be materially relevant to the impact of the chemical on humans or the environment. It could be an important difference in terms of technical feasibility because current tire production processes are designed to work with solid antidegradant.
	Molecular weight	Yes	As shown in Table 5.9, the molecular weights range broadly across the possible alternatives. Molecular weight influences migration of the molecule in tire rubber and is thus an important factor in performance.
	Density	Unclear	Density information is lacking for many possible alternatives. Most have densities around 1 g/mL. Density could be important in terms of technical feasibility of incorporating the chemical into rubber compound.
	Vapor pressure	Potentially	As would be expected for compounds with high molecular weights, 6PPD and the possible alternatives all have low vapor pressures (maximum 1.56 E-3 mmHg at 25ºC). Vapor pressure would not be expected to constitute a materially relevant difference in terms of performance or environmental impact. In terms of technical feasibility, vapor pressure is important because the antidegradant has to survive the high temperatures of the tire manufacturing process without excessive loss.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Melting point	Potentially	As noted above, some of the possible alternatives are solids (like 6PPD) and some are liquids. The physical state could impact the technical feasibility of incorporation into rubber compound but should not affect environmental impacts.
	Boiling point	Potentially	As shown in Table 5.9, all of the possible alternatives have high boiling points (the lowest, 44PD is 98ºC). Boiling point would not be expected to be a materially relevant difference in terms of either technical feasibility or environmental impact.
	Flash point	Yes	Flash point is not one of the SCP mandated relevant factors. This property is materially relevant however, because it relates to manufacturing safety concerns with high temperature processes.
	Water solubility	Yes	As shown in Table 5.9, water solubility among the various possible alternatives varies by more than 10 orders of magnitude. Water solubility will have a significant bearing on movement of the chemical from tire wear particles through the environment.
	Lipid solubility	Yes	As shown in Table 5.9, the log Kow (an indicator of lipid solubility) varies substantially among the possible alternatives. Lipid solubility will have a significant impact on where in the environment the chemical will partition.
	Octanol-water partition coefficient (log K_{ow})	Yes	
	Organic carbon partition coefficient (K_{oc})	Yes	As shown in Table 5.9, the K_{oc} varies substantially among the possible alternatives. K_{oc} will have a significant impact on where in the environment the chemical will partition (*e.g.*, water *versus* sediment).
	Sorption coefficient for soil and sediment	Unclear	No data could specifically be located for this factor but see the discussion above for K_{oc}.
	Octanol-air partition coefficient (K_{oa})	Unclear	No data on this parameter could be located. See below regarding Henry's Law constant.
	Diffusivity in air and water	Potentially	As shown in Table 5.9, this parameter varied relatively modestly across the possible alternatives and is therefore unlikely to result in a material difference among them.
	Henry's Law constant	Yes	This parameter measures the tendency of a chemical to partition between water *versus* air. This parameter varies substantially among the possible alternatives and would be important in assessing environmental mobility of the chemical. Its relevance is somewhat linked to both water solubility and vapor pressure.
	Redox potential	Unclear	As shown in Table 5.9, redox potential data are available for 6PPD and a few of the possible alternatives. The values are all fairly similar, so this is not expected to make a material difference among possible alternatives where such information is available. Information is lacking, however, for many of the possible alternatives.
	Photolysis rates	Unclear	As shown in Table 5.9, there is a significant difference in photolysis potential among 6PPD and the possible alternatives. However, all have very low vapor pressures and would not be expected to be present in the atmosphere to an appreciable extent. However, all might be present in airborne dust where the impact of photolysis is not known.
	Hydrolysis rates	Unclear	As shown in Table 5.9, no data on hydrolysis rate constants for 6PPD nor any of the possible alternatives could be located.

Category	Factor that Is Relevant if Materially Different Between Priority Product and Alternatives	Relevant?*	Basis
	Dissociation constants	Unclear	Dissociation constant data were only located for a few of the possible alternatives. The available data suggest a limited potential for dissociation and therefore this factor is not believed to be materially relevant.
	Reactivity, including electrophilicity	Yes	The products are all chemically reactive as part of their function. To perform adequately, they must be chemically reactive, and the degree of reactivity is important to their antidegradant function in the tire.
Product Function and Performance*	Are there material differences in terms of the useful life of the product?	Potentially	It is possible that a 6PPD alternative that is not as effective could result in a shorter useful life for the product. This would have negative impacts on raw materials and energy consumption during production, waste generation, consumer costs and potentially consumer safety (if consumers replace tires less frequently due to cost). Thus, there are very strong incentives not to accept alternatives that result in a short product life.
	Are there material differences in terms of the function and performance of the product?	Potentially	It is the position of the consortium members that tires must perform in a manner that is safe and consistent with both federal regulations and company product stewardship requirements. An alternative that does not have comparable function and performance as 6PPD would not be acceptable.
	Are there material differences in terms of the functional acceptability of the product?	No	It is the position of the consortium members that any 6PPD alternative must function comparably to 6PPD as an antidegradant.
	Are there material differences in terms of the technical feasibility of the product?	Potentially	There is no alternative that will be a "drop in" replacement for 6PPD. Most alternatives will require modification of the tire formulation and/or the tire production process (*e.g.*, balancing processing time *vs* curing rate or scorch time). The extent of modification required will likely vary considerably among the possible alternatives and will have to be investigated through production process research.
Economic Impacts*	Will the product and its alternatives have a different cost to consumers or other users?	Potentially	It is possible that the use of a possible 6PPD alternative in tires could have some effect on the cost of the product. There will likely be substantial costs for new production equipment as well as product testing required by law or company product stewardship specifications which would have to be reflected in the cost of the product. Since many of the possible alternatives are not commercially produced at scale, it is unclear how large that difference in cost could be. This will be addressed more fully in Stage 2.

Notes:
CalDTSC = California Department of Toxic Substances Control; CARB = California Air Resources Board; ECHA = European Chemicals Agency; HFC = Hydrofluorocarbon; LCA = Life Cycle Assessment; MCL = Maximum Contaminant Level; RE = Responsible Entity; REACH = Registration, Evaluation, Authorisation, and Restriction of Chemicals; US EPA = United Sates Environmental Protection Agency; VOC = Volatile Organic Compound.
* Whether a factor was considered relevant to drawing a distinction between possible alternatives and candidate chemical in the Priority Product was described using five terms. The terms "yes" and "no" were used when the available data indicated a clear material difference would be expected or is obvious. The terms "potentially" and "unlikely" were used when the available data were too limited to be fully confident on whether a material difference can be expected but the available data leaned towards one direction (*i.e.*, towards either yes or no but not reliably). Finally, the term "unclear" was used when data were not available to give an indication of whether a factor would be relevant or not.
** For theses relevant factors, we consider the impacts of the Priority Product and possible alternatives but not of chemicals upstream in their product lifecycle.
§ Public health impacts relate to 6PPD and possible alternatives. Hazards of 6PPDQ are not included because data for this chemical are limited and data for the quinone products of possible alternatives are unavailable, making comparison impossible.
Safer Consumer Products (SCP) regulations: CalDTSC (2013) (22 CCR § 69505.5).

Table 4.5 Life Cycle Elements Considered in Evaluating Potential Exposures

Category	Element	Relevant?*	Basis
Chemical Quantity Information	Would the alternative change the quantities of the chemical(s) of concern or other replacement chemicals necessary to manufacture the product?	Unclear	For possible alternatives to 6PPD as an antidegradant, data are not yet available to determine how the quantity required per tire might change. It is expected that the amount of antiozonant will not change substantially (*e.g.*, by several fold) but this remains to be seen.
	Would the alternative change the quantities of the chemical(s) of concern or other replacement chemicals placed into the stream of commerce in California?	Unclear	
Market Presence of Product	Would the alternative change statewide sales of the product by volume?	Potentially	Since all possible alternatives are replacements for 6PPD, tire sales volume and number of units should not change unless costs significantly increase or unless the use of the alternative decreases the life of the tire (*i.e.*, increasing the wear or aging rate), which would require more frequent replacement. Also, an alternative that affects retread potential could require larger sales of new truck and bus tires.
	Would the alternative change statewide sales of the product by number of units?		
	Would the alternative change the intended product use(s), and types and age groups of targeted customer base(s)?	No	Tires would be used in the same manner and by the same type of individuals. Tires are not used in different ways by different segments of the population.
Occurrence or Potential Occurrence of Exposure	Will there be a difference in occurrence or potential occurrence of exposure to Candidate Chemicals in the product?	Potentially	If the selected alternative is a PPD, it may not affect exposure to candidate chemicals (while still having an improved hazard profile for fish species of concern). If another, non-PPD alternative is selected, this could change the potential for candidate chemical exposure.
Household and Workplace Presence	Will the product be used in the home?	No	No, the product is not used inside the home. Tires may be stored in the home, but it is abrasion of tires by roads which results in the release. Thus, even if stored in the home there is minimal potential for exposure.
	Will the product be used in the workplace?	Yes	Tires are used on vehicles used during work (*e.g.*, cars used for work and trucks and buses). However, that use involves minimal exposure for the worker because the tires are not located where the work is located. In some cases, tires are used in tire warehouses and dealerships where this is potential for exposure. The extent of exposure is unknown.
Potential Exposure	Are there differences in the manufacturing, use, storage, transportation, waste, or end-of-life management of the product and alternatives?	Unclear	Details about how tires could be manufactured with the selected alternative(s) are lacking. It is assumed some differences in manufacturing would be required but the degree of change is unknown at this time. Refer to Table 4.4 for the lifecycle step-by-step consideration.
	Is the product manufactured, stored, or transported through California but not used in California?	No	The product is used in California.
	Is the product an intermediate product used to manufacture an exempted product?	No	No, 6PPD is used to manufacture tires which are not an exempted product.

Category	Element	Relevant?*	Basis
	Does the product have household use?	No	No, the product is not used inside the home. Tires may be stored in the home (*e.g.*, garage) but it is abrasion of tires by roads which results in the release. Thus, even if stored in the home there is minimal potential for exposure.
	Does the product have recreational use?	No	The priority product is not intended for recreational use. At end of life, the product may be used as crumb rubber fill in recreational fields.
	Are there sensitive subpopulations that use the product and alternatives?	Yes	Sensitive populations include workers, sensitized individuals, children, the elderly, and pregnant women. These individuals do use vehicles containing tires in a manner similar to the general population. However, their use does not result in particular exposure. If the use of spent tires as crumb rubber fill is considered, there may be particular types of exposure to certain populations. However, it is not clear if use of spent tires for this purpose falls within the designation of the priority product or whether such materials would need to be designated as their own priority product.
	Is the product used in homes?	No	No, the product is not used inside the home. Tires may be stored in the home (*e.g.*, garage) but it is abrasion of tires by roads which results in the release. Thus, even if stored in the home there is minimal potential for exposure.
	Is the product used in schools?	No	Tires are not intended for use inside schools. School buses have tires, but this use does not appear related to the intention of this relevant factor.
	Is the product used in workplaces?	Yes	Tires are used on vehicles used during work (*e.g.*, cars used for work and trucks and buses). However, that use involves minimal exposure for the worker because the tires are not located where the work is located. In some cases, tires are used in tire warehouses and dealerships where this is potential for exposure. The extent of exposure is unknown.
	Is the product used in other unusual locations?	Yes	Spent tires are used in various applications including energy production, retaining walls, marine applications, and as noted above, as an artificial turf component.
	Is there a difference in the frequency, extent, level, and duration of exposure potential for the product and its alternatives during use?	Unclear	Tires will be used in the same manner regardless of whether 6PPD or an alternative is used. If the possible alternative lacks 6PPD/6PPDQ toxicity to certain fish species, the impact of the exposure will be different.
	Is there a difference in the frequency, extent, level, and duration of exposure potential for the product and its alternatives at end-of-life?	Unclear	At this time, it is unclear what the end-of-life implications of 6PPD alternatives are for the end-of-life stage. This will be further explored in Stage 2.
Potential Exposure	Is there a difference in how the candidate chemical is contained within the product and its alternatives?	Potentially	It is anticipated that most possible alternatives would be non-bound in the polymer structure so as to be able to migrate through the tire as needed. Graphene is one exception as it will not migrate through the rubber matrix.
	Is there a difference in terms of engineering and administrative controls to reduce exposure among the product and its alternatives?	Unclear	To date, we have not identified any engineering or administrative controls involved in any of the possible alternatives being evaluated.

Category	Element	Relevant?*	Basis
	Is there a difference in the potential of the candidate chemical and degradation products to release into, accumulate in, and persist in the environment?	Yes	As noted in Table 5.9, the possible alternatives have different physical and chemical properties that could impact their ability to be released into, accumulate in, and persist in the environment.

Notes:

* Whether a factor was considered relevant to drawing a distinction between possible alternatives and candidate chemical in the Priority Product was described using five terms. The terms "yes" and "no" were used when the available data indicated a clear material difference would be expected or is obvious. The terms "potentially" and "unlikely" were used when the available data were too limited to be fully confident on whether a material difference can be expected but the available data leaned towards one direction (*i.e.*, towards either yes or no but not reliably). Finally, the term "unclear" was used when data were not available to give an indication of whether a factor would be relevant or not.

Table 4.6 Production Process Chemistry for 6PPD and Possible Alternatives

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
6PPD	793-24-8	6PPD is produced *via* the reduction of either P-nitro- or P-nitrosodiphenylamine to form P-aminodiphenylamine, followed by reaction with methyl isobutyl ketone (MIBK) and hydrogenation over a catalyst (PubChem). The former is produced by the by reaction of an alkyl ether of 4-nitrosophenol with aniline (PubChem). MIBK is derived from acetone *via* the intermediate mesityl oxide. The key ingredients are therefore 4-nitrosophenol, aniline, and acetone. Acetone is produced in multiple ways including oxidation of cumene; dehydrogenation or oxidation of isopropyl alcohol with metallic catalyst; vapor-phase oxidation of butane; by-product of synthetic glycerol production. Aniline is produced from nitrobenzene, which is itself produced by reaction of benzene with forms of nitric acid. Nitrosophenol is produced by the reaction of nitrous acid on phenol; phenol itself is produced by oxidation of cumene. The base ingredients are therefore hydrocarbons such as cumene, benzene, and butane as well as various catalysts and reagents (*e.g.* , acids).	Yes. Cumene, benzene, butane, and subsequent chemicals in the production chain are all likely derived from fossil fuel sources.	acetone aniline benzene butane cumene glycerol isopropyl alcohol mesityl oxide metallic catalysts methyl isobutyl ketone P-aminodiphenylamine nitric acid nitrobenzene P-nitrodiphenylamine P-nitrosodiphenylamine 4-nitrosophenol nitrous acid phenol
7PPD (N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamin)	3081-01-4	No PubChem data on manufacturing but is likely to be similar to 6PPD with the use of different isomers. Likely to have the same impact on raw material requirements.	Yes, expected to be similar to 6PPD.	Yes, expected to be similar to 6PPD.
IPPD (N-isopropyl-N'-phenyl-p-phenylenediamine)	101-72-4	Reaction of p-chloronitrobenzene with aniline to yield p-nitrodiphenylamine which is reductively alkylated with acetone over a nickel/chromium catalyst. Chloronitrobenzenes are produced by nitration of chlorobenzene which is itself produced by reaction of benzene with gaseous chlorine in the presence of a catalyst. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. In both cases, benzene is derived from fossil fuel sources. Acetone is produced in multiple ways including oxidation of cumene; dehydrogenation or oxidation of isopropyl alcohol with metallic catalyst; vapor-phase oxidation of butane; by-product of synthetic glycerol production. The base ingredients are therefore benzene, cumene, nitric acid, an unstated catalyst, chlorine, and isopropyl alcohol.	Yes. Cumene, benzene, and subsequent chemicals in the production chain are all likely derived from fossil fuel sources.	acetone aniline benzene butane chlorine chlorobenzenes chloronitrobenzenes cumene glycerol isopropyl alcohol nickel/chromium catalyst nitric acid nitrobenzene P-nitrodiphenylamine
CPPD (N-cyclohexyl-N'-phenyl-p-phenylenediamine)	101-87-1	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
DPPD (N,N′-diphenyl-p-phenylenediamine)	74-31-7	Prepared by condensing hydroquinone or p-aminophenol with aniline. Hydroquinone is produced *via* multiple pathways: *via* hydroxylation of phenol with hydrogen peroxide, *via* oxidation of aniline with manganese dioxide, or from derivatization of benzene and cumene. Phenol is typically produced via oxidation of benzene or toluene. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid.	Yes. Cumene, benzene, and toluene are all likely derived from fossil fuel sources.	aniline p-aminophenol benzene cumene hydroquinone hydrogen peroxide manganese dioxide nitric acid nitrobenzene phenol toluene
6QDI (N-1,3-dimethyl butyl-N′-phenyl quinone diimine)	52870-46-9	6QDI is the oxidized form of 6PPD (where the nitrogen atoms around the central phenyl ring have double bonds instead of single bond plus a hydrogen atom). It therefore would have the same production process as 6PPD.	Yes, expected to be the same as 6PPD.	Expected to be the same as 6PPD.
TMQ (polymerized 2,2,4-trimethyl-1,2-dihydroquinoline)	147-47-7	Reaction of quinoline and acetone. Quinoline is produced *via* reaction of aniline with glycerol and nitrobenzene in presence of sulfuric acid. Acetone is produced in multiple ways including oxidation of cumene; dehydrogenation or oxidation of isopropyl alcohol with metallic catalyst; vapor-phase oxidation of butane; and by-product of synthetic glycerol production. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. Nitrosophenol is produced by the reaction of nitrous acid on phenol; phenol itself is produced by oxidation of cumene. Glycerol is derived from plant matter while nitrobenzene (as noted above) is derived from benzene and nitric acid. The base ingredients are therefore hydrocarbons such as cumene, benzene, and butane as well as various catalysts and reagents (*e.g.* , acids).	Yes. Cumene, benzene and butane are all likely derived from fossil fuel sources.	acetone aniline benzene butane cumene glycerol isopropyl alcohol nitric acid nitrobenzene nitrosophenol nitrous acid phenol quinoline sulfuric acid various catalysts
77PD (N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine)	3081-14-9	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	Self-condensation of p-octylaniline in the presence of mineral acids such as hydrochloric acid. By analogy with ethylaniline, octyl aniline is likely produced by heating aniline and octanol with sulfuric acid, with subsequent distillation. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. Hydrochloric acid is produced by reaction of sodium chloride and sulfuric acid or sulfur dioxide or as a by-product of the synthesis of chlorinated hydrocarbons.	Yes. Benzene and other chemicals produced from fossil fuel materials.	aniline benzene chlorinated hydrocarbons hydrochloric acid nitric acid nitrobenzene octanol p-octylaniline sulfuric acid sulfur dioxide

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
44PD (N,N'-Di-sec-butyl-p-phenylenediamine)	101-96-2	Reaction of p-phenylenediamine and 2-butanone, followed by catalytic hydrogenation of the alkyl diamine. Alternatively, reaction of butylamine and hydroquinone (reductive amination). Butylamine is produced *via* reaction of ammonia with butyl alcohol. Ammonia is produced *via* reaction of nitrogen and hydrocarbons from natural gas sources. Butyl alcohol is similarly obtained commercially *via* oxidation of fossil fuel sources. Hydroquinone is produced *via* multiple pathways: *via* hydroxylation of phenol with hydrogen peroxide, *via* oxidation of aniline with manganese dioxide, or from derivatization of benzene and cumene. Phenol is typically produced via oxidation of benzene or toluene. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. 2-Butanone is produced from butyl alcohol which is commercially produced from natural gas constituents.	Yes. Benzene, cumene, natural gas, toluene, and other chemicals produced from fossil fuel materials.	alkyl diamine ammonia aniline benzene butyl alcohol butylamine 2-butanone cumene hydrogen peroxide hydroquinone manganese dioxide natural gas nitric acid nitrobenzene phenol p-phenylenediamine toluene
CCPD (N,N'-dicyclohexyl-p-phenylenediamine)	4175-38-6	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
DAPD (diaryl-p-phenylene diamine)	68953-84-4	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
DNPDA (N,N'-Di-2-naphthyl-p-phenylenediamine)	93-46-9	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
NBC (Nickel dibutyldithiocarbamate)	13927-77-0	Reaction of aqueous solutions of sodium dibutyldithiocarbamate and nickel chloride, acetate, or sulfate. Sodium dibutyldithiocarbamate is produced by reaction of carbon disulfide with dibutylamine in the presence of aqueous sodium hydroxide. Carbon disulfide is produced by combining sulfur with charcoal or methane. Dibutylamine is produced *via* reaction of ammonia with butyl bromide or chloride which, in turn, are produced by reacting the halogen gas with natural gas fractions. Sodium hydroxide is produced commercially *via* electrolysis of sodium chloride. Nickel chloride/acetate/sulfate are produced by reacting nickel ores (*e.g.*, nickel oxide) with the requisite acid.	Yes. There are hydrocarbons and other chemicals produced from fossil fuel materials	acids ammonia butyl bromide or chloride carbon disulfide charcoal dibutylamine methane nickel chloride, acetate, or sulfate nickel ores (e.g., nickel oxide) sodium chloride sodium dibutyldithiocarbamate sodium hydroxide sulfur

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
Ethoxyquin	91-53-2	Reaction of acetone with p-phenetidine and iodine at 120-130 C. Distillation to isolate ethoxyquin. Acetone is produced in multiple ways including oxidation of cumene; dehydrogenation or oxidation of isopropyl alcohol with metallic catalyst; vapor-phase oxidation of butane; by-product of synthetic glycerol production. p-Phenetidine (ethoxylaniline). No data in PubChem but presumably involves oxidation of aniline. Iodine is obtained from natural sources (brine) often with the use of sulfuric acid and chlorine.	Yes. There are hydrocarbons and other chemicals produced from fossil fuel materials	acetone aniline butane chlorine cumene ethoxyquin glycerol iodine isopropyl alcohol metallic catalyst p-phenetidine (ethoxylaniline) sulfuric acid
Dilauryl thiodipropionate	123-28-4	Reaction of thiodipropionitrile (TDPN) with lauryl alcohol using acid catalysts (hydrochloric acid and sulfuric acid). Lauryl alcohol produced by addition of ethylene to triethylaluminum or hydrogenation of methyl laurate. Also produced *via* reduction of esters of lauric acid with sodium and absolute alcohol or by reduction of coconut-oil fatty acids. Ethylene is obtained from fossil fuel sources. Hydrochloric acid is produced by reaction of sodium chloride and sulfuric acid or sulfur dioxide or as a by-product of the synthesis of chlorinated hydrocarbons. Sulfuric acid is produced by reacting sulfur dioxide with oxygen or nitric oxide	Yes. There are hydrocarbons and other chemicals produced from fossil fuel materials	chlorinated hydrocarbons coconut fatty acids ethanol ethylene hydrochloric acid lauric acid lauryl alcohol methyl laurate nitric oxide oxygen sodium chloride sulfur dioxide sulfuric acid thiodipropionitrile (TDPN) triethylaluminum
DTPD (N,N'-Ditolyl-p-phenylenediamine)	68953-84-4	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
1,4-Benzenediamine, N,N'-bis(2-methylphenyl)	15017-02-4	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	None Provided	No PubChem data on manufacturing. However, it contains the 6PPD structure bonded to thioanisole between the terminal benzene moiety of 6PPD and the terminal methyl moiety of thioanisole. It is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle from the production of 6PPD. Additionally, phenyl mercaptan and an alkylating agent are used to manufacture thioanisole (US Patent 4124646A) so it is likely they are also part of the production process. Thus, aside from reacting phenyl mercaptan with an alkylating agent, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD Phenyl Mercaptan
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine; or similar chemical 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
RU997 Irgazone 997	444992-04-5	No PubChem data on manufacturing. However, CAS 444992-04-05 is a reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether. N-phenyl-N'-(1,3 dimethylbutyl)-p-penylenediamine is a PPD family molecule, so it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have a similar production process as 6PPD.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD glycidylthioether
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
This is a class of compounds. Reference uses case where R1 and R2 are methyl; n,p and q are zero and m=1 and is in the para position. Reference compound is CAS 6358-22-1	6358-22-1	This class of compounds is produced by reaction of N,N-Dimethyl-p-phenylenediamine and phenol. N,N-Dimethyl-p-phenylenediamine is produced *via* the reduction of p-nitrosodimethylaniline with zinc dust and hydrochloric acid, and the oxidation of cumene. P-nitrosodimethylaniline is produced *via* reduction of nitrous acid with dimethylaniline. Dimethylaniline is produced from aniline and methanol under pressure in the presence of acidic catalysts. Therefore, the key ingredients are aniline, methanol, and cumene.	Yes, cumene, aniline, and methanol are likely derived from fossil fuel remnants.	Aniline Cumene Dimethylaniline Methanol Nitrous Acid
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	None Provided	No PubChem data on manufacturing. However, as the same class of chemical as N,N-Dimethyl-p-phenylenediamine it is likely that chemicals such as dimethylaniline, nitrous acid, aniline, methanol, and cumene are all parts of the production cycle. Thus, it appears likely to have similar production processes as other compounds in the same family as N,N-Dimethyl-p-phenylenediamine	Yes, cumene, aniline, and methanol are likely derived from fossil fuel remnants.	Expected to be similar to Phenol, 4-[[4-(dimethylamino)phenyl]amino]-
Mixed xylene diamines N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	No PubChem data on manufacturing. However, as the same class of chemical as benzylamine it is likely that chemicals such as chlorine, toluene, and ammonia are all parts of the production cycle. Thus, it appears likely to have similar production processes as other compounds in the Benzylamine family. Benzylamine is produced by the reaction of benzyl chloride with ammonia in aqueous solution. Benzyl chloride is produced by passing chlorine over boiling toluene, and then washing with water.	Yes, Toluene is produced during petroleum refining operations.	Ammonia Benzylamine Benzyl chloride Chlorine Toluene
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine, TAPDT	121246-28-4	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
N-Phenyl-1-naphthylamine	90-30-2	Reaction of alpha-napthylamine (CAS 134-32-7) with aniline, and purified *via* distillation. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. Alpha-napthylamine is produced from either reduction by catalytic hydrogenation with a nickel catalyst or being reduced with iron in hydrochloric acid. 1-nitronapthalene in turn is prepared by the action of acids (nitric and sulfuric) on ground napthalene. The key ingredients are therefore benzene, nitric acid, napthalene, nitric acid, and hydrochloric acid.	Yes. Napthalene is derived from coal tar.	Aniline Benzene Hydrochloric Acid Metallic Catalyst Napthalene α-Napthylamine Nitric Acid Nitrobenzene 1-Nitronapthalene Sulfuric Acid

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
N-Phenyl-2-naphthylamine	135-88-6	Produced either by heating 2-naphthol with aniline hydrochloride, or condensation of 2-naphthol and aniline in the presence of a catalyst. 2-Napthol is produced by caustic fusion of napthalene-2-sulfonic acid. No PubChem data is available on the production of napthlene-2-sulfonic acid, however it is likely this process involves napthalene and sulfonic acid. Aniline is produced from nitrobenzene which is itself produced by reaction of benzene with forms of nitric acid. Aniline hydrochloride is produced from a reaction of aniline and hydrochloride. The key ingredients are therefore benzene, aniline, hydrochloride, napthalene, sulfonic acid, and nitric acid.	Yes. Napthalene is derived from coal tar.	Aniline Aniline Hydrochloride Benzene Benzenamine Hydrochloride Napthalene 2-Naphthol Nitric Acid Nitrobenzene Sulfonic Acid
Irganox 1520	110553-27-0	The only available PubChem manufacturing data is a TSCA Commercial Activity Status for Phenol. CAS 110553-27-0 can thus be defined as a phenol family compound. It is likely that chemicals such as cumene and oxygen are parts of the production cycle. Thus, it is likely that production involves oxidation of cumene with oxygen to cumene hydroperoxide, and cleavage of cumene hydroperoxide in an acidic medium to phenol and acetone. The compound, additionally, has two long alkyl sulfur chains. However, there is no manufacturing information available for these structures on PubChem.	Yes. Cumene is likely derived from fossil fuel sources.	Cumene Oxygen
Graphene	1034343-98-0	Produced from organic materials that are rich in carbon, such as coal, lignite, wood, nut shells, peat, pitches, and cokes. Manufacturing is done through either thermal activation or chemical activation.	Some carbon sources are fossil fuel based	Carbon
1,1' - Pentamethylenebis(2,2-Di-n- Butylhydrazine)	None Provided	No PubChem data on manufacturing. However, 1,1' - pentamethylenebis(2,2-Di-n-Butylhydrazine) is a hydrazine, so it is likely that chemicals such as chlorine, sodium hydroxide, and ammonia are parts of the production cycle. The production of hydrazine involves the reaction of sodium hypochlorite and ammonia to yield chloramine and sodium hydroxide, followed by the reaction of chloramine, ammonia, and sodium hydroxide to yield hydrazine, sodium, chloride, and water. Sodium hypochlorite is produced when chlorine is added to a cold dilute solution of sodium hydroxide.	Hydrazine is not fossil fuel based, but compound has large alkyl groups that are likely fossil fuel based	Ammonia Chloramine Chlorine Hydrazine Sodium Hydroxide Sodium Hypochlorite
α- C-4- hydroxy- 3,5-dimethylphenyl (Lowinox WSP - 77-62-3) . No number for nitrone - N-isopropyl nitrone and Lowinox WSP	77-62-3 No CAS for N-isopropyl nitrone	No PubChem data on manufacturing. However, CAS 77-62-3 is a phenol family compound, so it is likely that chemicals such as cumene and oxygen are parts of the production cycle. Thus, it is likely that production involves oxidation of cumene with oxygen to cumene hydroperoxide, and cleavage of cumene hydroperoxide in an acidic medium to phenol and acetone. No PubChem manufacturing information is available for N-isopropyl nitrone. However, N-isopropyl nitrone is likely a formaldehyde family compound because Nitrone(75-17-2) is defined as a formaldehyde family compound by the TSCA. It is then likely that chemicals such as methanol are a part of the production process.	Yes. Cumene is likely derived from fossil fuel sources.	Cumene Formaldehyde Methanol Oxygen
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	None Provided	No PubChem data on manufacturing. However, as a PPD-family molecule it is likely that chemicals such as aniline, nitrobenzene, and benzene are all parts of the production cycle. Thus, it appears likely to have similar production processes as the other PPDs.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	None Provided	No PubChem data on manufacturing. However as an aniline-family molecule it is likely that chemicals such as nitrobenzene and benzene are both parts of the production cycle. It is likely that the nitration of benzene with mixed acid, and the hydrogenation of nitrobenzene are both parts of the production process. As this chemical has the same MIBK derivative tail structure as 6PPD it is likely that acetone is also a key component of the manufacturing process.	Yes, expected to be similar to 6PPD.	Expected to be similar to 6PPD
α- C-4- Hydroxy- 3,5-dimethylphenyl- N-tert. butyl nitrone	None Provided	No PubChem manufacturing information is available for α- C-4- hydroxy- 3,5- dimethyl phenyl- N-tert. butyl nitrone. However, this chemical is likely a formaldehyde family compound because nitrone (CAS 75-17-2) is defined as a formaldehyde family compound by the TSCA. According to the patent related to identification of this possible alternative (see Appendix D), the chemical was produced by reaction of N-tert-butyl-hydroxylamine and 3,5-dimethyl-4-hydroxybenzaldehyde in ethanol. No information could be located in PubChem for these two reagents but benzaldehydes in general are reported to be ultimately derived from toluene.	Yes. toluene is likely derived from fossil fuel sources.	t-Butyl hydroxylamine Dimethyl benzaldehyde Ethanol Toluene
Amine functionalized lignin	None Provided	Lignin is a waste product of wood processing. Lignin must be isolated from the wood pulp and this appears to be done using various solvents such as sodium sulfide, dioxane, or methanol, along with acid catalysts or formaldehyde (Bertella and Luterbacher, 2020). The specific isolation process yields different results and would need to be optimized for an antiozonant. Formaldehyde and urea or azides have been suggested as possible reagents for amination of lignin (Bertella and Luterbacher, 2020) although the specific of amine functionalization to produce anti-ozone activity are not known. It should also be noted that as lignin is a biological material, consistency in material over time is a concern.	Not if lignin is obtained from wood product production waste	Azides Dioxane Formaldehyde Methanol Sodium sulfide Urea

Chemical	CAS No.	Production Process	Precursor Fossil Fuel Based?	Possible Chemicals Involved Across Lifecycle
Rambutan peel extract	None Provided	Rambutan peel extract is extracted from the peel of the tropic fruit, rambutan. Peels are washed, dried, and then extracted with various solvents such as water/ethanol or methanol. Hydrochloric acid and sodium hydroxide are also reported to be used during extraction (Zhang *et al.* , 2022). Purification of the crude extract has been conducted with purification resins, High-performance liquid chromatography (HPLC), etc. It seems likely that other methods would be required to produce extract at scale. Only one study is available on rambutan peel extract's potential antioxidant/antiozonant properties in tires (Sukatta *et al.* , 2021), in which the active ingredients responsible for potential antioxidant or antiozonant properties are not confidently identified. It is unclear if the existing volume of discarded rambutan peel would be able to produce enough extract to replace 6PPD in tires. It also seems likely that synthesis of the active ingredients (once these are known) to replace 6PPD in tires would likely involve use of fossil fuel based chemistry.	Not if produced solely from agricultural waste; yes if active ingredients are synthesized.	Ethanol Hydrochloric acid Methanol Possible fossil fuel based precursors Sodium hydroxide

Notes:

CAS No. = Chemical Abstracts Service Number; HPLC = High-Performance Liquid Chromatography; MIBK = Methyl isobutyl Ketone; PPD = Paraphenylene Diamines.

Table 5.1 Chemical-Specific Human Health Hazards (Group A Endpoints)

					Group A Endpoints											
Class of Compound	Chemical	CAS	Score[1]	Reference	Acute Mammalian Toxicity	Carcinogenicity	Eye Irritation/ Corrosion	Skin Irritation/ Corrosion (Dermatotoxicity)	Germ Cell Mutagenicity	Target Organ Toxicity – Single Exposure	Target Organ Toxicity – Repeated Exposure	Reproductive/ Developmental Toxicity	Sensitizer – Respiration[2]	Sensitizer – Skin	Endocrine Disruptor	California Proposition 65
Current Priority Product Candidate Chemical																
Phenylene Diamine related	N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)	793-24-8		ECHA, 2023; ToxServices, 2021a; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 4; Dermal: Not Classified; Inhalation: DG (ECHA, 2023; ToxServices, 2021a)	Not Classified	Not Classified (ECHA, 2023); Cat. 3 (ToxServices, 2021a)	Not Classified	Not Classified	Not Classified (ECHA, 2023); DG (ToxServices, 2021a)	Not Classified (ECHA, 2023); Cat. 2 (ToxServices, 2021a)	Cat. 1B (ECHA, 2023)	DG (ECHA, 2023); Cat. 1B based on skin sensitization and respiratory structural alert (ToxServices, 2021a)	Cat. 1 (ECHA, 2023); Cat. 1A (ToxServices, 2021a)	Not Listed (EU); Moderate based on altered female pubertal development in rats (ToxServices, 2021a)	Not Listed
			125		5	0	5	0	0	0	10	50	5	25	25	0
Potential Alternatives																
Phenylene Diamine	N-(1,4-dimethylpentyl)-N′-phenyl-p-phenylenediamine (7PPD)	3081-01-4		ECHA, 2023; ToxServices, 2021b; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified Dermal: Not Classified; Inhalation: DG (ECHA, 2023; ToxServices, 2021b)	Not Classified	Not Classified (ECHA, 2023); Cat. 3 (ToxServices, 2021b)	Not Classified	Not Classified	Not Classified	Not Classified (ECHA, 2023); Cat. 2 (ToxServices, 2021b)	Cat. 1B (ECHA, 2023; ToxServices, 2021b)	DG (ECHA, 2023); Cat. 1B based on skin sensitization and respiratory structural alert (ToxServices, 2021b)	Cat. 1 (ECHA, 2023); Cat. 1A (ToxServices, 2021b);	Not Listed (EU); Moderate based on altered female pubertal development in rats for surrogate 6PPD CAS 793-24-8 (ToxServices, 2021b)	Not Listed
			120		0	0	5	0	0	0	10	50	5	25	25	0
Phenylene Diamine	N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)	101-72-4		ECHA, 2023; ToxServices, 2021c; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 4; Dermal: Not Classified; Inhalation: DG (ECHA, 2023; ToxServices, 2021c)	DG (ECHA, 2023); Not classified based on surrogate 6PPD (ToxServices, 2021c)	Not Classified (ECHA, 2023); Cat. 2B (ToxServices, 2021c)	Not Classified	Not Classified	Not Classified (ECHA, 2023); DG (ToxServices, 2021c)	Not Classified (ECHA, 2023); Cat. 2 (ToxServices, 2021c)	Not Classified (ECHA, 2023); Cat. 1B based on 6PPD (ToxServices, 2021c)	DG (ECHA, 2023); Cat. 1B based on skin sensitization and respiratory structural alert (ToxServices, 2021c)	Cat. 1 (ECHA, 2023); Cat. 1A (ToxServices, 2021c)	Not Listed (EU); Moderate based on altered female pubertal development in rats for surrogate 6PPD CAS 793-24-8. In silico modeling reported IPPD to be a potential endocrine receptor modulator (ToxServices, 2021c)	Not Listed
			150		5	25	5	0	0	0	10	50	5	25	25	0
Phenylene Diamine	N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1		CalOEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though very little data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Not Classified	Not Classified	Not Classified	Cat. 2	Not Classified	Not Classified	Cat. 2	DG	Cat. 1	Not Listed (EU)	Not Listed
			80		0	0	0	0	25	0	0	25	5	25	0	0
Phenylene Diamine related	N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9		ECHA, 2023; ToxServices, 2021d; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: DG	DG (ECHA, 2023); Not classified based on surrogate 6PPD (ToxServices, 2021d)	Cat. 2	Not Classified	DG (ECHA, 2023); Not classified based on surrogate 6PPD (ToxServices, 2021d)	DG (ECHA, 2023); Cat. 3 (ToxServices, 2021d	DG (ECHA, 2023); Cat. 2 based on surrogate 6PPD (ToxServices, 2021d)	DG (ECHA, 2023); Cat. 1B based on 6PPD (ToxServices, 2021d)	DG	Not classified (ECHA, 2023); Cat. 1A based on surrogate 6PPD (ToxServices, 2021d)	Not Listed (EU); Moderate based on altered female pubertal development in rats for surrogate 6PPD (ToxServices, 2021d)	Not Listed
			175		0	25	5	0	25	5	10	50	5	25	25	0
Dihydroquinoline	Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ Oligomer)	26780-96-1		ECHA, 2023; ToxServices, 2021e; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 4 (based on surrogate ethoxyquin CAS 91-53-2) (ToxServices, 2021e); Not classified (ECHA, 2023); Dermal: Not classified (based on surrogate ethoxyquin CAS 91-53-2), Not classified (ECHA, 2023); Inhalation: Not classified (based on surrogate ethoxyquin CAS 91-53-2); DG (ECHA, 2023)	Cat. 2 (ToxServices, 2021e); Not classified (ECHA, 2023)	Not classified	Not classified	Not classified	Not classified (ECHA, 2023); Cat. 1 based on surrogate ethoxyquin CAS 91-53-2 even though the more similar surrogate TMDHQ, oligomers (26780-96-1) was not a hazard for both oral and dermal (ToxServices, 2021e)	Not classified (ECHA, 2023); Cat. 1 (ToxServices, 2021e)	Not classified (ECHA, 2023); Cat. 2 based on a surrogate TMDHQ, oligomers (26780-96-1) and surrogate ethoxyquin CAS 91-53-2 (ToxServices, 2021e)	DG (ECHA, 2023); Not classified (ToxServices, 2021e)	Not classified based on surrogate TMDHQ, oligomers (26780-96-1) (ToxServices, 2021e); Not classified (ECHA, 2023)	Not Listed (EU); DG (ToxServices, 2021d)	Not Listed
			170		5	75	0	0	0	25	25	25	5	0	10	0
Phenylene Diamine	N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9		ECHA, 2023; ToxServices, 2021f; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 4; Dermal: Not Classified; Inhalation: DG	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified (ECHA, 2023); Cat. 2 (ToxServices, 2021f)	Not Classified (ECHA, 2023); Cat. 2 for Developmental toxicity (ToxServices, 2021f)	DG (ECHA, 2023); Cat. 1B based on skin sensitization and respiratory structural alert (ToxServices, 2021f)	Cat. 1	Not Listed (EU); DG (ToxServices, 2021f)	Not Listed
			80		5	0	0	0	0	0	10	25	5	25	10	0
Diphenyl amine	4,4'-Dioctyldiphenylamine (DOPD)	101-67-7		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	N,N′-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 3; Dermal: Cat 3; Inhalation: Cat 3	DG	Cat. 2	Cat. 1C	Not Classified	DG	Cat. 2	Not Classified	DG	Cat. 1A	Not Listed (EU)	Not Listed
			90		10	25	5	5	0	5	10	0	5	25	0	0
Phenylene diamine	N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Cat. 2	DG	Cat. 1B	Not Listed (EU)	Not Listed
			55		0	0	0	0	0	0	0	25	5	25	0	0
Phenylene Diamine	N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6		ToxServices, 2021g; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 3 (based on surrogate 44PD) Dermal: Cat. 3 (based surrogate 44PD) Inhalation: DG	Not classified based on surrogate 44PD	Cat. 2A based on surrogate 44PD	Cat. 1 based on surrogate 44PD	Not classified	DG	Cat. 1 based on surrogate 44PD	Cat. 2 based on surrogate 44PD	Cat 1B based on surrogate 44PD's dermal sensitization data and respiratory sensitization structural alert (ToxServices, 2021g)	Cat. 1A based on surrogate 44PD	Not Listed (EU); DG (ToxServices, 2021g)	Not Listed
			115		10	0	5	5	0	5	25	25	5	25	10	0

					Group A Endpoints										
Class of Compound	Chemical	CAS	Score[1]	Reference	Acute Mammalian Toxicity	Carcinogenicity	Eye Irritation/ Corrosion	Skin Irritation/ Corrosion (Dermatotoxicity)	Germ Cell Mutagenicity	Target Organ Toxicity – Single Exposure	Target Organ Toxicity – Repeated Exposure	Reproductive/ Developmental Toxicity	Sensitizer – Respiration[2]	Sensitizer – Skin	Endocrine Disruptor	California Proposition 65
Phenylene diamine	Diaryl-p-phenylene diamine (DAPD is a class, main commercial DAPD is DTPD CASRN 68953-84-4)	68953-84-4		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Cat. 2	DG	Cat. 1B	Not Listed (EU)	Not Listed
			55		0	0	0	0	0	0	0	25	5	25	0	0
Phenylene diamine	N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA, CASRN 93-46-9)	93-46-9		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Metal dithiocarbamate	Nickel dibutyldithiocarbamate (NBC)[3]	13927-77-0		ECHA, 2023; ToxServices, 2021h; Cal OEHHA, 2023; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Cat. 2 (ECHA, 2023); Cat. 1 (ToxServices, 2021h)	Cat. 2 (ECHA, 2023); Cat. 2A (ToxServices, 2021h)	Not Classified	Not Classified	Not Classified	DG (ECHA, 2023); Cat. 1 (ToxServices, 2021h)	Not Classified (ECHA, 2023); Cat. 2 Repro (ToxServices, 2021h)	DG (ECHA, 2023); Cat. 1B based on professional judgement even though compound is not a dermal sensitizer and does not trigger structural alerts (ToxServices, 2021h)	Not Classified	Not Listed (EU); DG (ToxServices, 2021h)	Carcinogen as Nickel Compound
			170		0	100	5	0	0	0	25	25	5	0	10	75 (see note 2)
Dihydroquinoline	Ethoxyquin	91-53-2		ECHA, 2023; ToxServices, 2021i; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	**ECHA:** Oral: Cat. 4; Dermal: Not Classified; Inhalation: DG **ToxServices:** Oral: Cat. 4; Dermal: Cat. 4; Inhalation: Cat. 4	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified (ECHA, 2023); Cat. 1 (ToxServices, 2021i)	Not Classified (ECHA, 2023); Cat. 1 (ToxServices, 2021i)	Not Classified (ECHA, 2023); Cat. 2 (ToxServices, 2021i)	DG	Not Classified (ECHA, 2023); Cat. 1B (ToxServices, 2021i)	Not Listed (EU); Moderate based on "antiandrogenic effects exhibited in an in vitro screening study of 200 pesticides, and some positive high throughput in vitro screening assays for estrogen receptor, androgen receptor, steroidogenesis, and thyroid receptor activities" and TEDX listing (ToxServices, 2021)	Not Listed
			135		5	0	0	0	0	25	25	25	5	25	25	0
Sulfur compound	Dilauryl thiodipropionate	123-28-4		ECHA, 2023; ToxServices, 2021j; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: DG	DG (ECHA, 2023); Not classified based on modeling (ToxServices, 2021j)	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	DG (ECHA, 2023); Not classified based on negative skin sensitization data (ToxServices, 2021j)	Not Classified	Not Listed (EU); DG (ToxServices, 2021j)	Not Listed
			40		0	25	0	0	0	0	0	0	5	0	10	0
Phenylene Diamine	N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine	4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene Diamine (Kruger)	RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5		NZ Environmental Risk Management Authority, 2005; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	Irgazone 997: Skin sensitizer Cat. 1	Not Listed (EU) though no data are available for this chemical	Not Listed
			130		5	25	5	5	25	5	5	25	5	25		
Phenylene Diamine	4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Phenylene diamine	Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													

Class of Compound	Chemical	CAS	Score[1]	Reference	Group A Endpoints: Acute Mammalian Toxicity	Carcinogenicity	Eye Irritation/ Corrosion	Skin Irritation/ Corrosion (Dermatotoxicity)	Germ Cell Mutagenicity	Target Organ Toxicity – Single Exposure	Target Organ Toxicity – Repeated Exposure	Reproductive/ Developmental Toxicity	Sensitizer – Respiration[2]	Sensitizer – Skin	Endocrine Disruptor	California Proposition 65
Dihydroquinoline	N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R = N(C2H5)2	No CAS		Cal OEHHA, 2023; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Hindered amine	N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Triazine	2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)	121246-28-4		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	DG	Not Classified	Cat. 1B	Not Listed (EU)	Not Listed
			50		0	0	0	0	0	0	0	25	0	25	0	0
Phenylnaphthyl amines	N-Phenyl-1-naphthylamine	90-30-2		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Cat. 4; Dermal: Not Classified; Inhalation: DG	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Cat. 2	Not Classified	DG	Cat. 1B	Not Listed (EU)	Not Listed
			45		5	0	0	0	0	0	10	0	5	25	0	0
Phenylnaphthyl amines	N-Phenyl-2-naphthylamine	135-88-6		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: DG; Dermal: DG; Inhalation: DG	Cat. 2	Cat. 2	Cat. 2	DG	DG	DG	DG	DG	Cat. 1	Not Listed (EU)	Not Listed
			180		5	75	5	5	25	5	5	25	5	25	0	0
Ether + Phenol	[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)[4]	110553-27-0		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: DG	DG	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	DG	Not Classified	Not Listed (EU)	Not Listed
			30		0	25	0	0	0	0	0	0	5	0	0	0
Inorganic	Graphene	1034343-98-0		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: DG; Inhalation: Not Classified	DG	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	DG	DG	Not Classified	Not Listed (EU)	Not Listed
			55		0	25	0	0	0	0	0	25	5	0	0	0
Hydrazine	1,1' -Pentamethylenebis(2,2-Di-n-Butylhydrazine)	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Nitrone + Phenolic AO	α- C-4- hydroxy- 3,5- dimethylphenyl - N-isopropyl and Lowinox WSP	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3		ECHA, 2023; Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	Oral: Not Classified; Dermal: Not Classified; Inhalation: Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	Not Classified	DG	Not Classified	Not Listed (EU)	Not Listed
			5		0	0	0	0	0	0	0	0	5	0	0	0
Phenothiazine	N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Amine	7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													

					Group A Endpoints											
Class of Compound	**Chemical**	**CAS**	**Score**[1]	**Reference**	**Acute Mammalian Toxicity**	**Carcinogenicity**	**Eye Irritation/ Corrosion**	**Skin Irritation/ Corrosion (Dermatotoxicity)**	**Germ Cell Mutagenicity**	**Target Organ Toxicity – Single Exposure**	**Target Organ Toxicity – Repeated Exposure**	**Reproductive/ Developmental Toxicity**	**Sensitizer – Respiration**[2]	**Sensitizer – Skin**	**Endocrine Disruptor**	**California Proposition 65**
Amine	2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Amine	4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	None provided		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Nitrone	α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Polymeric amine functionalized lignin	Amine functionalized lignin	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													
Gallate related	Rambutan peel extract	No CAS		Cal OEHHA, 2024; Danish EPA, 2023; Commission of the European Communities, 2001	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	Not Listed (EU) though no data are available for this chemical	Not Listed
			Not assigned based on complete data gap													

Notes:
CAS = Chemical Abstracts Service Number; Cat. = Category; CLP = Classification, Labelling, and Packaging Regulation; DG = Data Gap; ECHA = European Chemicals Agency; EU = European Union; GHS = Globally Harmonized System of Classification and Labelling of Chemicals.

(1) This is assuming that the concentration of the chemical in the tire is <10%.
(2) ToxServices Greenscreen® assessments classified 6PPD and several potential alternatives as respiratory sensitizers based on dermal sensitization hazard, structural alert, and/or professional judgement. Gradient listed ToxService's hazard assignments, but did not score the endpoint based on respirator sensitization assignment. Instead, a data gap score was assigned. See report Section 5.1.2 for more details.
(3) NBC CAS 13927-77-0 is classified Cat. 1 for carcinogenicity under ToxServices GS, 2021 and Cat. 2 under ECHA dossier. It is also on California Prop 65 as a carcinogen. The highest score was counted (*i.e.* , Cat. 1) and counted only once.

(4) A potential alternative is Irganox 1520 CAS 110553-27-0 blended with Vulcazon AFS. However, according to the source patent (Pirelli Tyre S.P.A, 2018), the best ratio is where 100% of blend is Irganox 1520. Additionally, no data were located for Vulcazon AFS. Thus, data and scoring is 100% based on Irganox 1520 CAS 110553-27-0.

Legend for Group A Hazards:

Cat. 1	Category 1 is most hazardous classification for all endpoints. For a minority of endpoints (*i.e.* , acute mammalian and chronic aquatic toxicity), Category 4 is the least hazardous. For the rest of the endpoints, excluding physical endpoints, Category 2 is the least hazardous. "Not Classified" indicates no hazard according to endpoint-specific GHS criteria. Specific color-coding varies by health endpoint according to GreenScreen Chemical Hazard Criteria Section V - Annex 1 (Clean Production Action, 2018). Texts are underlined when information from difference sources result in different classifications. When there are different classifications for an endpoint, color and scoring are based on more conservative classifications.
Cat. 2	
Cat. 3	
Cat. 4	
Not Classified/Not Listed	
DG	

Table 5.2 Chemical-Specific Human Health Hazards (Group B Endpoints)[1]

Chemical	CAS	Reference	Group B Endpoints										
			Respiratory Toxicity	Cardiovascular Toxicity	Epigenetic Toxicity	Hematotoxicity	Reactive in Biological Systems	Hepatotoxicity and Digestive System Toxicity	Immunotoxicity	Musculoskeletal Toxicity	Nephrotoxicity	Neurotoxicity	Ototoxicity
Current Priority Product Candidate Chemical													
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)	793-24-8	ECHA, 2023; ToxServices, 2021a, DTSC, 2022	May be a respiratory toxicant in Coho salmon (DTSC, 2022).	May be a vascular toxicant in Coho salmon (DTSC, 2022).	Not genotoxic; no other relevant data found	May induce anemia in rats at high doses, but dossier did not classify (ECHA, 2023).	DTSC lists 6PPDQ as reactive in biological systems in the Priority Product Profile	Increase in liver weight with fatty changes and vacuolar liver degeneration in rats, but dossier did not classify (ECHA, 2022).	Dermal sensitizer	DG	No relevant adverse effects observed	No relevant adverse effects observed in a 2 year oral study in rats (ECHA, 2023)	DG
Possible Alternatives													
N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD)	3081-01-4	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	DG	Unclear	Increase in liver weight in rats, however to not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer based on similar chemicals and structural alerts.	DG	DG	DG	DG
N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD)	101-72-4	ECHA, 2023	Respiratory irritation were seen in subchronic animal studies, but dossier did not classify.	DG	Not genotoxic; no other relevant data found	Treatment related changes in several hematology parameters found in rats, but dossier did not classify.	Unclear	Increase in liver weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer	Incomplete skeletal ossification in rat offsprings, however, maternal toxicity was observed at the same dose, but dossier did not classify.	Increased kidney weight, however not considered adverse in the absence of other effects. Dossier also did not classify.	DG	DG
N-cyclohexyl-N'-phenyl-p-phenylenediamine (CPPD)	101-87-1	-	DG	DG	DG	DG	Unclear	DG	DG	DG	DG	DG	DG
N,N'-diphenyl-p-phenylenediamine (DPPD)	74-31-7	ECHA, 2023	DG	DG	Mutagenic in *in vitro* assays, no *in vivo* data	Treatment related changes in several hematology parameters in rats, but dossier did not classify.	Unclear	Decrease in liver weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer	DG	Increase kidney weight and incidence of calcification, but dossier did not classify.	DG	DG
N-1,3-dimethyl butyl-N'-phenyl quinone diimine (6QDI)	52870-46-9	-	DG for all endpoints.										
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found.	DG	DG	Depressed liver function, fatty liver, enlarged liver, gross nodules in the liver in rats but dossier did not classify.	Not a dermal sensitizer. No other relevant data found.	In rat offsprings, statistically significant increase in skeletal abnormalities found in the presence of maternal toxicity. Dossier also did not classify.	DG	DG	DG
N,N'-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	No relevant adverse effects observed	Unclear	Increase in liver weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer	No treatment-related skeletal abnormalities found in rabbits or rats.	No relevant adverse effects observed	DG	DG
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	-	DG for all endpoints.										
N,N'-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	Potential anemia found in rats, but study authors reported the data to be equivocal.	Unclear	Slight decrease in liver weight in male rats, however, hepato-chemistry showed no impaired liver function.	Dermal sensitizer	No relevant adverse effects observed	No relevant adverse effects observed	DG	DG
N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	Macrocytic anemia found in rats, but effects were reversible. Dossier did not classify.	Unclear	Increase in liver weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer	DG	Increase in kidney weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	DG	DG
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	-	DG	DG	DG	DG	Unclear	DG	DG	DG	DG	DG	DG
Diaryl-p-phenylene diamine (DAPD)	68953-84-4	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	Macrocytic anemia found in rats, but effects were reversible. Dossier did not classify.	Unclear	Increase in liver weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	Dermal sensitizer	DG	Increase in kidney weight in rats, however not considered adverse in the absence of other effects. Dossier also did not classify.	DG	DG
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	-	DG for all endpoints.										
Nickel dibutyldithiocarbamate (NBC)	13927-77-0	ECHA, 2023; ToxServices, 2021h	DG	Dose-dependent degeneration of the heart muscles in rats with presence of fibrotic areas. Dossier did not classify.	Not genotoxic; no other relevant data found	Treatment related changes in several hematology parameters in rats. Dossier did not classify.	DG	Decreased liver weights, dose-dependent hyperemia in the liver. Dossier did not classify.	Histiocytosis in the parathymic lymph nodes in rats. Not a dermal sensitizer.	Degeneration of skeletal muscle in rats accompanied by necrosis and mononuclear inflammation in high-dose males. Dossier did not classify.	No relevant adverse effects observed	DG	DG
Ethoxyquin	91-53-2	ECHA, 2023; ToxServices, 2021i	DG	DG	Not genotoxic; no other relevant data found	Treatment related changes in several hematology parameters in rats, but dossier did not classify.	DG	Adverse liver effects observed in rats and dogs, including hepatocellular necrosis, cytoplasmic vacuolation, and bile-duct hyperplasia. Dossier did not classify.	Weak dermal sensitizer in one animal study, but dossier did not classify.	DG	Dose-dependent nephropathy, regeneration of the tubular epithelium, renal tubular dilatation, and papillary necrosis in rats. Dossier did not classify.	Study authors of an acute inhalation study suggested potential neurotoxic effects based on tremors observed. Dossier did not classify.	DG
Dilauryl thiodipropionate	123-28-4	ECHA, 2023	DG	Inflammation of cardiac tissues at high dose, but ECHA dossier did not classify	Not genotoxic; no other relevant data found	No treatment-related adverse effects compared to historical control	DG	No relevant adverse effects observed	DG	No relevant adverse effects observed	DG	DG	DG
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	-	DG for all endpoints.										
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	-	DG for all endpoints.										
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	-	DG for all endpoints.										
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	-	DG for all endpoints.										

Chemical	CAS	Reference	Group B Endpoints										
			Respiratory Toxicity	Cardiovascular Toxicity	Epigenetic Toxicity	Hematotoxicity	Reactive in Biological Systems	Hepatotoxicity and Digestive System Toxicity	Immunotoxicity	Musculoskeletal Toxicity	Nephrotoxicity	Neurotoxicity	Ototoxicity
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS	-	DG for all endpoints.										
RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5	-	DG for all endpoints.										
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	-	DG for all endpoints.										
Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	-	DG for all endpoints.										
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	-	DG for all endpoints.										
N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	-	DG for all endpoints.										
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)	121246-28-4	-	DG for all endpoints.										
N-Phenyl-1-naphthylamine	90-30-2	ECHA, 2023	No reliable studies are located	DG	Not genotoxic; no other relevant data found	Hemolytic anemia found in rats. Dossier classified category 2.	DG	No reliable studies are located	Dermal sensitizer	No relevant adverse effects observed	Degeneration/regeneration of the proximal tubules in male rats and centrilobular hypertrophy in female rats, but dossier did not classify	No relevant adverse effects observed	DG
N-Phenyl-2-naphthylamine	135-88-6	ECHA, 2023	DG	DG	DG	DG	DG	DG	Dermal sensitizer	DG	DG	DG	DG
[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)[2]	110553-27-0	ECHA, 2023	DG	DG	Not genotoxic; no other relevant data found	No relevant adverse effects observed	DG	No relevant adverse effects observed	Not a dermal sensitizer. No other relevant data found.	No relevant adverse effects observed	DG	DG	DG
Graphene	1034343-98-0	ECHA, 2023	No relevant adverse effects observed	DG	Not genotoxic; no other relevant data found	DG	DG	DG	Not a dermal sensitizer. No other relevant data found.	DG	DG	DG	DG
1,1' -Pentamethylenebis(2,2-Di-n-Butylhydrazine)	No CAS	-	DG for all endpoints.										
α- C-4- hydroxy- 3,5- dimethylphenyl - N-isopropyl and Lowinox WSP	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	ECHA, 2023	DG	No relevant adverse effects observed	Not genotoxic; no other relevant data found	No relevant adverse effects observed	DG	No relevant adverse effects observed	Not a dermal sensitizer. No other relevant data found.	DG	DG	No relevant adverse effects observed	DG
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	-	DG for all endpoints.										
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	-	DG for all endpoints.										
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	-	DG for all endpoints.										
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	-	DG for all endpoints.										
α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	No CAS	-	DG for all endpoints.										
Amine functionalized lignin	No CAS	-	DG for all endpoints.										
Rambutan peel extract	No CAS	-	DG for all endpoints.										

Notes:
CAS = Chemical Abstracts Service Number; DG = Data Gap.
(1) This table presents the hazards of the individual product ingredients, which may not reflect the hazards of the actual final tire product when fully cured.
(2) A potential alternative is Irganox 1520 CAS 110553-27-0 blended with Vulcazon AFS. However, according to the source patent (Pirelli Tyre S.P.A, 2018), the best ratio is where 100% of blend is Irganox 1520. Additionally, no data were located for Vulcazon AFS. Thus, data and scoring is 100% based on Irganox 1520 CAS 110553-27-0.

Legend for Group B Hazards:

Potential Concern
No Relevant Adverse Effects Observed
DG

Table 5.3 Chemical-Specific Environmental and Physical Hazards

					Environmental					Physical			
Chemical	**CAS**	**Environmental Score[1]**	**Physical Score[1]**	**Reference**	**Aquatic Toxicity – Acute**	**Aquatic Toxicity – Chronic**	**Persistent**	**Bioaccumulation**	**Terrestrial Ecotoxicity (from Pharos Only)**	**Global Warming Potential**	**Ozone Depleting Potential**	**CAA VOC Contributing to Smog Formation**	**Flammability**
Current Priority Product Candidate Chemical													
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)	793-24-8			ECHA, 2023; ToxServices GreenScreen, 2021a; PubChem, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	**ECHA (2023):** Not readily biodegradable in water (2% in 28 days), however half-life in freshwater is 2.9 hours. Strong absorption to soil; **ToxServices (2021a):** Persistent, modeled half-life in soil is 1,800 hours (75 days)	**ECHA (2023):** BCF of 569 (QSAR) which would be considered not bioaccumulative under California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5. 6PPD hydrolyzes in water with half-life of 8 hours. Hydrolysis products 4-hydroxydiphenylamine (experimental BCF 3.3-40 in Cyprinus carpio), n-phenyl-p-benzoquinone monoimine (experimental BCF in Cyprinus carpio is <1.2-23), and 1,3-dimethylbutylamine (experimental BCF in Cyprinus carpio is <1.7-17) are all not bioaccumulative (ECHA, 2023); **ToxServices (2021a):** Bioaccumulative based on measured BCFs of 1,500-1,700 for the surrogate N-(1-methylheptyl)-N'-phenylbenzene-1,4-diamine (CAS 15233-47-3).	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
Possible Alternatives													
N-(1,4-dimethylpentyl)-N′-phenyl-p-phenylenediamine (7PPD)	3081-01-4			ECHA, 2023; ToxServices GreenScreen, 2021b; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	**ECHA (2023):** Not readily biodegradable in water (0% degraded in 35 days). Half-life in aerobic soil is <45.6 hours (1.9 days). Strong absorption to soil. **ToxServices (2021b):** Persistent, modeled half-life in soil is 75 days	**ECHA (2023):** BCF of 1197 L/Kg (QSAR) which would be considered bioaccumulative under California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5. However, 7PPD hydrolyzes in water (pH 7, 20C) with half-life of 7 hours. Hydrolysis products of 7PPD, 4-anilinophenol (4-hydroxydiphenylamine) (experimental BCF 3.3-49) and its oxidized form N-Phenylphenyl-p-benzoquinone monoimine (BCF <1.2 - 23), are not bioaccumulative. **ToxServices (2021b):** Bioaccumulative based on measured BCFs of 1,500-1,700 for the surrogate N-(1-methylheptyl)-N'-phenylbenzene-1,4-diamine (CAS 15233-47-3).	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)	101-72-4			ECHA, 2023; ToxServices GreenScreen, 2021c; PubChem, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	**ECHA (2023):** Not readily biodegradable in water (18.9% degraded in 32 days). Half-life in Mississippi river water is 2.5 hours. Moderate absorption to soil. **ToxServices (2021c):** Persistent, modeled half-life in soil is 75 days.	**ECHA (2023):** BCF of 31.2 (QSAR) which is considered not bioaccumulative under California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5. IPPD hydrolyzes in water with half-life of 2.5 hours. Hydrolysis products of IPPD, 4-hydroxydiphenylamine (experimental BCF 3.3-49) and p-quinoneimine-N-phenyl (BCF <1.2 - 23), are not bioaccumulative. **ToxServices (2021c):** Very low bioaccumulation based on measured log kow (2.77).	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		100	0		25	25	50	0	0	0	0	0	0
N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1			US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		Not assigned	0							0	0	0	0
N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7			ECHA, 2023; PubChem, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	Not readily biodegradable in water (0.2% degraded in 14 days). A dissipation half-life (DT50) of 187.46 years (QSAR).	BCF of 260-2,150 derived in Cyprinus carpio from an experimental OECD 305C study. Given the bioconcentration threshold (BCF/BAF = 1000) under California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5, DPPD's BCFs straddles both bioaccumulative and not bioaccumulative. DPPD is conservatively classified as bioaccumulative.	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9			ECHA, 2023; ToxServices GreenScreen, 2021d; US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013; ECHA Harmonized CLP, 2023	Cat. 1	Cat. 1	DG (ECHA, 2023); Persistent based on estimated half-life of 337.5 days in sediment, its predicted dominant environmental compartment (ToxServices, 2021d)	DG (ECHA, 2023); Bioaccumulative based on measured BCFs of 1,500-1,700 for the surrogate N-(1-methylheptyl)-N'-phenylbenzene-1,4-diamine (CAS 15233-47-3).	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ Oligomer)	147-47-7			ECHA, 2023; ToxServices GreenScreen, 2021e; US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013	Cat. 2 based on surrogate Ethoxyquin CAS 91-53-2 (ToxServices, 2021e); No data (ECHA, 2023)	Cat. 2 based on modeled data (ToxServices, 2021e); Cat. 3 (ECHA, 2023)	Persistent based on modeled half-life in soil is 75 days (ToxServices, 2021e); No biodegradation of TMQ was observed in 28 days in an EU Method C.4-E test (ECHA, 2023).	Very low bioaccumulative potential based on measured log kow of 2.93 (ToxServices, 2021e); Not bioaccumulative based on BCF between 108 and 1300 in Cyprinus carpio based on OECD 305C test (ECHA, 2023).	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		70	0		10	10	50	0	0	0	0	0	0
N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9			ECHA, 2023; ToxServices GreenScreen, 2021f; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	**ECHA (2023):** Not readily biodegradable in water (12% in 28 days). **ToxServices (2021f):** Persistent based on a degradation of 12% in 28 days in an OECD 301C study and 50% in 35 days in an OECD 301B study. Half-life in soil is 75 days, which is the dominant medium according to modeling.	**ECHA (2023):** Not bioaccumulative. 77PD's half-life in water is 3.6 hours. The BCFs for the primary hydrolysis products of 77PD are all below California Code of Regulations title 22, Division 4.5, Chapter 54, Article 5, bioconcentration threshold of BCF/BAF = 1000. **ToxServices (2021f):** Bioaccumulative under GHS based on a modeled BAF of 614.6. However, this BAF is not considered bioaccumulative under California Code of Regulations title 22, Division 4.5, Chapter 54, Article 5.	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		100	0		25	25	50	0	0	0	0	0	0

Chemical	CAS	Environmental Score[1]	Physical Score[1]	Reference	Environmental					Physical			
					Aquatic Toxicity – Acute	Aquatic Toxicity – Chronic	Persistent	Bioaccumulation	Terrestrial Ecotoxicity (from Pharos Only)	Global Warming Potential	Ozone Depleting Potential	CAA VOC Contributing to Smog Formation	Flammability
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7			US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		Not assigned based on complete data	0							0	0	0	0
N,N′-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2			ECHA, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	Not readily biodegradable based on a degradation of 12% at day 28 in an OECD 301C study and 50% at day 35 in an OECD 301B study for the surrogate 77PD (CASRN 3081-14-9)	**ECHA (2023):** Not bioaccumulative based on two derived BCFs: 95.15 L/kg (QSAR) and 125.9 L/kg ww	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		100	0		25	25	50	0	0	0	0	0	0
N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4			ECHA, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	Persistent based on negligible biodegradation in multiple studies.	Bioaccumulative based on measured BCF of 2107 in rainbow trout.	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6			ToxServices, 2021g; US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013	Cat. 1 based on surrogate 44PD	Cat. 1 based on surrogate 44PD	Persistent based on modeled half-life of 75 days in soil, which is the primary partitioning compartment.	Bioaccumulative based on modeled BAF of 1059.	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
Diaryl-p-phenylene diamine (DAPD is a class, main commercial DAPD is DTPD CASRN 68953-84-4)	68953-84-4			ECHA, 2023; US EPA, 2018; IPCC, 2013	Cat. 1	Cat. 1	Persistent based on negligible biodegradation in multiple studies.	Bioaccumulative based on measured BCF of 2107 in rainbow trout.	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		150	0		25	25	50	50	0	0	0	0	0
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9			US EPA Comptox, 2023; US EPA, 2018; IPCC, 2013	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		Not assigned based on complete data gap	0							0	0	0	0
Nickel dibutyldithiocarbamate (NBC)	13927-77-0			ECHA, 2023; ToxServices GreenScreen, 2021h; US EPA, 2018; IPCC, 2013	Not Classified	**ECHA (2023):** Chronic 4 **ToxServices (2021h)**: Not classified	Persistent based on a degradation of 0% at day 28 in an OECD 301B test.	**ECHA (2023):** Not bioaccumulative based on a modeled BCF of 75.96 L/kg **ToxServices (2021h):** Not bioaccumulative. BCFs are between 100 and 500	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		50	0		0	0	50	0	0	0	0	0	0
Ethoxyquin	91-53-2			ECHA, 2023; ToxServices GreenScreen, 2021i; US EPA, 2018; IPCC, 2013	**ECHA (2023):** Not classified **ToxServices (2021i):** Cat. 2	Cat. 2	**ECHA (2023):** Not readily biodegradable (QSAR) **ToxServices (2021i)**: Not readily biodegradable and partitioning to the soil with a half-life of 75 days.	**ECHA (2023):** Not bioaccumulative based on a modeled BCF of 455.8 L/kg **ToxServices (2021i):** Very low for bioaccumulation based on a measured log Kow value of 3.39 at pH 7 and an estimated BCF value of 129.3	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		70	0		10	10	50	0	0	0	0	0	0
Dilauryl thiodipropionate	123-28-4			ECHA, 2023; ToxServices GreenScreen, 2021j; US EPA, 2018; IPCC, 2013	Not Classified	Not Classified	Readily biodegradable based on 82% degraded in 28 days in an OECD 301C study.	Not bioaccumulative based on a modeled BCF of 7.43 (**ECHA, 2023**) and modeled BAG of 1.078 **(ToxServices, 2021j)**	DG	No	No	Not a VOC (low vapor pressure)	Not Classified
		0	0		0	0	0	0	0	0	0	0	0
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS			US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS			US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS			US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine or similar chemical 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	No CAS			US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine-R1 and R2 are methyl	No CAS			US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	

Chemical	CAS	Environmental Score[1]	Physical Score[1]	Reference	Environmental: Aquatic Toxicity – Acute	Environmental: Aquatic Toxicity – Chronic	Environmental: Persistent	Environmental: Bioaccumulation	Environmental: Terrestrial Ecotoxicity (from Pharos Only)	Physical: Global Warming Potential	Physical: Ozone Depleting Potential	Physical: CAA VOC Contributing to Smog Formation	Physical: Flammability
RU997 Irgazone 997 Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether.	444992-04-5	65	0	NZ Environmental Risk Management Authority, 2005; US EPA Comptox, 2023	Irgazone 997: Cat. 3 5	DG 10	DG 25	DG 25	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	DG
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	0	0	US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	DG
This is a class of compounds - Reference uses case where R1 and R2 are methyl; n,p and q are zero and m=1 and is in the para position . Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	0	0	US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	DG
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	0	0	US EPA EPISuite, 2019	DG	DG	DG	DG	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	DG
Mixed xylene diamines N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine- 25790-41-4	25790-41-4	0	0	US EPA CompTox, 2023 US EPA EPISuite, 2019	DG	DG	DG	DG	DG 0	No 0	No 0	Not a VOC (low vapor pressure) 0	**CompTox**: Flashpoint: 94.3°C 0
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine, TAPDT	121246-28-4	100	0	ECHA (2023)	Cat. 1 25	Cat. 1 25	**ECHA (2023):** Not readily biodegradable based on 18% degradation in water at 28 days (OECD TG 301B) 50	**ECHA (2023):** Not bioaccumulative based on a modeled BCF average of 16 L/Kg (QSAR) 0	DG 0	No 0	No 0	Not a VOC (low vapor pressure) 0	**ECHA (2023)**: Not Classified 0
N-Phenyl-1-naphthylamine	90-30-2	150	0	ECHA (2023)	Cat. 1 25	Cat. 1 25	**ECHA (2023):** Not readily biodegradable based on 0% degradation water at 28 days in an OECD TG 301C study (Kanne 1980 as cited in ECHA, 2023). Similar results were reported 1t 14 days in an OECD TG 301C study (MITI Database, 2002 as cited in ECHA, 2023). Inherent biodegradation observed in a CO2 evolution study following a US EPA recommendation, 50% degradation was reported within 5 days in sewage effluent and >75% and 100% degradation within 2 and 10 days, respectively in supplemented sewage sludge (Sikka *et al.,* 1981, as cited in ECHA, 2023). For lake water, 50% degradation after 5 days and > 90% degradation after 18 days were observed. 50	**ECHA (2023):** BCF values ranging from 427 to 2490; Bioaccumulative based on the upper end BCF range for fish (OECD TG 305C). 50	DG 0	No 0	No 0	Not a VOC (low vapor pressure) 0	Not Classified 0
N-Phenyl-2-naphthylamine	135-88-6	20	0	ECHA (2023)	DG 10	Cat. 2 10	DG 0	Not bioaccumulative based Log Pow of 23C 0	DG 0	No 0	No 0	Not a VOC (low vapor pressure) 0	Not Classified 0
[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)[2]	110553-27-0	10	0	ECHA (2023)	Not Classified 0	Not Classified 0	ECHA (2023): Not readily biodegradable based on 4% degradation in water at 28 days (OECD TG 301B). ECHA (2023): Moderately biodegradable based on the DT50 = 0.33 - 0.43 days in water/sediment (OECD TG 308). 10	**ECHA (2023):** Not bioaccumulative based on a measured BCF of 36 L/Kg in fish (OECD TG 305) 0	DG 0	No 0	No 0	Not a VOC (low vapor pressure) 0	Not Classified 0
Graphene	1034343-98-0	85	0	ECHA (2023)	Cat. 3 5	Cat. 3 5	Inorganic; In a ready biodegradability test (OECD 301D), graphene degraded 0% by % ThCOD in 28 days. 50	Inorganic, no BCF or Log kow data 25	DG 0	No 0	No 0	DG 0	Not Classified 0
1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	0	0		DG	DG	DG	DG 0	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	DG
α- C-4- hydroxy- 3,5-dimethylphenyl - N-isopropyl and Lowinox WSP CAS 77-62-3	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	0	0		Not Classified 0	**ECHA (2023)**: Cat. 4 0	DG	DG	DG	No 0	No 0	Not a VOC (low vapor pressure) 0	Not Classified 0

Chemical	CAS	Environmental Score[1]	Physical Score[1]	Reference	Environmental: Aquatic Toxicity – Acute	Environmental: Aquatic Toxicity – Chronic	Environmental: Persistent	Environmental: Bioaccumulation	Environmental: Terrestrial Ecotoxicity (from Pharos Only)	Physical: Global Warming Potential	Physical: Ozone Depleting Potential	Physical: CAA VOC Contributing to Smog Formation	Physical: Flammability
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS				DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS				DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS				DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS				DG	DG	DG	DG	DG	No	No	Not a VOC (low vapor pressure)	DG
		0	0							0	0	0	
α- C-4- Hydroxy- 3,5-dimethylphenyl-N-tert. butyl nitrone	No CAS				DG	DG	DG	DG	DG	No	No	?	?
		0	0							0	0	0	
Amine functionalized lignin	No CAS				DG	DG	DG	DG	DG	No	No	?	?
		0	0							0	0	0	
Rambutan peel extract	No CAS				DG	DG	DG	DG	DG	No	No	DG	DG
		0	0							0	0	0	

Notes:

BCF = Bioconcentration Factor; CAA = Clean Air Act; CAS = Chemical Abstracts Service Number; DG = Data Gap; ECHA = European Chemicals Agency; GHS = Globally Harmonized System of Classification and Labelling of Chemicals; GWP = Global Warming Potential; K_{ow} = Octanol-Water Partition Coefficient; OECD = The Organisation for Economic Co-operation and Development; ODP = Oxygen-Depleting Potential; TG = Test Guideline; TSCA = Toxic Substances Control Act; US EPA = United States Environmental Protection Agency; VOC = Volatile Organic Compound.

Ingredients are considered bioaccumulative if BCF is >1,000 according to California Code of Regulations, according to title 22, Division 4.5, Chapter 54, Article 5 (Cal OEHHA, 2012). US EPA's list of ozone-depleting substances (US EPA, 2018) was used to evaluate ODP. Pharos (Healthy Building Network, 2023) was used to inform terrestrial toxicity. GWP was evaluated using Table 8.a.1 of the IPCC 5th Technical Report (IPCC, 2013). VOCs were considered chemicals with vapor pressures equal to or greater than 0.1 mm mercury (Hg) at 20C based on criteria in CARB (2009). Additionally, we noted whether the chemical is listed as a substance exempted under 40 CFR § 51.100 (CARB, 2009).

(1) This is assuming that the concentration of the chemical in the tire is <10%.

(2) A potential alternative is Irganox 1520 CAS 110553-27-0 blended with Vulcazon AFS. However, according to the source patent (Pirelli Tyre S.P.A, 2018), the best ratio is where 100% of blend is Irganox 1520. Additionally, no data were located for Vulcazon AFS. Thus, data and scoring is 100% based on Irganox 1520 CAS 110553-27-0.

Legend:

Categories assigned according to ECHA dossiers (ECHA, 2023) and Pharos (Healthy Building Network, 2023). Specific color coding varies by endpoint according to GreenScreen Chemical Hazard Criteria Section V - Annex 1 (Clean Production Action, 2018). Texts are underlined when information from difference sources result in different classifications. When there are different classifications for an endpoint, color and scoring are based on more conservative classifications.

Category 1	Category 1 is most hazardous classification for all endpoints. For a minority of endpoints (*i.e.*, chronic aquatic toxicity), Category 4 is the least hazardous. For the rest of the endpoints, excluding physical endpoints, Category 2 is the least hazardous. Not classified indicated no hazard according to endpoint-specific GHS criteria.
Category 2	
Category 3	
Category 4	
Category 5	

Table 5.4 Acute Toxicity Data in Salmonids Reported in Existing Scientific Literature

Chemical Name	CAS No.	Species	Parent Compound: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Parent Compound: Duration of Exposure	Quinone: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Quinone: Duration of Exposure	Citations
			µg/L	hr	µg/L	hr	
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)	793-24-8	Coho salmon (Oncorhynchus kisutch), juvenile	250 (flow-through, measured)	24	0.041 (static, measured)	24	Tian *et al.,* 2021; Lo *et al.* , 2023
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	>3.5 (static, measured)	96	Hiki and Yamamoto, 2022
		Rainbow trout (Oncorhynchus mykiss), juvenile	140 (static, nominal)	96	0.64 (static, measured)	96	Monsanto Co., 1977, as cited in EcoTox, 2023; Nair *et al.,* 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	>50 (flow-through, measured)	24	Greer *et al.* , 2023
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	67 (flow and measurement not specified)	N/R	Lo *et al.* , 2023
		Atlantic salmon (Salmo salar)	N/A	N/A	>12.16 (static, measured)	48	Foldvik *et al.,* 2022
		Brown Trout (Salmo trutta)	N/A	N/A	>12.16 (static, measured)	48	Foldvik *et al.,* 2022
		Arctic char (Salvelinus alpinus)	N/A	N/A	>14.2 (static, measured)	96	Brinkmann *et al.,* 2022
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	>3.8 (static, measured)	96	Hiki and Yamamoto, 2022
		Brook trout (Salvelinus fontinalis)	N/A	N/A	0.59 (static, measured)	24	Brinkmann *et al.,* 2022
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	0.51 (static, measured)	24	Hiki and Yamamoto, 2022
N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD)	3081-01-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)	101-72-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	>50 (static, measured)	96	Nair *et al.* , 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	>50 (static, measured)	96	Nair *et al.* , 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	>50 (static, measured)	96	Nair *et al* ., 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N-1,3-dimethyl butyl-N'-phenyl quinone diimine (6QDI)	52870-46-9	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	638 (semi-static, measurement not specified)	96	N/A	N/A	Flexsys, 2007, as cited in ECHA, 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N'-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	Coho salmon (Oncorhynchus kisutch), juvenile	24 (flow-through, measured)	96	>226 (flow-through, measured)	96	Chapelet *et al.,* 2023
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N’-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	130 (static, nominal)	96	N/A	N/A	Unnamed study, 1983, as cited in ECHA, 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	480 (flow-through, measured)	96	>50 (static, measured)	96	Unnamed study, 1997, as cited in ECHA, 2023; Nair *et al.* , 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	130 (based on surrogate 44PD) (static, nominal)	96	N/A	N/A	ToxServices, 2021
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Diaryl-p-phenylene diamine (DAPD is a class, main commercial DAPD is DTPD CASRN 68953-84-4)	68953-84-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	>480 (flow-through, measured)	96	N/A	N/A	Dionne, 1995, as cited in ECHA, 2023 (Weight of evidence 001)
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
Nickel dibutyldithiocarbamate (NBC)	13927-77-0	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	>100,000 (static, measurement not specified)	96	N/A	N/A	Mayer and Ellersieck, 1986
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Ethoxyquin	91-53-2	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	18,000 (flow-through, measured)	96	N/A	N/A	Unnamed Study, 2007, as cited in ECHA, 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Dilauryl thiodipropionate	123-28-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Parent Compound: Duration of Exposure	Quinone: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Quinone: Duration of Exposure	Citations
			µg/L	hr	µg/L	hr	
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol	6358-22-1	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)	121246-28-4	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N-Phenyl-1-naphthylamine	90-30-2	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	440 (semi-static, nominal)	96	N/A	N/A	Unnamed Study, 1981, as cited in ECHA, 2023
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
N-Phenyl-2-naphthylamine	135-88-6	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)	110553-27-0	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Graphene	1034343-98-0	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound		Quinone		Citations
			Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Duration of Exposure	
			µg/L	hr	µg/L	hr	
1,1' - Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
α- C-4- hydroxy- 3,5-dimethylphenyl - N-isopropyl and Lowinox WSP	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Parent Compound: Duration of Exposure	Quinone: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Quinone: Duration of Exposure	Citations
			µg/L	hr	µg/L	hr	
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Chemical Name	CAS No.	Species	Parent Compound: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Parent Compound: Duration of Exposure	Quinone: Acute LC_{50} (lowest reported) (flow conditions, exposure measurement)	Quinone: Duration of Exposure	Citations
			µg/L	hr	µg/L	hr	
α- C-4- Hydroxy- 3,5- dimethylphenyl- N-tert. butyl nitrone	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Amine functionalized lignin	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	
Rambutan peel extract	No CAS	Coho salmon (Oncorhynchus kisutch), juvenile	N/A	N/A	N/A	N/A	
		Landlocked masu salmon (Oncorhynchus masou masou), juvenile	N/A	N/A	N/A	N/A	
		Rainbow trout (Oncorhynchus mykiss)	N/A	N/A	N/A	N/A	
		Sockeye salmon (Oncorhynchus nerka)	N/A	N/A	N/A	N/A	
		Chinook salmon (Oncorhynchus tshawytscha)	N/A	N/A	N/A	N/A	
		Atlantic salmon (Salmo salar)	N/A	N/A	N/A	N/A	
		Brown Trout (Salmo trutta)	N/A	N/A	N/A	N/A	
		Arctic char (Salvelinus alpinus)	N/A	N/A	N/A	N/A	
		Southern Asian dolly varden (Salvelinus curilus)	N/A	N/A	N/A	N/A	
		Brook trout (Salvelinus fontinalis)	N/A	N/A	N/A	N/A	
		White-spotted char (Salvelinus leucomaenis pluvius)	N/A	N/A	N/A	N/A	

Notes:

a.i. = Active Ingredient; CAS No. = Chemical Abstracts Service Number; hr = Hour; N/A = Not Available; N/R = Not Reported.

Table 5.5 Scoring Matrix – Human Health Endpoints[1]

Hazard Endpoint	Classification	Concentration in Product			
		<10%	10-29%	30-59%	60-100%
Carcinogenicity	Category 1	100	100	100	100
	Category 2/Prop 65	75	75	75	75
	Data Gap	25	25	50	50
Acute Toxicity	Category 1	75	75	100	100
	Category 2	50	50	75	75
	Category 3	10	25	50	50
	Category 4	5	5	10	10
	Data Gap	5	10	25	50
Mutagenicity[2]	Category 1	50	50	50	50
	Category 2	25	25	25	25
	Data Gap	25	25	50	50
Reproductive Toxicity[2]	Category 1	50	50	50	50
	Category 2/Prop 65	25	25	25	25
	Data Gap	25	25	50	50
Developmental Toxicity[2]	Category 1	50	50	50	50
	Category 2/Prop 65	25	25	25	25
	Data Gap	25	25	50	50
Endocrine[3]	EU Priority List or Endocrine concern	25	25	25	25
	Data gap	10	10	10	10
Systemic Toxicity/Organ Toxicity – Single Dose[2]	Category 1	25	25	50	50
	Category 2	10	10	25	25
	Category 3	5	5	15	15
	Data Gap	5	10	25	50
Systemic Toxicity/Organ Toxicity – Repeated Dose[2]	Category 1	25	25	50	50
	Category 2	10	10	25	25
	Data Gap	5	10	25	50
Skin Sensitizer[4]	Category 1	25	25	50	50
	Data Gap	5	10	25	50
Respiratory Sensitizer[4]	Category 1	25	25	50	50
	Data Gap	5	10	25	50
Eye Irritant[5]	Category 1	5	10	25	25
	Category 2	5	5	10	10
	Data Gap	5	10	25	25
Skin Irritant[5]	Category 1	5	10	25	25
	Category 2	5	5	10	10
	Data Gap	5	10	25	25
Not Required to Be Classified/Not Listed		0	0	0	0

Notes:

AA = Alternatives Analysis; CSI = Chemical Scoring Index; EU = European Union; GHS = Globally Harmonized System of Classification and Labelling of Chemicals; SCP = Safer Consumer Products.

(1) The original CSI approach did not evaluate products if "more than 30% of [the] product's composition is due to the contribution of components with 'No Data Available,'" with the idea that the product will be re-evaluated at a later time "when more information may be available" (Verslycke *et al.*, 2014). We did not follow this approach, because the SCP regulations do not require additional testing, and the timeframe for compliance would not allow for this. Additionally, the original CSI approach does not penalize data gaps on an *endpoint by endpoint* basis. This approach only penalizes a product if <30% of its composition is accounted for by components with data gaps (although the number of data gaps is immaterial), with a singular maximum penalty score of 100 for the environmental categories, 100 for the human health categories, and 50 for the physical

categories. If chemicals with data gaps account for ≥30% of a product's composition, the product would be classified as "Do Not Evaluate." Thus, the CSI approach lacks granularity in terms of how many or which health endpoints have missing data. For this Abridged AA, we added endpoint by endpoint penalty scores for data gaps, which is more conservative than the CSI approach. These data gap scores were assigned based on hazard severity (*i.e.*, the maximum carcinogenicity and mutagenicity data gaps are scored 50 *versus* 10 for endocrine disruption). Also, in general, data gap penalty scores are lower than the Category 1 hazard scores for the same endpoint, and the data gap penalty scores generally decrease with decreasing chemical concentrations, except for some categories of particular concern (*e.g.*, Category 1 carcinogens).

(2) Under the original CSI approach, scores did not differ between these endpoints To provide more granularity in the scoring, for this Abridged AA, we adopted the maximum CSI score for Category 1 hazards for all of the abovementioned hazard endpoints. However, we scaled down to a lower score for subsequent subcategories (approximately 50% of the Category 1 score for Category 2 and so on). This approach is in line with the spirit of the GHS and CSI.

(3) Endocrine hazard was moved from ecological toxicity, under the CSI to human health toxicity, under this Abridged AA's approach. Additionally, we used a score of 25 instead of the original 50 in the CSI for endocrine disruptors, because the EU's Endocrine Disruptor Priority List, which we used in this assessment, is a listing of chemicals with potential endocrine risk that should be explored *via* testing, rather than a list based on studies showing actual effects. In contrast, the maximum score for mutagenicity is 50 and is based on positive findings of a mutagenic effect.

(4) We created separate skin and respiratory sensitization categories from the original CSI's "sensitizer" category, to be consistent with the SCP regulations' required toxicity categories. Additionally, we used a maximum score of 50 instead of the original 25 in the CSI for skin and respiratory sensitization. This is because the original CSI approach was developed for oil and gas applications, in which sensitization was less of an issue. Because sensitization is an important hazard for spray foam insulation and consumer products in general, we increased the maximum score for these endpoints.

(5) We created separate categories for eye and skin irritation from the CSI's "irritant" category, to be more consistent with the SCP regulations' required toxicity categories. We assigned a maximum data gap score of 25 for products in which components with no data account for more than 30% of the composition, matching the score of 25 for Category 1 skin or eye irritants, because these are common hazards.

Table 5.6 Scoring Matrix – Ecological Health Endpoints[1]

Hazard Endpoint	Classification	Concentration in Product			
		<10%	10-29%	30-59%	60-100%
Acute Aquatic Toxicity	Category 1	25	50	75	100
	Category 2	10	25	50	75
	Category 3	5	10	25	50
	Data Gap	10	25	50	75
Chronic Aquatic Toxicity[2]	Category 1	25	50	75	100
	Category 2	10	25	50	75
	Category 3	5	10	25	50
	Data Gap	10	25	50	75
Terrestrial Toxicity[3]	Yes	25	50	75	100
	Data Gap	0	0	0	0
Bioaccumulative	Yes	50	50	50	50
	Data Gap	25	25	25	25
Persistent	Persistent	50	50	50	50
	Inherently Biodegradable	10	10	10	10
	Readily Biodegradable	0	0	0	0
	Data Gap	25	25	25	25
Not Required to Be Classified		0	0	0	0

Notes:

AA = Alternatives Assessment; CSI = Chemical Scoring Index; SCP = Safer Consumer Products.

(1) The original CSI approach did not evaluate products if "more than 30% of [the] product's composition is due to the contribution of components with 'No Data Available,'" with the idea that the product will be re-evaluated at a later time "when more information may be available" (Verslycke *et al.*, 2014). We did not follow this approach, because the SCP regulations do not require additional testing, and the timeframe for compliance would not allow for this. Additionally, the original CSI approach does not penalize data gaps on an *endpoint by endpoint* basis. This approach only penalizes a product if <30% of its composition is accounted for by components with data gaps (although the number of data gaps is immaterial), with a singular maximum penalty score of 100 for the environmental categories, 100 for the human health categories, and 50 for the physical categories. If chemicals with data gaps account for ≥30% of a product's composition, the product would be classified as "Do Not Evaluate." Thus, the CSI approach lacks granularity in terms of how many or which health endpoints have missing data. For this Abridged AA, we added endpoint by endpoint penalty scores for data gaps, which is more conservative than the CSI approach. The data gap penalty scores are lower than the Category 1 hazard scores for the same endpoint, and the data gap penalty scores generally decrease with decreasing chemical concentrations, except for certain endpoints of particular concern (*i.e.*, persistent and bioaccumulative).

(2) The CSI does not have scores for chronic aquatic toxicity. Thus, the CSI's scores for acute aquatic toxicity were used.

(3) The CSI does not have scores for terrestrial toxicity. Thus, we created scores for this endpoint. However, because many chemicals lack data for this endpoint, the data gap penalty score was zero.

Table 5.7 Scoring Matrix – Physical/Chemical Hazards[1]

Hazard Endpoint	Classification	Concentration in Product			
		<10%	10-29%	30-59%	60-100%
Ozone Depletion Potential	Yes	50	50	50	50
Direct Global Warming Contributor	Yes	10	25	50	75
Flammability (Liquid or Solid)	Category 1	25	50	75	100
	Category 2	10	25	50	75
	Category 3	5	10	25	50
VOC Contributing to Tropospheric Ozone Formation[2]	Yes	10	25	50	75
	Data Gap	5	10	25	25
"No" or Data Gap for Any Category Besides VOC		0	0	0	0

Notes:

AA = Alternatives Assessment; CSI = Chemical Scoring Index; SCP = Safer Consumer Products; VOC = Volatile Organic Compound.

(1) The original CSI approach did not evaluate products if "more than 30% of [the] product's composition is due to the contribution of components with 'No Data Available,'" with the idea that the product will be re-evaluated at a later time "when more information may be available" (Verslycke *et al*., 2014). We did not follow this approach, because the SCP regulations do not require additional testing, and the timeframe for compliance would not allow for this. Additionally, the original CSI approach does not penalize data gaps on an *endpoint by endpoint* basis. This approach only penalizes a product if <30% of its composition is accounted for by components with data gaps (although the number of data gaps is immaterial), with a singular maximum penalty score of 100 for the environmental categories, 100 for the human health categories, and 50 for the physical categories. If chemicals with data gaps account for ≥30% of a product's composition, the product would be classified as "Do Not Evaluate." Thus, the CSI approach lacks granularity in terms of how many or which health endpoints have missing data. For this Abridged AA, we added endpoint by endpoint penalty scores for data gaps, which is more conservative than the CSI approach. The data gap penalty scores are lower than the data-supported hazard scores for the same endpoint, and data gap penalty scores generally decrease with decreasing chemical concentrations.

(2) For this endpoint, we used a maximum score of 75 instead of the original maximum score of 50 in the CSI. Because VOCs' contribution to ozone formation is an important hazard for products, such as spray foam insulation, that are used in urban areas, and because smog formation is a particular concern for California cities, we increased the maximum score for this endpoint.

Table 5.8 Chemical-Specific Hazard Scoring Summary

Class of Compound	Chemical	CAS	Human Health Score	Environmental Score	Physical Score	Total Score[1]	Notes
Current Priority Product Candidate Chemical							
Phenylene Diamine related	N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)	793-24-8	125	150	0	275	Data-rich. GreenScreen™ Benchmark 1 - Avoid - Chemical of High Concern
Potential Alternatives							
Phenylene Diamine	N-(1,4-dimethylpentyl)-N′-phenyl-p-phenylenediamine (7PPD)	3081-01-4	120	150	0	270	Data-rich. Suspected PBT according to ECHA, evaluation in progress. GreenScreen Benchmark 1 - Avoid - Chemical of High Concern
Phenylene Diamine	N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)[2]	101-72-4	150	100	0	250	Data-rich. GreenScreen™ assessment used surrogate 6PPD for some endpoints. GreenScreen™ Benchmark 1 - Avoid - Chemical of High Concern
Phenylene Diamine	N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on mostly data gap	No data
Phenylene Diamine	N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7	80	150	0	230	Data-rich
Phenylene Diamine related	N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9	175	150	0	325	Many data gaps. GreenScreen™ Benchmark 1 - Avoid - Chemical of High Concern. GreenScreen™ assessment used surrogates, 6PPD, for most endpoints.
Dihydroquinoline	Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	170	70	0	240	GreenScreen™ assessment used surrogate TMQ oligomer and ethoxyquin for most endpoints. GreenScreen™ Benchmark 2 - Use but search for safer substitutes. Classified as Cat. 1 for target organ toxicity, both single and repeated exposure.
Phenylene Diamine	N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	80	100	0	180	Data-rich. GreenScreen™ Benchmark 2 - Use but search for safer substitutes
Diphenyl amine	4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine	N,N′-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	90	100	0	190	Data-rich
Phenylene diamine	N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	55	150	0	205	Data-rich. Suspected PBT according to ECHA, evaluation in progress. Proposed as reproductive/developmental toxicity Category 1B under EU harmonized classification, classification not adopted yet.
Phenylene Diamine	N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	115	150	0	265	Many data gaps. GreenScreen™ Benchmark 1 - Avoid - Chemical of High Concern. GreenScreen™ assessment used surrogates, 44PD and 77PD, for most endpoints.
Phenylene diamine	Diaryl-p-phenylene diamine (DAPD is a class, main commercial DAPD is DTPD CASRN 68953-84-4)	68953-84-4	55	150	0	205	Data-rich. Suspected PBT according to ECHA, evaluation in progress. Proposed as reproductive/developmental toxicity Category 1B under EU harmonized classification, classification not adopted yet.
Phenylene diamine	N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Metal dithiocarbamate	Nickel dibutyldithiocarbamate (NBC)	13927-77-0	170	50	0	220	Data-rich. GreenScreen™ Benchmark 1 - Avoid - Chemical of High Concern. On many regulatory restriction lists due to nickel.

Class of Compound	Chemical	CAS	Human Health Score	Environmental Score	Physical Score	Total Score[1]	Notes
Dihydroquinoline	Ethoxyquin	91-53-2	135	70	0	205	Data-rich. GreenScreen™ Benchmark 2 - Use but search for safer substitutes
Sulfur compound	Dilauryl thiodipropionate	123-28-4	40	0	0	40	Data-rich. GreenScreen™ Benchmark 3_{dg} - Use but still opportunity for improvement
Phenylene Diamine	N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine	N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine	4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine	N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine	4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene Diamine (Kruger)	RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5	130	65	0	195	Almost entirely data gap, other than skin sensitization and aquatic toxicity
Phenylene Diamine	4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Phenylene diamine	Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Dihydroquinoline	N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Hindered amine	N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Triazine	2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)	121246-28-4	50	100	0	150	Data rich
Phenylnaphthyl amines	N-Phenyl-1-naphthylamine	90-30-2	45	150	0	195	Data rich
Phenylnaphthyl amines	N-Phenyl-2-naphthylamine	135-88-6	180	20	0	200	Data rich - Classified as a Cat. 2 carcinogen among other hazards
Ether + Phenol	[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)[3]	110553-27-0	30	10	0	40	Data rich
Inorganic	Graphene	1034343-98-0	55	85	0	140	Data rich

Class of Compound	Chemical	CAS	Human Health Score	Environmental Score	Physical Score	Total Score[1]	Notes
Hydrazine	1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Nitrone + Phenolic AO	α- C-4- hydroxy- 3,5- dimethylphenyl - N-isopropyl and Lowinox WSP	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	5 (for Lowinox WSP, however, no information on nitrone as a class)	0 (for Lowinox WSP, however, no information on nitrone as a class)	0 (for Lowinox WSP, however, no information on nitrone as a class)	Not assigned based on lack of data for nitrone as a class	Data rich for Lowinox WSP - 77-62-3; however, no information on nitrone as a class
Phenothiazine	N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Amine	7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Amine	2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Amine	4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Nitrone	α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Polymeric amine functionalized lignin	Amine functionalized lignin	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data
Gallate related	Rambutan peel extract	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data

Notes:

CAS = Chemical Abstracts Service Number; DG = Data Gap; ECHA = European Chemicals Agency; EU = European Union; PBT = Persistent, Bioacculative, and Toxic.

The Chemical Scoring Index (CSI) approach (Verslycke *et al.,* 2014) was modified to provide quantitative hazard scores. The higher the score, the worse the hazard profile; however, these scores should only be used as approximations of hazards (*i.e.,* ball parks), due to the underlying uncertainties.

(1) This is assuming that the concentration of the chemical in the tire is <10%.

(2) One of the consortium members disagree with ToxServices using 6PPD as a read-across to IPPD based on available information (ToxServices, 2021c)

(3) A potential alternative is Irganox 1520 CAS 110553-27-0 blended with Vulcazon AFS. However, according to the source patent (Pirelli Tyre S.P.A, 2018), the best ratio is where 100% of blend is Irganox 1520. Additionally, no data were located for Vulcazon AFS. Thus, data and scoring is 100% based on Irganox 1520 CAS 110553-27-0.

Table 5.9 Physical-Chemical Properties

Chemical	CAS No.	SMILES	Molecular Weight	Density at 20°C (g/cm^3)	Log K_{ow} at 20°C (Octanol-Water Partition Coefficient, Describes Lipid Solubility)	Log K_{oa} at 25°C (Octanol-Air Partition Coefficient)	Log K_{oc} (Organic Carbon Partition Coefficient, Describes Sorption in Soil and Sediment)	K_H[1] (Henry's Law Constant at 25°C, atm-m^3/mole)	Vapor Pressure (Saturated, mm Hg at 25°C)	Melting Point (°C at 1 atm)	Boiling Point[2] (°C at 1 atm)	Water Solubility (mg/L at 25 °C)	Physical State	Hydrolysis Rate Constant ($M^{-1}s^{-1}$)	Dissociation Constant at 20°C	Photolysis Rate Constant (s^{-1})	Standard Reduction Potential (V)	Air Diffusion Coefficient (Diffusivity) (cm^2/s) at 20°C and 1 atm	Water Diffusion Coefficient (Diffusivity) (cm^2/s) at 20°C and 1 atm	Reactivity/ Electrophilicity Index	Environmental Half-life in Air (Days)	Environmental Half-life in Air (Hrs)
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6-PPD)	793-24-8	CC(C)CC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	268.41	0.995 at 50°C	4.68	11.542	4.363	3.36E-09	4.93E-06	121.5	369.67	2.83	Solid	NA	2.00E-07	1.63E-04	NA	4.22E-02	4.20E-06	NA	0.047	0.567
Possible alternatives																						
N-(1,4-dimethylpentyl)-N′-phenyl-p-phenylenediamine (7PPD)	3081-01-4	CC(C)CCC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	282.43	1.01	5.17	11.909	4.623	4.46E-09	2.11E-06	129.78	381.27	0.67	Liquid	NA	2.00E-07	1.63E-04	NA	4.10E-02	4.05E-06	NA	0.047	0.563
N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)	101-72-4	CC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	226.32	1.04	3.28	10.51	3.636	1.44E-09	7.11E-05	74	161	58.071	Solid	NA	1.58E-07	1.58E-7 - 1.74E-7	NA	4.66E-02	4.76E-06	NA	0.049	0.588
N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1	C1CCC(CC1)NC2=CC=C(C=C2)NC3=CC=CC=C3	266.39	NA	4.64	11.858	3.854	1.48E-09	1.24E-06	134.41	388.82	6.6544	Solid	NA	NA	NA	NA	4.24E-02	4.37E-06	NA	0.046	0.548
N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7	C1=CC=C(C=C1)NC2=CC=C(C=C2)NC3=CC=CC=C3	260.34	1.268	4.04	12.117	4.715	2.05E-10	**6.35E-09**	**144**	**220-225**	1.5867	Solid	NA	NA	NA	NA	4.32E-02	4.56E-06	NA	0.053	0.642
N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9	CC(C)CC(C)N=C1C=CC(=NC2=CC=CC=C2)C=C1	266.39	NA	5.86	7.58	5.62	4.66E-04	4.85E-05	64.21	352.87	4.08E-02	Liquid	NA	NA	NA	NA	4.24E-02	4.21E-06	NA	0.088	1.055
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	Polymer	173.26	1.042 at 20°C	**3.9 at 25°C**	NA	NA	NA	**< 4.8E-06**	**48**	**> 280**	**< 1.00E0**	Solid	NA	Insignificant	NA	NA	5.29E-02	5.59E-06	NA	NA	**2**
N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	CC(C)CCC(C)NC1=CC=C(C=C1)NC(C)CCC(C)C	304.52	0.909	6.3	11.701	4.532	9.72E-08	8.22E-06	112.67	364.35	0.074747	Liquid	NA	3.16E-08	8.96E-05	NA	3.91E-02	3.68E-06	NA	0.085	1.021
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	CCCCCCCCC1=CC=C(C=C1)NC2=CC=C(C=C2)CCCCCCCC	393.66	NA	11.26	13.819	7.016	6.76E-05	2.11E-09	184.89	477.99	3.94E-07	Solid	NA	NA	NA	NA	3.35E-02	3.20E-06	NA	0.049	0.586
N,N′-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	CCC(C)NC1=CC=C(C=C1)NC(C)CC	220.36	0.94	3.5	9.638	3.118	1.78E-08	1.56E-03	**18**	**98**	32.117	Liquid	NA	3.16E-08	1.68E-5 - 2.52E-4	NA	4.70E-02	4.55E-06	NA	0.091	1.095
N,N'-Ditolyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	CC1=CC=C(C=C1)NC2=CC(=CC=C2)NC3=CC=C(C=C3)C	288.4	1.2	**3.93**	13.12	5.126	2.49E-10	1.01E-07	158.74	421.38	1.56E-01	Solid	NA	3.98E-02	Not sure where to find this	NA	4.07E-02	4.21E-06	NA	0.053	0.641
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	C1CCC(CC1)NC2=CC=C(C=C2)NC3CCCCC3	272.44	NA	5.24	11.599	2.992	1.07E-08	2.24E-06	131.43	379.45	4.4631	Solid	NA	NA	NA	NA	4.17E-02	4.21E-06	NA	0.077	0.926
Diaryl-p-phenylene diamine (DAPD)	68953-84-4	CC1=CC=C(C=C1)NC2=CC(=CC=C2)NC3=CC=C(C=C3)C	288.4	1.2	**3.93**	13.12	5.126	2.49E-10	1.01E-07	158.74	421.38	1.56E-01	Solid	NA	3.98E-02	Not sure where to find this	NA	4.07E-02	4.21E-06	NA	0.053	0.641
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	C1=CC=C2C=C(C=CC2=C1)NC3=CC=C(C=C3)NC4=CC5=CC=CC=C5C=C4	360.46	NA	6.39	16.488	6.765	1.95E-12	1.43E-11	**235**	539.98	6.90E-04	Solid	NA	NA	NA	NA	3.60E-02	3.84E-06	NA	0.027	19.253
Nickel dibutyldithiocarbamate (NBC)	13927-77-0	CCCCN(CCCC)C(=S)[S-].CCCCN(CCCC)C(=S)[S-].[Ni+2]	467.43	1.301	**5.44**	9.34E-06	6.254	NA	3.98E-04	9.02E+01	**296**	8.31E+01	Solid: Particulate/ powder	NA	NA	NA	NA	3.71E-02	3.30E-06	NA	0.058	0.691
Ethoxyquin	91-53-2	CCOC1=CC2=C(C=C1)NC(C=C2C)(C)C	217.31	1.031	3.87	8.875	3.104	2.42E-07	1.32E-04	104.68	**123-125**	20.093	Liquid	NA	2.75E-5 (at 22°C)	NA	NA	4.79E-02	4.89E-06	NA	0.083	1.001
Dilauryl thiodipropionate	123-28-4	O=C(OCCCCCCCCCCCC)CCSCCC(=O)OCCCCCCCCCCCC	514.85	1.04	11.79	15.576	6.973	5.73E-07	8.89E-09	**40-42**	519.29	5.15E-07	Solid: Flakes	NA	NA	NA	NA	3.06E-02	2.76E-06	NA	0.205	2.465
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	C1=C(NC(C=CC2)=CC=2)C=CC(=C1)NC(C(C1=CC2)=CC=2)C(=CC=C2)C1=C2	348.45	NA	5.41	15.53	6.318	1.85E-12	1.59E-10	216.27	507.87	5.59E-03	Solid	NA	NA	NA	NA	0.0367	3.90E-06	NA	0.051	0.607
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	C1C=CC=C(C=1)NC(=CC=C1NC(=CC=C2)C(CC3=CC4)=C2C3=CC=4)C=C1	349.45	NA	6.06	15.65	6.522	6.36E-12	1.25E-10	217.84	511.22	1.46E-03	Solid	NA	NA	NA	NA	0.0367	3.90E-06	NA	0.053	0.64
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	CC(C)CC(C)NC1=CC=C(C=C1)NC2=CC=C(C=C2)CSC3=CC=CC=C3	390.59	NA	6.99	16.480	6.422	7.19E-12	3.74E-10	204.49	498.68	1.70E-03	Solid	NA	NA	NA	NA	3.52E-02	3.46E-06	NA	0.046	0.549
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	CC1=CC=C(N1C2=CC=C(C=C2)NC3=CC=CC=C3)C	262.36	NA	5.04	14.535	4.631	7.83E-12	5.47E-07	147.48	397.43	7.19E-01	Solid	NA	NA	NA	NA	4.29E-02	4.46E-06	NA	0.053	0.641
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine or similar chemical 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	No CAS	C1=CC=C(C=C1)NC2=CC=C(C=C2)NCCNC3=CC=C(C=C3)NC4=CC=CC=C4	394.52	NA	4.4	19.709	6.87	1.20E-17	8.35E-12	235.45	548.93	4.34E-02	Solid	NA	NA	NA	NA	3.51E-02	3.53E-06	NA	0.048	0.58
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS	CC1=C(C(=CC=C1)NC2=CC=C(C=C2)NC3=CC=CC=C3)C	288.4	NA	5.13	13.122	5.143	2.49E-10	1.07E-07	158.74	421.38	1.56E-01	Solid	NA	NA	NA	NA	4.07E-02	4.21E-06	NA	0.053	0.641
RU997 Irgazone 997 Reaction product of N-phenyl-N′-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether	444992-04-5	C1=CC(=CC=C1)NC1C=CC(=CC=1)N(CC(O)CSC(C)(C)CCCCCCCCC)C(CC(C)C)C	526.87	NA	10.6	20.959	7.037	1.07E-12	1.16E-15	253.56	587.68	1.54E-05	Solid	NA	NA	NA	NA	2.98E-02	2.76E-06	NA	0.04	28.55
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	CC(C)CC(C)NC1=CC=C(C=C1)NC2=CC=C(C=C2)O	284.4	NA	3.85	14.694	4.471	3.50E-13	6.70E-08	152.39	404.5	5.68E+00	Solid	NA	NA	NA	NA	4.18E-02	4.15E-06	NA	0.047	0.566
This is a class of compounds. Reference uses case where R1 and R2 are methyl; n,p and q are zero and m=1 and is in the para position. Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	CN(C)C1=CC=C(C=C1)NC2=CC=C(C=C2)O	228.3		2.64	12.788	3.28	1.74E-12	1.48E-06	132.28	361.66	3.74E+02	Solid	NA	NA	NA	NA	4.78E-02	4.92E-06	NA	0.053	0.633
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	CCN(CC)C1=CC2=C(C=C1)NC(C=C2C)(C)C	244.38	NA	4.46	9.912	3.329	8.64E-08	2.19E-05	123.66	341.46	5.98E+00	Solid	NA	NA	NA	NA	4.44E-02	4.43E-06	NA	0.035	25.243
Mixed xylene diamines N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	Mixture																				
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine, TAPDT	121246-28-4	CC(C)CCC(C)NC1=CC=C(C=C1)NC2=NC(=NC(=N2)NC3=CC=C(C=C3)NC(C)CCC(C)C)NC4=CC=C(C=C4)NC(C)CCC(C)C	694.03	**1.07 at 20°C**	11.9	30.903	11.407	2.43E-21	1.57E-19	**54**	**225**	6.94E-07	Solid	NA	NA	NA	NA	2.62E-02	2.40E-06	NA	0.038	27.144

Chemical	CAS No.	SMILES	Molecular Weight	Density at 20°C (g/cm^3)	Log K_{ow} at 20°C (Octanol-Water Partition Coefficient, Describes Lipid Solubility)	Log K_{oa} at 25°C (Octanol-Air Partition Coefficient)	Log K_{oc} (Organic Carbon Partition Coefficient, Describes Sorption in Soil and Sediment)	K_H[1] (Henry's Law Constant at 25°C, atm-m^3/mole)	Vapor Pressure (Saturated, mm Hg at 25°C)	Melting Point (°C at 1 atm)	Boiling Point[2] (°C at 1 atm)	Water Solubility (mg/L at 25 °C)	Physical State	Hydrolysis Rate Constant ($M^{-1}s^{-1}$)	Dissociation Constant at 20°C	Photolysis Rate Constant (s^{-1})	Standard Reduction Potential (V)	Air Diffusion Coefficient (Diffusivity) (cm^2/s) at 20°C and 1 atm	Water Diffusion Coefficient (Diffusivity) (cm^2/s) at 20°C and 1 atm	Reactivity/ Electrophilicity Index	Environmental Half-life in Air (Days)	Environmental Half-life in Air (Hrs)
N-Phenyl-1-naphthylamine	90-30-2	C1=CC=C(C=C1)NC2=CC=CC3=CC=CC=C32	219.29	**1.16 at 20°C**	**4.28**	9.576	4.473	1.03E-07	**7.63E-06**	**62**	**335**	**3.96E+00**	**Solid**	NA	**1.17E-05**	**1.33E-04 - 2.02E-03**	NA	4.66E-02	5.10E-06	NA	0.031	22.222
N-Phenyl-2-naphthylamine	135-88-6	C1=CC=C(C=C1)NC2=CC3=CC=CC=C3C=C2	219.29	**1.242 at 25°C**	**4.38**	9.756	4.464	1.03E-07	1.64E-06	**108**	**395.5**	1.26E+00	Solid	NA	NA	NA	NA	4.66E-02	5.10E-06	NA	0.031	22.222
Irganox 1520	110553-27-0	CCCCCCCCSCC1=CC(=C(C(=C1)C)O)CSCCCCCCCC	424.75	**0.981 at 20°C**	10.2	16.9	7.637	4.53E-09	2.13E-11	**14**	508.31	8.89E-06	Liquid	NA	**2.51E-11**	**7.60E-11**	NA	3.38E-02	3.13E-06	NA	0.143	1.721
Graphene	1034343-98-0	NA	NA	**2.259 at 20°C**	NA	NA	NA	NA	NA	**>4000**	NA	**<3 mg/L**	Solid: Powder	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1' -Pentamethylenebis(2,2-Di-n-Butylhydrazine)	No CAS	CCCCN(CCCC)NCCCCCNN(CCCC)CCCC	356.64	NA	5.57	14.49	5.724	2.94E-11	2.21E-07	151.05	411.96	3.86E+03	Solid	NA	NA	NA	NA	3.66E-02	3.27E-06	NA	0.052	0.625
α- C-4- hydroxy- 3,5- dimethylphenyl (Lowinox WSP). No number for nitrone- N-isopropyl nitrone and Lowinox WSP	Lowinox WSP - 77-62-3, No CAS for nitrone	NA Mixture																				
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	CC(C)CC(C)NC1=CC2=C(C=C1)NC3=CC=CC=C3S2	298.45	NA	5.76	14.2	4.615	8.89E-11	1.14E-07	170.85	414.55	6.37E-01	Solid	NA	NA	NA	NA	4.13E-02	4.18E-06	NA	0.047	0.567
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	CC(C)CC(C)NC1=CC2=C(C=C1)NC3=C(C2=O)CCCC3	298.43	NA	5.2	14.358	3.496	1.70E-11	7.60E-08	173.7	420.42	2.17E+00	Solid	NA	NA	NA	NA	4.06E-02	4.10E-06	NA	0.09	1.084
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	CC(C)CC(C)NC1=CC2=C(C=C1)NC(=C2)C3CCCCC3	298.48	NA	6.81	13.443	5.92	5.69E-09	1.11E-07	157.01	421.39	1.91E-01	Solid	NA	NA	NA	NA	3.96E-02	3.94E-06	NA	0.045	0.543
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	CC(C)CC(C)NC1=CC=C(C=C1)C2=CC3=CC=CC=C3N2	292.43	NA	5.76	13.81	5.398	2.18E-10	1.99E-08	172.04	444.85	1.72E-01	Solid	NA	NA	NA	NA	4.03E-02	4.08E-06	NA	0.042	29.969
α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	No CAS	C1(/C=[N+](\[O-])C(C)(C)C)=CC(C)=C(C(C)=C1)O	221.3	NA	1.83	14.249	4.264	9.32E-15	1.02E-09	191.87	455.63	5.11E+01	Solid	NA	NA	NA	NA	4.87E-02	4.83E-06	NA	0.436	5.227
Amine functionalized lignin	No CAS	NA, polymer																				
Rambutan peel extract	No CAS	NA, complex mixture																				

Notes:

CAS No. = Chemical Abstracts Service Registry Number; DG = Data Gap; NA = Not available; OH = Hydroxyl Radical; SMILES = Simplified Molecular-Input Line-Entry System; TSCA = Toxic Substances Control Act; US EPA = United States Environmental Protection Agency; UVCB = Unknown or Variable Composition, Complex Reaction Products and Biological Materials.

Bolded text indicates experimental values. Non-bolded text indicates modeled or calculated values. If available, experimental melting point, boiling point, vapor pressure, and water solubility values listed in the table were manually entered for more accurate modeling in US EPA's EPI Suite software (US EPA, 2019b).

Data were mainly obtained from ECHA (2023) and US EPA's EPI Suite software (US EPA, 2019).

(1) Reference hierarchy of Henry's Law Constant sources in EPI Suite: (1) Vapor pressure/water solubility, if experimental data are available; (2) Group; (3) Bond.

(2) Boiling point: Preference was given to experimental value reported at 1 atm or 760 mm Hg. Otherwise, a modeled estimate from EPI Suite was used (US EPA, 2019b).

Table 5.10 Physical-Chemical Properties and Hazards of Transformation Products of 6PPD and Possible Alternative Chemicals

Chemical Name	CAS No.	Transformation Product Name	Transformation Product CAS	log Kow	log Koc	VP (saturated mm Hg at 25 °C)	Water Solubility (mg/L)	ECHA Dossier GHS Conclusion	EU Persistent Bioaccumulative and Toxic	California Toxic Air Contaminant	California Proposition 65
6PPD	793-24-8	6PPD-quinone	2754428-18-5	No information in ECHA dossier				No ECHA dossier, however, existing aquatic data indicates acute toxicity to fish.	Not listed	Not listed	Not listed
		4-Hydroxydiphenylamine	122-37-2	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			No useful information in ECHA dossier	Not listed	Not listed	Not listed
		1,3-Dimethylbutylamine	108-09-8	No information in ECHA dossier			7.9 (From EPISUITE. Yaws, CL *et al.* (2001))	No ECHA dossier	Not listed	Not listed	Not listed
		p-Benzoquinone	106-51-4	Between 0.1 and 0.3 (at 23 °C)	No information in ECHA dossier	2.93E-02	1.47E+04 (at 20 °C)	Acute Tox. 3 (Oral), Aquatic Acute 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Acute Tox. 3 (Inhalation), Aquatic Chronic 1, Muta. 2, Skin Sens. 1, Flam. Sol. 1	Not listed	Listed	Not listed
		p-Hydroquinone	123-31-9	0.59 (at 20 °C)	1.585	2.40E-05	7.20E+04 (at 25 °C)	Aquatic Acute 1, Carc. 2, Muta. 2, Eye Dam. 1, Acute Tox. 4 (Oral), Skin Sens. 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Not listed
		Aniline	62-53-3	0.91 (at 25 °C)	2.6	3.05E-01	3.50E+04 (at 20 °C)	Carc. 2, STOT RE 1, Acute Tox. 3 (Dermal), Muta. 2, Eye Dam. 1, Acute Tox. 3 (Inhalation), Acute Tox. 3 (Oral), Aquatic Acute 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Listed (Cancer)
		N-Phenyl-p-benzoquinone-monoimine	2406-04-4	No information in ECHA dossier				No ECHA dossier	Not listed	Not listed	Not listed
		N-(1,3-Dimethylbutyl)-N'-(phenyl)-1,4-benzoquinonediimine (6QDI)	52870-46-9	4.2 (at 25 °C)	No information in ECHA dossier	7.50E-06	1.54E+01 (at 20 °C)	6QDI is an oxidation product of 6PPD which is expected to form under hydrolytic conditions in the presence of oxygen. There is no information on ECHA about GHS conclusions for 6QDI.	Not listed	Not listed	Not listed
N-(1,4-dimethylpentyl)-N'-phenyl-p-phenylenediamine (7PPD)	3081-01-4	4-Hydroxydiphenylamine	122-37-2	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			No useful information in ECHA dossier	Not listed	Not listed	Not listed
		N-Phenyl-p-benzoquinone-monoimine	2406-04-4	No information in ECHA dossier				No ECHA dossier	Not listed	Not listed	Not listed
		1,4-Dimethylpentylamine	28292-43-5	No information in ECHA dossier				No ECHA dossier	Not listed	Not listed	Not listed
		p-Benzoquinone (pH 4 and 7)	106-51-4	Between 0.1 and 0.3 (at 23 °C)	No information in ECHA dossier	2.93E-02	1.47E+04 (at 20 °C)	Acute Tox. 3 (Oral), Aquatic Acute 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Acute Tox. 3 (Inhalation), Aquatic Chronic 1, Muta. 2, Skin Sens. 1, Flam. Sol. 1	Not listed	Listed	Not listed
		p-Hydroquinone (pH 4)	123-31-9	0.59 (at 20 °C)	1.585	2.40E-05	7.20E+04 (at 25 °C)	Aquatic Acute 1, Carc. 2, Muta. 2, Eye Dam. 1, Acute Tox. 4 (Oral), Skin Sens. 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Not listed
		Aniline (pH 4, 7, and 9)	62-53-3	0.91 (at 25 °C)	2.6	3.05E-01	3.50E+04 (at 20 °C)	Carc. 2, STOT RE 1, Acute Tox. 3 (Dermal), Muta. 2, Eye Dam. 1, Acute Tox. 3 (Inhalation), Acute Tox. 3 (Oral), Aquatic Acute 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Listed (Cancer)
		4-(Phenylnitroso)benzen-1-olate (overoxidised 4-HDPA)	CAS not identified	Unable to assess due to lack of CAS				Unable to assess due to lack of CAS	CAS not identified		

Chemical Name	CAS No.	Transformation Product Name	Transformation Product CAS	log Kow	log Koc	VP (saturated mm Hg at 25 °C)	Water Solubility (mg/L)	ECHA Dossier GHS Conclusion	EU Persistent Bioaccumulative and Toxic	California Toxic Air Contaminant	California Proposition 65
N-isopropyl-N'-phenyl-p-phenyldiamine (IPPD)	101-72-4	4-Hydroxydiphenylamine	122-37-2	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			No useful information in ECHA dossier	Not listed	Not listed	Not listed
		Benzo-quinoneimine-N-phenyl	2406-04-4 (most	No information in ECHA dossier				No ECHA dossier	Not listed	Not listed	Not listed
N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N,N'-diphenyl-p-phenylenediamine (DPPD)	74-31-7	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9	4-Hydroxydiphenylamine	122-37-2	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			Acute Tox. 4, Skin Sens. 1, Aquatic Acute 1, Aquatic Chronic 1	Not listed	Not listed	Not listed
		p-Benzoquinone	106-51-4	Between 0.1 and 0.3 (at 23 °C)	No information in ECHA dossier	2.93E-02	1.47E+04 (at 20 °C)	Acute Tox. 3 (Oral), Aquatic Acute 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Acute Tox. 3 (Inhalation), Aquatic Chronic 1, Muta. 2, Skin Sens. 1, Flam. Sol. 1	Not listed	Listed	Not listed
		p-Hydroquinone	123-31-9	0.59 (at 20 °C)	1.585	2.40E-05	7.20E+04 (at 25 °C)	Aquatic Acute 1, Carc. 2, Muta. 2, Eye Dam. 1, Acute Tox. 4 (Oral), Skin Sens. 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Not listed
		Aniline	62-53-3	0.91 (at 25 °C)	2.6	3.05E-01	3.50E+04 (at 20 °C)	Carc. 2, STOT RE 1, Acute Tox. 3 (Dermal), Muta. 2, Eye Dam. 1, Acute Tox. 3 (Inhalation), Acute Tox. 3 (Oral), Aquatic Acute 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Listed (Cancer)
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	Quinone-diimine	CAS not identified	Unable to assess due to lack of CAS				CAS not identified	CAS not identified		
		N-1,4 Dimethyl-pentyl-p-phenol (4PD-OH)	CAS not identified	Unable to assess due to lack of CAS				CAS not identified	CAS not identified		
		1,4-Dimethylpentylamine	28292-43-5	-	-	-	-	No ECHA dossier	Not listed	Not listed	Not listed
		p-Benzoquinone	106-51-4	Between 0.1 and 0.3 (at 23 °C)	No information in ECHA dossier	2.93E-02	1.47E+04 (at 20 °C)	Acute Tox. 3 (Oral), Aquatic Acute 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Acute Tox. 3 (Inhalation), Aquatic Chronic 1, Muta. 2, Skin Sens. 1, Flam. Sol. 1	Not listed	Listed	Not listed
		p-Hydroquinone	123-31-9	0.59 (at 20 °C)	1.585	2.40E-05	7.20E+04 (at 25 °C)	Aquatic Acute 1, Carc. 2, Muta. 2, Eye Dam. 1, Acute Tox. 4 (Oral), Skin Sens. 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Not listed
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N,N'-Bis(1,4-dimethylpentyl)-p-phenyldiamine (44PD)	101-96-2	44-Quinone-diimine (44QDI)	CAS not identified	Unable to assess due to lack of CAS				CAS not identified	CAS not identified		
		N-1,4 Dimethyl-pentyl-p-phenol (4PD-OH)	CAS not identified	Unable to assess due to lack of CAS				CAS not identified	CAS not identified		
		1-Methyl-propylamine	13952-84-6	0.74	1.57	1.78E+02	1.12E+05 (at 20 °C)	Skin Corr. 1A, Flam Liq. 2, Aquatic Acute 1, Acute Tox. 4 (Inhalation), Acute Tox. 3 (Oral), Acute Tox. 4 (Oral)	Not listed	Not listed	Not listed
		p-Benzoquinone	106-51-4	Between 0.1 and 0.3 (at 23 °C)	No information in ECHA dossier	2.93E-02	1.47E+04 (at 20 °C)	Acute Tox. 3 (Oral), Aquatic Acute 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Acute Tox. 3 (Inhalation), Aquatic Chronic 1, Muta. 2, Skin Sens. 1, Flam. Sol. 1	Not listed	Listed	Not listed
		p-Hydroquinone	123-31-9	0.59 (at 20 °C)	1.585	2.40E-05	7.20E+04 (at 25 °C)	Aquatic Acute 1, Carc. 2, Muta. 2, Eye Dam. 1, Acute Tox. 4 (Oral), Skin Sens. 1, Aquatic Chronic 1, Skin Sens. 1B	Not listed	Listed	Not listed

Chemical Name	CAS No.	Transformation Product Name	Transformation Product CAS	log Kow	log Koc	VP (saturated mm Hg at 25 ^{o}C)	Water Solubility (mg/L)	ECHA Dossier GHS Conclusion	EU Persistent Bioaccumulative and Toxic	California Toxic Air Contaminant	California Proposition 65
N,N'-Ditoyl-p-phenylenediamine (Commercial DTPD)	68953-84-4	Hydroxydiphenylamine	122-37-2 (most likely)	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			No useful information in ECHA dossier	Not listed	Not listed	Not listed
		Methyl hydroxydiphenylamine	CAS not identified	Unable to assess due to lack of CAS				CAS not identified	CAS not identified		
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
Diaryl-p-phenylene diamine (DAPD)	68953-84-4	Hydroxydiphenylamine	122-37-2 (most likely)	2.82 (From EPISUITE. Hansch, C *et al.* (1995))	No information in ECHA dossier			No useful information in ECHA dossier	Not listed	Not listed	Not listed
		Methyl hydroxydiphenylamine	CAS not identified	Unable to assess due to lack of CAS				No useful information in ECHA dossier	CAS not identified		
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
Nickel dibutyldithiocarbamate (NBC)	13927-77-0	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
Ethoxyquin	91-53-2	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
Dilauryl thiodipropionate	123-28-4	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine or similar chemical 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine-R1 and R2 are methyl	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
RU997 Irgazone 997 Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether.	444992-04-5	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed

Chemical Name	CAS No.	Transformation Product Name	Transformation Product CAS	log Kow	log Koc	VP (saturated mm Hg at 25 °C)	Water Solubility (mg/L)	ECHA Dossier GHS Conclusion	EU Persistent Bioaccumulative and Toxic	California Toxic Air Contaminant	California Proposition 65
This is a class of compounds. Reference uses case where R1 and R2 are methyl; n,p and q are zero and m=1 and is in the para position. Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
Mixed xylene diamines N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine, TAPDT	121246-28-4	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
N-Phenyl-1-naphthylamine	90-30-2	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
N-Phenyl-2-naphthylamine	135-88-6	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
Irganox 1520	110553-27-0	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
Graphene	1034343-98-0	ECHA dossier contains no information on transformation products							Not listed	Not listed	Not listed
1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
α- C-4- hydroxy- 3,5-dimethylphenyl (Lowinox WSP). No number for nitrone - N-isopropyl nitrone and Lowinox WSP	Lowinox WSP - 77-62-3, No CAS for nitrone	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed

Chemical Name	CAS No.	Transformation Product Name	Transformation Product CAS	log Kow	log Koc	VP (saturated mm Hg at 25 °C)	Water Solubility (mg/L)	ECHA Dossier GHS Conclusion	EU Persistent Bioaccumulative and Toxic	California Toxic Air Contaminant	California Proposition 65
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
α- C-4- Hydroxy- 3,5-dimethylphenyl-N-tert. butyl nitrone	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
Amine functionalized lignin	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed
Rambutan peel extract	No CAS	No ECHA dossier available to support evaluation.							Not listed	Not listed	Not listed

Notes:

Orange shading indicates a breakdown product of potential concern.

Cas No. = Chemical Abstracts Service Number; ECHA = European Chemicals Agency; K_{OC} = Log Organic Carbon Partition Coefficient; K_{OW} = Log Octanol-Water Partition Coefficient.

Table 5.15 Stage 1 Alternatives Analysis Report Conclusions Based on Available Data

Chemical	CAS	Human Health Score (Table 5.1)	Environmental Score (Table 5.3)	Physical Score (Table 5.3)	Total Score (Table 5.8)	Salmonid Toxicity Parent (ug/L) (Table 5.4)	Salmonid Toxicity Quinone/O3 reaction product (ug/L) (Table 5.4)	Ingredient Exposure Potential (Table 5.9)	Appropriate for Additional Performance Evaluation (Tables 5.11-5.13)	Conclusions
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6-PPD)	793-24-8	125	150	0	275	140 (96 hr)	0.041 (24 hr)	-	**NA**	**Candidate chemical in priority product**
Possible Alternatives										
N-(1,4-dimethylpentyl)-N′-phenyl-p-phenylenediamine (7PPD)	3081-01-4	120	150	0	270	No data	No data	Similar environmental partitioning	Yes (Tables 5.11 and 5.12)	Evaluate in Stage 2.
N-isopropyl-N′-phenyl-p-phenylenediamine (IPPD)	101-72-4	150	100	0	250	No data	>50 (96 hr)	Slightly more likely to migrate in water	Yes (Table 5.11)	Evaluate in Stage 2.
N-cyclohexyl-N′-phenyl-p-phenylenediamine (CPPD)	101-87-1	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on mostly data gap	No data	>50 (96 hr)	Slightly more likely to migrate in water	Yes (Table 5.12)	Drop from further evaluation. Too many data gaps to assess.
N,N′-diphenyl-p-phenylenediamine (DPPD)	74-31-7	80	150	0	230	No data	>50 (96 hr)	Similar environmental partitioning	No (Table 5.12)	Drop from further evaluation due to poor performance data.
N-1,3-dimethyl butyl-N′-phenyl quinone diimine (6QDI)	52870-46-9	175	150	0	325	638 (96 hr)	No data	Substantially less water soluble and more fat soluble	No (Table 5.11, releases 6PPD)	Drop from further evaluation due to poor performance data, worse human health score than 6PPD.
Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ)	26780-96-1	170	70	0	240	No data	No data	Similar environmental partitioning	No (Table 5.11)	Drop from further evaluation due to poor performance data, worse human health score than 6PPD.
N,N′-Bis(1,4-dimethylpentyl)-p-phenylenediamine (77PD)	3081-14-9	80	100	0	180	24 (96 hr)	>226 (96 hr)	Similar environmental partitioning	Yes (Table 5.12)	Evaluate in Stage 2.
4,4'-Dioctyldiphenylamine (DOPD)	101-67-7	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Much less volatile and water soluble, much more carbon and fat soluble.	No (Table 5.11)	Drop from further evaluation. Too many data gaps to assess hazards and performance appears poor.
N,N′-Di-sec-butyl-p-phenylenediamine (44PD)	101-96-2	90	100	0	190	130 (96 hr)	No data	Much more volatile and water soluble, much less carbon and fat soluble.	No (Table 5.11)	Drop from further evaluation due to poor performance data.
N,N'-Ditolyl-p-phenylenediamine (Commercial	68953-84-4	55	150	0	205	480 (96 hr)	>50 (96 hr)	Similar environmental partitioning	No (Table 5.12)	Drop from further evaluation due to poor performance data.
N,N'-Dicyclohexyl-p-phenylenediamine (CCPD)	4175-38-6	115	150	0	265	No data	No data	Similar environmental partitioning	Yes (Table 5.12)	Evaluate in Stage 2.
Diaryl-p-phenylene diamine (DAPD)	68953-84-4	55	150	0	205	>480 (96 hr)	No data	Similar environmental partitioning	No (Table 5.12)	Drop from further evaluation due to poor performance data.
N,N'-Di-2-naphthyl-p-phenylenediamine (DNPDA)	93-46-9	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Much less volatile and water soluble, much more carbon and fat soluble.	No (Table 5.11)	Drop from further evaluation. Too many data gaps to assess and data indicate poor performance.
Nickel dibutyldithiocarbamate (NBC)	13927-77-0	170	50	0	220	>100,000 (96 hr)	No data	Similar environmental partitioning	No (Table 5.11)	Drop from further evaluation due to poor performance data, worse human health score than 6PPD.
Ethoxyquin	91-53-2	135	70	0	205	18,000 (96 hr)	No data	More water soluble, higher vapor pressure and lower carbon and fat solubility	No (Table 5.11)	Drop from further evaluation due to poor performance data.
Dilauryl thiodipropionate	123-28-4	40	0	0	40	No data	No data	Less water soluble, low vapor pressure and more carbon and fat soluble	No (Table 5.11)	Drop from further evaluation due to poor performance data.
N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Less water soluble, low vapor pressure and more carbon and fat soluble	Yes (Table 5.11)	Drop from further evaluation. Too many data gaps to assess.
N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Less water soluble, low vapor pressure and more carbon and fat soluble	No (Table 5.11)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
4-(2,5-dimethyl-1H-pyrrol-1-yl)-N-phenylaniline	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	No (Table 5.11)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
N,N - (ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine [example chemical from patent]	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	More carbon soluble, lower vapor pressure, less water soluble	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.

Chemical	CAS	Human Health Score (Table 5.1)	Environmental Score (Table 5.3)	Physical Score (Table 5.3)	Total Score (Table 5.8)	Salmonid Toxicity Parent (ug/L) (Table 5.4)	Salmonid Toxicity Quinone/O3 reaction product (ug/L) (Table 5.4)	Ingredient Exposure Potential (Table 5.9)	Appropriate for Additional Performance Evaluation (Tables 5.11-5.13)	Conclusions
4-N-(2,3-dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.
RU997, Irgazone 997 (Reaction product of N-phenyl-N'-(1,3dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether)	444992-04-5	130	65	0	195	No data	No data	Less water soluble, low vapor pressure and more carbon and fat soluble	No (Table 5.11)	Drop from further evaluation. Performance appears poor or lacks data.
4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.
Representative example from class (4-((4-(dimethylamino)phenyl)amino)phenol)	6358-22-1	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.
N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	Yes (Table 5.11)	Drop from further evaluation. Too many data gaps to assess.
N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine-	25790-41-4	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Mixture, properties undertermined	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.
2,4,6-tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5triazine (Durazone 37 or TAPDT)	121246-28-4	50	100	0	150	No data	No data	Far less water soluble and lower vapor pressure and much more carbon and fat soluble	No (Table 5.11)	Drop from further evaluation. Performance appears poor or lacks data.
N-Phenyl-1-naphthylamine	90-30-2	45	150	0	195	440 (96 hr)	No data	Similar environmental partitioning	No (Table 5.11)	Drop from further evaluation. Performance appears poor or lacks data.
N-Phenyl-2-naphthylamine	135-88-6	180	20	0	200	No data	No data	Similar environmental partitioning	No (Table 5.11)	Drop from further evaluation. Performance appears poor or lacks data.
[2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520 CAS 110553-27-0) blended with Vulcazon AFS[3]	110553-27-0	30	10	0	40	No data	No data	Less water soluble, low vapor pressure and more carbon and fat soluble	No (Table 5.11)	Drop from further evaluation. Performance appears poor or lacks data.
Graphene (e.g., Prophene™)	1034343-98-0	55	85	0	140	No data	No data	Organic carbon material, neglible vapor pressure (but may be suspended in air), similar water solubility	Yes (Table 5.13)	Evaluate in Stage 2.
1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Gimilar vapor pressure and carbon/fat solubility, greater water solubility	No (Table 5.11)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
α- C-4- hydroxy- 3,5-dimethylphenyl - N-isopropyl and Lowinox WSP CAS 77-62-3	Nitrone as a class, no CAS and Lowinox WSP - 77-62-3	5 (for Lowinox WSP, however, no information on nitrone as a class)	0 (for Lowinox WSP, however, no information on nitrone as a class)	0 (for Lowinox WSP, however, no information on nitrone as a class)	Not assigned based on lack of data for nitrone as a class	No data	No data	Mixture, properties for nitrone undetermined due to no CAS	Yes (Table 5.11)	Drop from further evaluation. Too many data gaps to assess.
N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	No (Table 5.13)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
7-(4-methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Greater lipid solubility, similar vapor pressure, lower water solubility	No (Table 5.13)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
2-cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Greater lipid solubility, similar vapor pressure, lower water solubility	No (Table 5.13)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.
4-(1H-indol-2-yl)-N-(4-methylpentan-2-yl)aniline	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Greater lipid solubility, similar vapor pressure, lower water solubility	No (Table 5.13)	Drop from further evaluation. Too many data gaps to assess and performance appears poor or lacks data.

Chemical	CAS					Salmonid Toxicity Parent (ug/L) (Table 5.4)	Salmonid Toxicity Quinone/O3 reaction product (ug/L) (Table 5.4)	Ingredient Exposure Potential (Table 5.9)	Appropriate for Additional Performance Evaluation (Tables 5.11-5.13)	Conclusions
		Human Health Score (Table 5.1)	Environmental Score (Table 5.3)	Physical Score (Table 5.3)	Total Score (Table 5.8)					
α- C-4- Hydroxy- 3,5-dimethylphenyl-N-tert. butyl nitrone	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Similar environmental partitioning	Yes (Table 5.11)	Drop from further evaluation. Too many data gaps to assess.
Amine functionalized lignin	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Polymer, properties undetermined	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.
Rambutan peel extract	No CAS	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	Not assigned based on complete data gap	No data	No data	Complex mixture, properties undertermined	Yes (Table 5.13)	Drop from further evaluation. Too many data gaps to assess.

Legend:

(red)	Less desirable than Priority Product (for CSI score, worse by more than 30%)
(yellow)	Similar to Priority Products
(green)	More desirable than Priority Product (for CSI score, better by more than 30%)
(gray)	Not Applicable: No Comparison Data Available

Appendix A

Glossary of Tire Related Terms

Antidegradant: Antidegradants are added to rubber compounds to protect tires from overly rapid deterioration by ozone, oxygen, fatigue, and heat. Antidegradants include both antioxidants and antiozonants. Antidegradants in tires must serve in two load performance conditions – static and dynamic operations modes - which describe when the tire is at rest or flexing under motion, respectively.

Antioxidant: A compound that helps to keep rubber from breaking down due to the effects of temperature and oxygen exposure.

Antiozonant: A compound that impedes the effects of exposure to ozone on the surface of the tire.

Bead: The tire bead is the portion (or component) of the tire that sits on the rim of the wheel. Tire beads are steel wire bundles that are coated with a specific rubber compound and secure the tire to the metal wheel.

Bead Filler: A rubber compound placed above the bead that may be used between the body plies, which wrap around the bead to enhance ride and handling characteristics.

Belts: Belts provide stability to the tread area of the tire, which minimizes wear and contributes to vehicle handling and traction. Typically, two belts with steel cords laid at opposing angles form a hoop under a tire's tread. The steel belt is coated with a rubber compound that is called a belt coat or belt skim compound.

Body Plies: Body plies function as the base structure of the tire and provide the strength to contain the inflation pressure. Most car tires have one or two body plies, each typically comprised of textile cords within a rubber layer. Truck and bus tires typically use steel cords for body plies.

Curing Systems: Sulfur, chemical accelerators (often derivatives of benzothiazole), stearic acid, and zinc oxide are crucial ingredients for vulcanization, which transforms soft uncured rubber into a solid elastic article during tire curing. Curing systems not only enable vulcanization, but also shorten the vulcanization time and impact the length and number of crosslinks in the rubber matrix which, in turn, affects the rubber's properties.

Dynamic Load Performance: Antioxidants and antiozonants with dynamic operation modes protect the tire while it is in motion and being flexed.

Endurance: Tire endurance is a measurement of how long a tire can withstand severe conditions before reaching its limit. Endurance can be tested by varying the speed, load, inflation pressure, temperature, and/or number of cycles.

Field Testing: Tire manufacturers may conduct field testing to obtain performance data for tires operated under real-life conditions for an extended period of time. Field testing is typically performed by a contracted fleet with routine monitoring by the tire manufacturer.

Fillers: Multiple grades of carbon black and coupled/uncoupled precipitated amorphous silica are used as fillers to reinforce the rubber and modify its properties, resulting in improved wear performance and traction.

Gravel Chip/Tear: For passenger and light truck tires that are intended to be driven off road, an evaluation is conducted on a vehicle on a gravel route to assess chipping and tearing of tread elements.

Handling: Handling is a result of tire/vehicle interactions in response to various driver inputs.

Inner Liner: A rubber compound used to retain the inflation pressure inside the tire.

Irregular Wear: Uneven or abnormal wear features observed during a wear test.

Natural Rubber: Natural rubber provides specific performance characteristics to tires, such as tear and fatigue crack resistance. Some tires, especially truck and bus tires, use natural rubber in tread compounds to provide reduced rolling resistance (the resistance the tire encounters when rolling down the road – an important consideration for fuel efficiency). Natual rubber is a form of polyisoprene which is obtained by tapping rubber trees (Hevea brasiliensis).

Non-Pneumatic Tire: A type of tire that is airless.

Original Equipment (OE): Equipment supplied on a vehicle at its time of purchase.

Original Equipment Manufacturer (OEM): Manufacturer of original equipment (OE) supplied on a vehicle at its time of purchase.

Original Equipment Tires (OE Tires): OE tires must meet specific, often numerous and complex performance requirements specific to the vehicle manufacturer. OE tires are designed to a specific vehicle model year/make/model/trim level combination, and any changes to the materials used to manufacture OE tires, or the tire design itself, would require approval from the vehicle manufacturer. While tires installed on new vehicles are not part of the Priority Product definition, OE tires are also considered replacement tires due to requirements in OE contracts for OE tires to be available as replacements, customer demand for OE tires in the replacement market, and to manage excess OE tire inventory. OE tires typically do not come with treadwear warranties. For purposes of this Stage 1 AA, OE tires are considered to be a subset of the replacement tire market and included in the analyses.

Pneumatic Tire: A type of tire that is filled with air.

Processing Aids: Bio-based oils, low aromatic petroleum oils, pine tar, and resins are the most common softening agents used in rubber compounding. Tackifying resins can be added to increase the rubber compound stickiness (tack), which helps the various tire components stick together assembly of tire components.

Replacement Tires: Tires designed for the replacement market to perform well on a wide range of vehicles – often as many as 30 different vehicle applications are appropriate for a single tire service description (tire size/speed rating/load index combination). Passenger and light truck replacement tires can be installed by a tire dealer or other tire service professional without original equipment manufacturer (OEM) approval.

Rolling Resistance: The force necessary to keep a tire rolling.

Rolling Resistance Coefficient (RRC): Rolling resistance is measured according to ISO 28580:2018 and is expressed in terms of rolling resistance coefficient (RRC). To measure rolling resistance, a load is placed on the tire while it is being forced to turn by the drum and the resistance force, which the tire generates to prevent it from turning, is measured.

Sidewall: A rubber compound used to cover the body plies on the sides of the tire, which provides abrasion, scuff, and weathering resistance.

Static Load Performance: Antioxidants and antiozonants with static operation modes form a coating that protect the tire when it is in its resting and stationary state.

Synthetic Polymers: The two main synthetic rubber polymers, or elastomers, used in tire manufacturing are butadiene rubber (BR) and styrene butadiene rubber (SBR). These synthetic rubber polymers are used in combination with natural rubber. The physical and chemical properties of these rubber polymers determine the performance of each component in the tire as well as the overall tire performance. Another important synthetic rubber is halogenated polyisobutylene rubber, commonly known as halobutyl rubber, which is used in the inner liner. This material causes the inner liner to have reduced air permeability, which helps to keep the tire inflated.

Tack: The stickiness of a green, or uncured, rubber compound.

Tire: As used in this document, "tire" refers to a pneumatic radial tire used with motor vehicles (*e.g.*, passenger cars and light duty trucks; heavy duty trucks and buses).

Tire Identification Number (TIN): A string of letters and numbers on the tire sidewall that begins with the letters DOT. New passenger and some new light truck tires are required by federal law to have a full TIN on the intended outboard side and a partial TIN on the intended inboard side. All new commercial truck and bus tires, motorcycle tires, and some light truck tires are required to have a full TIN on the intended outboard side.

Tire and Road Wear Particles (TRWP): Particles produced as the tire grips and interacts with the road surface during driving.

Tread: Located on the road-contacting portion of the tire, the tread rubber compound and tread pattern provide grip and abrasion resistance contributing to traction and treadwear.

Vulcanization: The process in which heat is applied to the green, or uncured, rubber compound causing a chemical reaction among sulfur, other chemicals, and polymers (elastomers) in the rubber compound. These reactions result in chemical bonds (cross links) between the polymer (elastomer) chains to produce cured tires.

Wear Rate: Usually measured in miles of travel per thousandth of an inch of tread depth loss (*i.e.*, miles per mil) or as tread loss per mileage increment (*i.e.*, mils/1,000 miles).

Appendix B

List of Products Covered by This AA

Responsible Entity Name	Brand/Trade Name	Tire Type
America Kenda Rubber Ind Co.	Kenda	Motorcycle Tires
America Kenda Rubber Ind Co.	Kenda	Light Duty Vehicle Tires
Apollo Tyres Limited	Apollo	Light Duty Vehicle Tires
Apollo Tyres Limited	Apollo	Medium Duty and Heavy Duty Vehicle Tires
Apollo Tyres Limited	Apollo	Motorcycle tires
Apollo Tyres Limited	Vredestein	Light Duty Vehicle Tires
Bridgestone Americas, Inc.	Bandag	Retread materials for tires
Bridgestone Americas, Inc.	Bridgestone	Light Duty Vehicle Tires
Bridgestone Americas, Inc.	Bridgestone	Medium and Heavy Duty Vehicle Tires
Bridgestone Americas, Inc.	Bridgestone	Motorcycle Tires
Bridgestone Americas, Inc.	Firestone	Light Duty Vehicle Tires
Bridgestone Americas, Inc.	Firestone	Medium and Heavy Duty Vehicle Tires
Bridgestone Americas, Inc.	Fuzion	Light Duty Vehicle Tires
Bridgestone Americas, Inc.	SureDrive	Light Duty Vehicle Tires
CEAT Limited	CEAT	Medium and Heavy Duty Vehicle Tires
CEAT Limited	CEAT	Motorcycle tires
CEAT Limited	CEAT	Light Duty Vehicle Tires
CEAT Limited	Private label	Medium and Heavy Duty Vehicle Tires
CEAT Limited	Private label	Light Duty Vehicle Tires
China Manufacturers Alliance, LLC	Double Coin	Medium and Heavy Duty Dehicle tires
China Manufacturers Alliance, LLC	Warrior	Medium and Heavy Duty Dehicle tires
Continental Tire the Americas, LLC	Airfix	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Airfix	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Airfix	Motorcycle tires
Continental Tire the Americas, LLC	Ameri*Steel	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	America	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Bandvulc	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	bandvulc	Retread materials for tires
Continental Tire the Americas, LLC	Barum	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Barum	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Barum	Motorcycle tires
Continental Tire the Americas, LLC	BestDrive	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Blackstone	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Capitol	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Continental	Medium and heavy duty tires
Continental Tire the Americas, LLC	Continental	Retread materials for tires
Continental Tire the Americas, LLC	Continental	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Continental	Motorcycle tires
Continental Tire the Americas, LLC	Contire	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Contitread	Retread materials for tires
Continental Tire the Americas, LLC	Cosmos	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Dunlop	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Dunlop	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Dunlop	Motorcycle tires
Continental Tire the Americas, LLC	ESA+ Tecar	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Eurostone	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Eurotec	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Eurotyre	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Euzkadi	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Euzkadi	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Fate	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Feu Vert	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Flamingo	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	General	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	General	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	General	Motorcycle tires
Continental Tire the Americas, LLC	General	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	General Tire	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Gislaved	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Global	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Hoosier	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Kingstone	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Kormoran	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Mabor	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Marongoni	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Matador	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Matador	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Mazama	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Midas	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Midas	Motorcycle tires
Continental Tire the Americas, LLC	Minerva	Light Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
Continental Tire the Americas, LLC	MYCAR	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Nichols	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Norauto	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Paxaro	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Platin	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Point S	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Retrak	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Roadhandler	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	ROADHOG	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Sebring	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Semperit	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Semperit	Motorcycle tires
Continental Tire the Americas, LLC	Semperit	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Sidewinder	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Sime	Motorcycle tires
Continental Tire the Americas, LLC	Sime Tyres	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	SIME TYRES	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	SIMEX	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	SIMEX	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	SIMEX	Motorcycle tires
Continental Tire the Americas, LLC	Speedy	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Sportiva	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Sumitomo	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Sumo	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Taxat	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Team Star	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	TEAMSTAR	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	tecnotread	Retread materials for tires
Continental Tire the Americas, LLC	Tiger Wheel	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Toyo	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Truckstar	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Tyfoon	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Ultrex IV	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Uniroyal	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Uniroyal	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Uniroyal	Medium Duty and Heavy Duty Tires
Continental Tire the Americas, LLC	Viking	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Yokohama	Light Duty Vehicle Tires
Continental Tire the Americas, LLC	Yokohama	Medium Duty and Heavy Duty Tires
Giti Tire	Dextero	Light Duty Vehicle Tires
Giti Tire	Giti	Light Duty Vehicle Tires
Giti Tire	Giti	Medium Duty and Heavy Duty Tires
Giti Tire	GT Radial	Light Duty Vehicle Tires
Giti Tire	GT Radial	Medium Duty and Heavy Duty Tires
Giti Tire	Primewell	Light Duty Vehicle Tires
Giti Tire	Rocky Mountain	Light Duty Vehicle Tires
Giti Tire	Runway	Light Duty Vehicle Tires
Guizhou Tyre Co., Ltd.	ADVANCE	Light Duty Vehicle Tires
Guizhou Tyre Co., Ltd.	ADVANCE	Medium Duty and Heavy Duty Tires
Guizhou Tyre Co., Ltd.	SAMSON	Medium Duty and Heavy Duty Tires
Guizhou Tyre Co., Ltd.	SAMSON	Light Duty Vehicle Tires
Guizhou Tyre Co., Ltd.	TORNADO	Medium Duty and Heavy Duty Tires
Guizhou Tyre Co., Ltd.	TORNADO	Light Duty Vehicle Tires
Hankook Tire America Corporation	Hankook	Light Duty Vehicle Tires
Hankook Tire America Corporation	Hankook	Medium Duty Vehicle Tires
Hankook Tire America Corporation	Hankook	Heavy Duty Vehicle Tires
Hankook Tire America Corporation	Hankook & New Englander	Light Duty Vehicle Tires
Hankook Tire America Corporation	Hankook & Traction Control	Light Duty Vehicle Tires
Hankook Tire America Corporation	Laufenn	Light Duty Vehicle Tires
Hankook Tire America Corporation	Laufenn	Medium Duty Vehicle Tires
Hankook Tire America Corporation	Laufenn	Heavy Duty Vehicle Tires
Hankook Tire America Corporation	PathFinder	Light Duty Vehicle Tires
Hankook Tire America Corporation	Statewide	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Achilles	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Advanta	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Advanta	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	American Roadstar	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	American Roadstar	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Antini	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Arroyo	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Arroyo	Medium Duty and Heavy Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
Jiangsu General Science Technology Co., Ltd.	Atlander	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Atlander	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Atturo	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Aufine	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Barkley	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Barkley	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	CELIMO	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	CELIMO	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Converse	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Duro	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Evertour	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Finalist	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Finalist	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Fury Off Road	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gladiator	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gladiator	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Goodtrip	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Goodtrip	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gremax	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gremax	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gripmax	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Gripower	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Hillrock	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Knight	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Kwik	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Lancaster	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Lancaster	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Landspider	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Landspider	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Lenso	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Lexmont	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Longmarch	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Magna	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Mastertrack	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Mastertrack	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Matrax	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Matrix	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Mazzini	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Megalodon	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Milestar	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Miletrip	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Mud Claw	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Nama	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Navitrac	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Nebula	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Neoterra	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Neoterra	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Randhawa	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Rockfleet	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Sentinel	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Sentinel	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Supercargo	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	TBBtires	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	TBBtires	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Tekpro	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Tesche	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Tomoro	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Towmax	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Travelstar	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Travelstar	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Unigrip	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Vantage	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Venom Power	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Vitour	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Xcellent	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Xcellent	Medium Duty and Heavy Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Zenna	Light Duty Vehicle Tires
Jiangsu General Science Technology Co., Ltd.	Zenna	Medium Duty and Heavy Duty Vehicle Tires
JK Tyre and Industries Limited	Celestis	Medium Duty and Heavy Duty Vehicle Tires
JK Tyre and Industries Limited	Coker	Light Duty Vehicle Tires
JK Tyre and Industries Limited	Ironman	Light Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
JK Tyre and Industries Limited	JK Tyre	Medium Duty and Heavy Duty Vehicle Tires
JK Tyre and Industries Limited	JK Tyre	Light Duty Vehicle Tires
JK Tyre and Industries Limited	New Pride	Medium Duty and Heavy Duty Vehicle Tires
JK Tyre and Industries Limited	Pearly	Medium Duty and Heavy Duty Vehicle Tires
JK Tyre and Industries Limited	Tornel	Light Duty Vehicle Tires
JK Tyre and Industries Limited	Vikrant	Medium Duty and Heavy Duty Vehicle Tires
Kumho Tire	Kumho Tire	Light Duty Vehicle Tires
Kumho Tire	Kumho Tire	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Altenzo	Light Duty Vehicle Tires
Linglong Americas	AMP	Light Duty Vehicle Tires
Linglong Americas	Annex	Light Duty Vehicle Tires
Linglong Americas	Atlas	Light Duty Vehicle Tires
Linglong Americas	Atlas	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Aufine	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Black Bear	Light Duty Vehicle Tires
Linglong Americas	Constellation	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Contender	Light Duty Vehicle Tires
Linglong Americas	Crosswind	Light Duty Vehicle Tires
Linglong Americas	Crosswind	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Custom	Light Duty Vehicle Tires
Linglong Americas	Dynatrac	Light Duty Vehicle Tires
Linglong Americas	Dynatrac	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Epic Tour	Light Duty Vehicle Tires
Linglong Americas	Evoluxx	Light Duty Vehicle Tires
Linglong Americas	Evoluxx	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Finalist	Light Duty Vehicle Tires
Linglong Americas	Freedom Hauler	Light Duty Vehicle Tires
Linglong Americas	Freedom Hauler	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Geostar	Light Duty Vehicle Tires
Linglong Americas	Geostar	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Geo-Trac	Light Duty Vehicle Tires
Linglong Americas	Giovanna	Light Duty Vehicle Tires
Linglong Americas	Gladiator	Light Duty Vehicle Tires
Linglong Americas	Gladiator	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	GREEN-Max	Light Duty Vehicle Tires
Linglong Americas	GREEN-Max	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Gripmax	Light Duty Vehicle Tires
Linglong Americas	Gripmax	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Gripower	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Grit King	Light Duty Vehicle Tires
Linglong Americas	Grit Master	Light Duty Vehicle Tires
Linglong Americas	Hemisphere	Light Duty Vehicle Tires
Linglong Americas	Hercules	Light Duty Vehicle Tires
Linglong Americas	Hercules	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Hubtrac	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Ironman	Light Duty Vehicle Tires
Linglong Americas	Ironman	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Leao	Light Duty Vehicle Tires
Linglong Americas	Leao	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Linglong	Light Duty Vehicle Tires
Linglong Americas	Linglong	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Milestar	Light Duty Vehicle Tires
Linglong Americas	Nama	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Omni	Light Duty Vehicle Tires
Linglong Americas	Percheron	Light Duty Vehicle Tires
Linglong Americas	Percheron	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Performer	Light Duty Vehicle Tires
Linglong Americas	Pinnacle	Light Duty Vehicle Tires
Linglong Americas	Pinnacle	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Predator	Light Duty Vehicle Tires
Linglong Americas	Prometer	Light Duty Vehicle Tires
Linglong Americas	Prometer	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Provato	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Provato	Light Duty Vehicle Tires
Linglong Americas	Provider	Light Duty Vehicle Tires
Linglong Americas	Provider	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Remington	Light Duty Vehicle Tires
Linglong Americas	RoadOne	Light Duty Vehicle Tires
Linglong Americas	Roadone	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Sentry	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Solidana	Medium Duty and Heavy Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
Linglong Americas	Super Cargo	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Superior	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Suretrac	Light Duty Vehicle Tires
Linglong Americas	Suretrac	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Symmetry	Light Duty Vehicle Tires
Linglong Americas	Synergy	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Taskmaster	Light Duty Vehicle Tires
Linglong Americas	Trailermaster	Light Duty Vehicle Tires
Linglong Americas	Trailermaster	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	TransEagle	Light Duty Vehicle Tires
Linglong Americas	TransEagle	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Travelstar	Light Duty Vehicle Tires
Linglong Americas	Travelstar	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Tri-Ace	Light Duty Vehicle Tires
Linglong Americas	Venezia	Light Duty Vehicle Tires
Linglong Americas	Venom Power	Light Duty Vehicle Tires
Linglong Americas	Venom Power	Medium Duty and Heavy Duty Vehicle Tires
Linglong Americas	Vercelli	Light Duty Vehicle Tires
Linglong Americas	Versatyre	Light Duty Vehicle Tires
Linglong Americas	Wild Spirit	Light Duty Vehicle Tires
Linglong Americas	Zenna	Light Duty Vehicle Tires
Linglong Americas	Zenna	Medium Duty and Heavy Duty Vehicle Tires
Maxxis Technology Center (Cheng Shin USA Tech Center)	Maxxis	Light Duty Vehicle Tires
Maxxis Technology Center (Cheng Shin USA Tech Center)	Maxxis	Medium Duty and Heavy Duty Vehicle Tires
Michelin North America Inc.	BF Goodrich	Light Duty Vehicle Tires
Michelin North America Inc.	BF Goodrich	Medium Duty and Heavy Duty Vehicle Tires
Michelin North America Inc.	Megamile	Retread material for tires
Michelin North America Inc.	Michelin	Light Duty Vehicle Tires
Michelin North America Inc.	Michelin	Medium Duty and Heavy Duty Vehicle Tires
Michelin North America Inc.	Michelin	Motorcycle tires
Michelin North America Inc.	Michelin	Retread material for tires
Michelin North America Inc.	Oliver	Retread material for tires
Michelin North America Inc.	Recamic	Retread material for tires
Michelin North America Inc.	Riken	Light Duty Vehicle Tires
Michelin North America Inc.	Uniroyal	Light Duty Vehicle Tires
Michelin North America Inc.	Uniroyal	Medium Duty and Heavy Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ACHILLES	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ACHILLES	Medium and heavy duty tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ATR 122	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ATR RADIAL	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ATR SPORT	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	ATR-K	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	BELLAGIO	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	CORSA	Motorcycle tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	CORSA	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	GOLDENBRIDGE	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	MILESTAR	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	MONTANA	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	NEUTON	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	PINSO	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	RADAR	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	SINGA RADIAL	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	STRADA	Light Duty Vehicle Tires
Michelin North America, Inc. on behalf of PT Multistrada Arah Sarana TBK	SYRON	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	Aspen	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	Geotour	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	Hercules	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	NEXEN	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	Sceptor	Light Duty Vehicle Tires
NEXEN TIRE CORPORATION	Solar	Light Duty Vehicle Tires
Nokian Tyres US Operations LLC	Nokian Tyres	Light Duty Vehicle Tires
Nokian Tyres US Operations LLC	Nokian Tyres	Medium Duty and Heavy Duty Vehicle Tires
Nokian Tyres US Operations LLC	Nokian Tyres	Retread material for tires
Nokian Tyres US Operations LLC	Nordman	Light Duty Vehicle Tires
Nokian Tyres US Operations LLC	Private brand	Light Duty Vehicle Tires
Ohtani Radial Co., Ltd	Otani	Tires
Otani Tire Co., Ltd	Otani	Tires
Pirelli Tire LLC	Metzeler	Motorcycle Tires
Pirelli Tire LLC	Pirelli	Light Duty Vehicle Tires
Pirelli Tire LLC	Pirelli	Motorcycle Tires
Prinx Chengshan Holdings Limited	AMP/TWG	Light Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
Prinx Chengshan Holdings Limited	Crossmax/Otai	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Fortune	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Fortune	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Kelly/Goodyear	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Muscle Power/Delta	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Pathraider/Otai	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Prinx	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Prinx	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Radar/Omni United	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Rainier St/Otai	Light Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Sotera/Otai	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Synergy/Sutong	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Tourador/Otai	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	UniRoyal/TBC	Medium Duty and Heavy Duty Vehicle Tires
Prinx Chengshan Holdings Limited	Wellplus/Otai	Medium Duty and Heavy Duty Vehicle Tires
Prometeon Tyre Group Commercial Solutions, LLC	Nextroad	Medium and Heavy Duty Vehicle Tires
Prometeon Tyre Group Commercial Solutions, LLC	Pirelli	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	AEROTYRE	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ALBOURGH	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ALBOURGH	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	AMERICAN ROAD STAR	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	AMERICAN ROAD STAR	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	AMERICAN TOURER	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ARROYO	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ARROYO	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	AVANTECH	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Avantech	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	BARKLEY	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	BARKLEY	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	DAVANTI	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	DCENTI	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Delinte	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Delinte	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	DELTA	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ELDORAD	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	GREENTRAC	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	GREENTRAC	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Groundspeed	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Groundspeed	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	HOPEWAY	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	KADO	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Kinforest	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	KINFOREST	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDFLEET	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDFLEET	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDGOLDEN	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDGOLDEN	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDSAIL	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LANDSAIL	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LAZZAZ	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LEXANI	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LIONHART	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	LIONHART	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	MASTERSTEEL	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Mavis	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	MOHAVE	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	MUDDER TRUCKER	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	MULTI-MILE	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	NATIONAL	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	NEBULA	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	NEBULA	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	NEOTERRA	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	PACE	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	PANTERA	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	PATRIOT	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	PHYRON	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	PHYRON	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	RADAR	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	RADAR	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Raiden	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ROADHOG	Light Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
Qingdao Sentury Tire Co., Ltd.	ROLLING BIG POWER	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ROLLING BIG POWER	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	SENTURY	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	SpeedMax	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	SURETRAC	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	SURETRAC	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	TRANSMAX	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	TRANSMAX	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	TYFOON	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	VANDERBILT	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	VELOZZA	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	VENEZIA	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	VERCELLI	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Vercelli II	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Vercelli IV	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	Wild Spirit	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ZEETEX	Light Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ZETA	Medium and Heavy Duty Vehicle Tires
Qingdao Sentury Tire Co., Ltd.	ZETA	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Blackhawk	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Blackhawk	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Dynamo	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Dynamo	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Ironhead	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Ironhead	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Maxam	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Private brand	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Roadx	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Roadx	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Rovelo	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Rovelo	Medium Duty and Heavy Duty Vehicle Tires
Sailun Group Co., Ltd.	Sailun	Light Duty Vehicle Tires
Sailun Group Co., Ltd.	Sailun	Medium Duty and Heavy Duty Vehicle Tires
SHANDONG HAOHUA TIRE CO.,LTD.	APLUS	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	COMPASAL	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	GRANDSTONE	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	HAOHUA	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	LANVIGATOR	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	MAGNA	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	POWERTRAC	PASSENGER CAR TIRE and Truck&BUS tire

Responsible Entity Name	Brand/Trade Name	Tire Type
SHANDONG HAOHUA TIRE CO.,LTD.	ROYAL BLACK	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	WIDEWAY	PASSENGER CAR TIRE and Truck&BUS tire
SHANDONG HAOHUA TIRE CO.,LTD.	WINDFORCE	PASSENGER CAR TIRE and Truck&BUS tire
Shandong Jinyu Tire Co., Ltd.	Amulet	Medium Duty and Heavy Duty Vehicle Tires
Shandong Jinyu Tire Co., Ltd.	Eudemon	Medium Duty and Heavy Duty Vehicle Tires
Shandong Jinyu Tire Co., Ltd.	Evergreen	Medium Duty and Heavy Duty Vehicle Tires
Shandong Jinyu Tire Co., Ltd.	Geoquest	Medium Duty and Heavy Duty Vehicle Tires
Shandong Jinyu Tire Co., Ltd.	Vitour	Medium Duty and Heavy Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Aspen GT-AS	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Delta	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Doral	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Dunlop	Motorcycle tires
Sumitomo Rubber Industries, Ltd.	Dunlop	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Dunlop	Medium Duty and Heavy Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Eldorado	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Falken	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Falken	Medium Duty and Heavy Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Geotour	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Grand Spirit	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Mazama	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Multi-Mile	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	National	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Ohtsu	Medium Duty and Heavy Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Ohtsu	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Sumitomo	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Sumitomo	Medium Duty and Heavy Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	Trailcutter AT4S	Light Duty Vehicle Tires
Sumitomo Rubber Industries, Ltd.	XTRRT	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	ARIZONIAN	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Avon	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Avon	Motorcycle tires
The Goodyear Tire & Rubber Company	Beltak	Retread
The Goodyear Tire & Rubber Company	BIG O	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Blackstone	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	BLUE STREAK TBA 8	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	BLUE STREAK TBA 9	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	BLUE STREAK-BLSTRK	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	BLUE STREAK-GDYR	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Centara	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Cooper	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Cooper	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Cooper	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dean	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dean	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dean PB	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Debica	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Debica	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Debica	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Diamondback	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Diplomat	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Douglas	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dunlop	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dunlop	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dunlop	Motorcycle tires
The Goodyear Tire & Rubber Company	Dunlop	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dunlop	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Dunlop	Motorcycle tires
The Goodyear Tire & Rubber Company	Durun	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Falke	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Fulda	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Fulda	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Fulda	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Futura	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Geotred	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Geotred	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Goodyear	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Goodyear	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Goodyear	Retread
The Goodyear Tire & Rubber Company	Hercules	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Ironman	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Kelly	Medium Duty and Heavy Duty Vehicle Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
The Goodyear Tire & Rubber Company	Kelly	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Kelly	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Lemans	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Lexington	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Loadrunner	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Mastercraft	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Mastercraft	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Mickey Thompson	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Mickey Thompson	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Mickey Thompson	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Motomaster	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Motrio	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Non-core brand	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	O'Green	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Omega	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Provato	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Remington	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Remington	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Roadmaster	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Roadstone	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Sava	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Sava	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Sava	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Sava	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Starfire	Light Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Starfire	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Steelmark	Medium Duty and Heavy Duty Vehicle Tires
The Goodyear Tire & Rubber Company	Ultima	Retread
Toyo Tire Holdings of Americas Inc.	ARCTIC CLAW	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	BIG O	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	FIRESTONE	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	IRONMAN	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	NITTO	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	ROAD HUGGER	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	TOYO	Light Duty Vehicle Tires
Toyo Tire Holdings of Americas Inc.	TOYO	Medium and Heavy Duty Vehicle Tires
Yokohama Tire Corporation	Galaxy	Medium Duty and Heavy Duty Vehicle Tires
Yokohama Tire Corporation	Yokohama	Light Duty Vehicle Tires
Yokohama Tire Corporation	Yokohama	Medium Duty and Heavy Duty Vehicle Tires
Yokohama TWS North America, Inc.	Mitas	Motorcycle Tires
ZC Rubber America Inc.	ADVANTA	Passenger Car Tires
ZC Rubber America Inc.	ADVANTA	Light Truck Tires
ZC Rubber America Inc.	ADVANTA	Medium Truck Tires
ZC Rubber America Inc.	AMERICAN TOURER	Passenger Car Tires
ZC Rubber America Inc.	AMERICAN TOURER	Light Truck Tires
ZC Rubber America Inc.	AMERICAN TOURER	Medium Truck Tires
ZC Rubber America Inc.	AMERICUS	Passenger Car Tires
ZC Rubber America Inc.	AMERICUS	Light Truck Tires
ZC Rubber America Inc.	AMERICUS	Medium Truck Tires
ZC Rubber America Inc.	AMP	Passenger Car Tires
ZC Rubber America Inc.	AMP	Light Truck Tires
ZC Rubber America Inc.	AMP	Medium Truck Tires
ZC Rubber America Inc.	ANGLER	Passenger Car Tires
ZC Rubber America Inc.	ANGLER	Light Truck Tires
ZC Rubber America Inc.	ANGLER	Medium Truck Tires
ZC Rubber America Inc.	ARISUN	Passenger Car Tires
ZC Rubber America Inc.	ARISUN	Light Truck Tires
ZC Rubber America Inc.	ARISUN	Medium Truck Tires
ZC Rubber America Inc.	ARISUN	Motorcycle tires
ZC Rubber America Inc.	BISON	Passenger Car Tires
ZC Rubber America Inc.	BISON	Light Truck Tires
ZC Rubber America Inc.	BISON	Medium Truck Tires
ZC Rubber America Inc.	BULL	Passenger Car Tires
ZC Rubber America Inc.	BULL	Light Truck Tires
ZC Rubber America Inc.	BULL	Medium Truck Tires
ZC Rubber America Inc.	CASTLE ROCK	Light Truck Tires
ZC Rubber America Inc.	CASTLE ROCK	Medium Truck Tires
ZC Rubber America Inc.	CAVALRY	Passenger Car Tires
ZC Rubber America Inc.	CAVALRY	Light Truck Tires
ZC Rubber America Inc.	CAVALRY	Medium Truck Tires
ZC Rubber America Inc.	CHAOYANG	Passenger Car Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
ZC Rubber America Inc.	CHAOYANG	Light Truck Tires
ZC Rubber America Inc.	CHAOYANG	Medium Truck Tires
ZC Rubber America Inc.	CHAOYANG	Motorcycle tires
ZC Rubber America Inc.	COSMO	Passenger Car Tires
ZC Rubber America Inc.	COSMO	Light Truck Tires
ZC Rubber America Inc.	COSMO	Medium Truck Tires
ZC Rubber America Inc.	DCENTI	Passenger Car Tires
ZC Rubber America Inc.	DCENTI	Light Truck Tires
ZC Rubber America Inc.	DCENTI	Medium Truck Tires
ZC Rubber America Inc.	DIDAR	Passenger Car Tires
ZC Rubber America Inc.	DIDAR	Light Truck Tires
ZC Rubber America Inc.	DIDAR	Medium Truck Tires
ZC Rubber America Inc.	DORAL	Passenger Car Tires
ZC Rubber America Inc.	DORAL	Light Truck Tires
ZC Rubber America Inc.	DORAL	Medium Truck Tires
ZC Rubber America Inc.	FINALIST	Passenger Car Tires
ZC Rubber America Inc.	FINALIST	Light Truck Tires
ZC Rubber America Inc.	FINALIST	Medium Truck Tires
ZC Rubber America Inc.	FORCELAND	Passenger Car Tires
ZC Rubber America Inc.	FORCELAND	Light Truck Tires
ZC Rubber America Inc.	FORCELAND	Medium Truck Tires
ZC Rubber America Inc.	FREEDOM HAULER	Passenger Car Tires
ZC Rubber America Inc.	FREEDOM HAULER	Light Truck Tires
ZC Rubber America Inc.	FREEDOM HAULER	Medium Truck Tires
ZC Rubber America Inc.	GOLDEN CROWN	Passenger Car Tires
ZC Rubber America Inc.	GOLDEN CROWN	Light Truck Tires
ZC Rubber America Inc.	GOLDEN CROWN	Medium Truck Tires
ZC Rubber America Inc.	GOODRIDE	Passenger Car Tires
ZC Rubber America Inc.	GOODRIDE	Light Truck Tires
ZC Rubber America Inc.	GOODRIDE	Medium Truck Tires
ZC Rubber America Inc.	GOODRIDE	Motorcycle tires
ZC Rubber America Inc.	GREMAX	Passenger Car Tires
ZC Rubber America Inc.	GREMAX	Light Truck Tires
ZC Rubber America Inc.	GREMAX	Medium Truck Tires
ZC Rubber America Inc.	HERCULES	Passenger Car Tires
ZC Rubber America Inc.	HERCULES	Light Truck Tires
ZC Rubber America Inc.	HERCULES	Medium Truck Tires
ZC Rubber America Inc.	HI-RUN	Passenger Car Tires
ZC Rubber America Inc.	HI-RUN	Light Truck Tires
ZC Rubber America Inc.	HI-RUN	Medium Truck Tires
ZC Rubber America Inc.	IRONMAN	Passenger Car Tires
ZC Rubber America Inc.	IRONMAN	Light Truck Tires
ZC Rubber America Inc.	IRONMAN	Medium Truck Tires
ZC Rubber America Inc.	MAGNA	Passenger Car Tires
ZC Rubber America Inc.	MAGNA	Light Truck Tires
ZC Rubber America Inc.	MAGNA	Medium Truck Tires
ZC Rubber America Inc.	MASTERTRACK	Passenger Car Tires
ZC Rubber America Inc.	MASTERTRACK	Light Truck Tires
ZC Rubber America Inc.	MASTERTRACK	Medium Truck Tires
ZC Rubber America Inc.	MILESTAR	Passenger Car Tires
ZC Rubber America Inc.	MILESTAR	Light Truck Tires
ZC Rubber America Inc.	MILESTAR	Medium Truck Tires
ZC Rubber America Inc.	MRT	Passenger Car Tires
ZC Rubber America Inc.	MRT	Light Truck Tires
ZC Rubber America Inc.	MRT	Medium Truck Tires
ZC Rubber America Inc.	NIPON	Passenger Car Tires
ZC Rubber America Inc.	NIPON	Light Truck Tires
ZC Rubber America Inc.	NIPON	Medium Truck Tires
ZC Rubber America Inc.	ORNATE	Passenger Car Tires
ZC Rubber America Inc.	ORNATE	Light Truck Tires
ZC Rubber America Inc.	ORNATE	Medium Truck Tires
ZC Rubber America Inc.	RADAR	Passenger Car Tires
ZC Rubber America Inc.	RADAR	Light Truck Tires
ZC Rubber America Inc.	RADAR	Medium Truck Tires
ZC Rubber America Inc.	RDR	Passenger Car Tires
ZC Rubber America Inc.	RDR	Light Truck Tires
ZC Rubber America Inc.	RDR	Medium Truck Tires
ZC Rubber America Inc.	RED FLAME	Passenger Car Tires
ZC Rubber America Inc.	RED FLAME	Light Truck Tires
ZC Rubber America Inc.	RED FLAME	Medium Truck Tires
ZC Rubber America Inc.	RISEN	Passenger Car Tires

Responsible Entity Name	Brand/Trade Name	Tire Type
ZC Rubber America Inc.	RISEN	Light Truck Tires
ZC Rubber America Inc.	RISEN	Medium Truck Tires
ZC Rubber America Inc.	SENTINEL	Passenger Car Tires
ZC Rubber America Inc.	SENTINEL	Light Truck Tires
ZC Rubber America Inc.	SENTINEL	Medium Truck Tires
ZC Rubber America Inc.	STERLING	Light Truck Tires
ZC Rubber America Inc.	STERLING	Medium Truck Tires
ZC Rubber America Inc.	SUPERCARGO	Passenger Car Tires
ZC Rubber America Inc.	SUPERCARGO	Light Truck Tires
ZC Rubber America Inc.	SUPERCARGO	Medium Truck Tires
ZC Rubber America Inc.	SUPERMAX	Passenger Car Tires
ZC Rubber America Inc.	SUPERMAX	Light Truck Tires
ZC Rubber America Inc.	SUPERMAX	Medium Truck Tires
ZC Rubber America Inc.	TAMARACK	Light Truck Tires
ZC Rubber America Inc.	TAMARACK	Medium Truck Tires
ZC Rubber America Inc.	TRAILFINDER	Passenger Car Tires
ZC Rubber America Inc.	TRAILFINDER	Light Truck Tires
ZC Rubber America Inc.	TRAILFINDER	Medium Truck Tires
ZC Rubber America Inc.	TRANSEAGLE	Passenger Car Tires
ZC Rubber America Inc.	TRANSEAGLE	Light Truck Tires
ZC Rubber America Inc.	TRANSEAGLE	Medium Truck Tires
ZC Rubber America Inc.	TRAVELSTAR	Passenger Car Tires
ZC Rubber America Inc.	TRAVELSTAR	Light Truck Tires
ZC Rubber America Inc.	TRAVELSTAR	Medium Truck Tires
ZC Rubber America Inc.	TRAZANO	Passenger Car Tires
ZC Rubber America Inc.	TRAZANO	Light Truck Tires
ZC Rubber America Inc.	TRAZANO	Medium Truck Tires
ZC Rubber America Inc.	TRAZANO	Motorcycle tires
ZC Rubber America Inc.	VENOM POWER	Passenger Car Tires
ZC Rubber America Inc.	VENOM POWER	Light Truck Tires
ZC Rubber America Inc.	WESTLAKE	Passenger Car Tires
ZC Rubber America Inc.	WESTLAKE	Light Truck Tires
ZC Rubber America Inc.	WESTLAKE	Medium Truck Tires
ZC Rubber America Inc.	WESTLAKE	Motorcycle tires
ZC Rubber America Inc.	YARTU	Passenger Car Tires
ZC Rubber America Inc.	YARTU	Light Truck Tires
ZC Rubber America Inc.	YARTU	Medium Truck Tires

Appendix C

SDS for Santoflex™ 6PPD Pastilles

SECTION 1. IDENTIFICATION

Product name	:	Santoflex(TM) 6PPD Pastilles
Product code	:	P3408704

Manufacturer or supplier's details

Company name of supplier	:	Flexsys Chemicals Belgium NV
Address	:	Scheldelaan 460, Haven 627 Antwerpen 2040
Emergency telephone	:	CHEMTREC: +1 703-741-5970

Recommended use of the chemical and restrictions on use

Recommended use	:	antioxidant (industrial) Stabilizer
Restrictions on use	:	None known.

SECTION 2. HAZARDS IDENTIFICATION

GHS classification in accordance with the OSHA Hazard Communication Standard (29 CFR 1910.1200)

Acute toxicity (Oral)	:	Category 4
Skin sensitization	:	Category 1
Reproductive toxicity	:	Category 1B

GHS label elements

Hazard pictograms :

Signal Word	:	Danger
Hazard Statements	:	H302 Harmful if swallowed. H317 May cause an allergic skin reaction. H360 May damage fertility or the unborn child.
Precautionary Statements	:	**Prevention:** P201 Obtain special instructions before use. P202 Do not handle until all safety precautions have been read and understood.

P261 Avoid breathing dust/ fume/ gas/ mist/ vapors/ spray.
P264 Wash skin thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P272 Contaminated work clothing should not be allowed out of the workplace.
P280 Wear protective gloves/ protective clothing/ eye protection/ face protection.

Response:

P301 + P312 + P330 IF SWALLOWED: Call a POISON CENTER/ doctor if you feel unwell. Rinse mouth.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P308 + P313 IF exposed or concerned: Get medical advice/ attention.
P333 + P313 If skin irritation or rash occurs: Get medical advice/ attention.
P363 Wash contaminated clothing before reuse.

Storage:

P405 Store locked up.

Disposal:

P501 Dispose of contents/ container to an approved waste disposal plant.

Other hazards

None known.

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance / Mixture : Substance

Substance name : N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine

CAS-No. : 793-24-8

Components

Chemical name	CAS-No.	Concentration (% w/w)
N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine	793-24-8	>= 95 - <= 100

Actual concentration is withheld as a trade secret

Flexsys is committed to the safety, health and environment of our employees, our customers, and the communities we operate within. As part of this commitment, Flexsys' Safety Data Sheets (SDS) are prepared in accordance with all applicable national and local regulations. The compositions of our documents reflect these requirements which include, but are not limited to, requirements under the Globally Harmonized System of Classification and Labeling (GHS). These compositions commonly involve the use of ranges versus specific analytical values. If you require a composition that is more specific , please refer to the Certificate of Analysis, sales specification, or contact your Customer Service Representative.

SECTION 4. FIRST AID MEASURES

If inhaled	:	Remove person to fresh air and keep comfortable for breathing. If breathing is difficult, give oxygen. Consult a physician if necessary.
In case of skin contact	:	Wash off immediately with soap and plenty of water while removing all contaminated clothes and shoes. If skin irritation or rash occurs: Get medical advice/ attention. Wash contaminated clothing before reuse.
In case of eye contact	:	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if symptoms occur.
If swallowed	:	Rinse mouth. Get medical attention if symptoms occur. Do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person.
Most important symptoms and effects, both acute and delayed	:	Harmful if swallowed. May cause an allergic skin reaction. May damage fertility or the unborn child.
Notes to physician	:	Treat symptomatically.

SECTION 5. FIRE-FIGHTING MEASURES

Suitable extinguishing media	:	Water spray Foam Dry powder Carbon dioxide (CO_2)
Unsuitable extinguishing media	:	Do not use a solid water stream as it may scatter and spread fire.
Specific hazards during fire fighting	:	Do not allow run-off from fire fighting to enter drains or water courses.
Hazardous combustion products	:	Carbon oxides Nitrogen oxides (NOx)
Further information	:	In case of fire and/or explosion do not breathe fumes.
Special protective equipment for fire-fighters	:	Wear an approved positive pressure self-contained breathing apparatus in addition to standard fire fighting gear.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protec-	:	Wear appropriate personal protective equipment.

tive equipment and emergency procedures		Avoid prolonged or repeated contact with skin. Avoid breathing dust/ fume/ gas/ mist/ vapors/ spray. Ensure adequate ventilation. Material can create slippery conditions. Local authorities should be advised if significant spillages cannot be contained.
Environmental precautions	:	Prevent further leakage or spillage if safe to do so. Avoid release to the environment. Collect spillage.
Methods and materials for containment and cleaning up	:	Sweep up and shovel into suitable containers for disposal.

SECTION 7. HANDLING AND STORAGE

Advice on safe handling	:	Wear appropriate personal protective equipment. Avoid breathing dust/ fume/ gas/ mist/ vapors/ spray. Handle product only in closed system or provide appropriate exhaust ventilation at machinery. Drain or remove substance from equipment prior to break-in or maintenance. Wash thoroughly after handling. Do not eat, drink or smoke when using this product. Contaminated work clothing should not be allowed out of the workplace.
Conditions for safe storage	:	Keep containers tightly closed in a dry, cool and well-ventilated place.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Ingredients with workplace control parameters

Contains no substances with occupational exposure limit values.

Engineering measures	:	Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level.

Personal protective equipment

Respiratory protection	:	Use a properly fitted, particulate filter respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection, use, and maintenance must be in accordance with regulatory requirements, if applicable. If engineering controls do not maintain airborne concentrations below recommended exposure limits (where

applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn.

Hand protection

Remarks : For prolonged or repeated contact use protective gloves. After contamination with product change the gloves immediately and dispose of them according to relevant national and local regulations.

Eye protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. Wear safety glasses with side shields (or goggles).

Skin and body protection : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Remove and wash contaminated clothing before re-use.

Protective measures : Ensure that eye flushing systems and safety showers are located close to the working place.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance : Pastilles

Color : purple, brown

Odor : aromatic

Odor Threshold : not determined

pH : not determined

Melting point/range : 120 °F / 49 °C
(1,013 hPa)

Boiling point/boiling range : 325 - 329 °F / 163 - 165 °C
(1.33 hPa)

Flash point : 396 °F / 202 °C
(1,013 hPa)
Method: Pensky-Martens closed cup

Evaporation rate : not determined

Flammability (solid, gas) : Not classified as hazardous.

Upper explosion limit / Upper flammability limit	:	not determined
Vapor pressure	:	0.000036 hPa (77 °F / 25 °C)
Relative vapor density	:	not determined
Relative density	:	0.995 (122 °F / 50 °C)
Density	:	995 kg/m3 (122 °F / 50 °C)
Solubility(ies)		
Water solubility	:	0.001 g/l (122 °F / 50 °C)
Solubility in other solvents	:	soluble Solvent: Hydrocarbons
Partition coefficient: n-octanol/water	:	log Pow: 4.68 (68 °F / 20 °C)
Autoignition temperature	:	1022 °F / 550 °C Method: VDI 2263 Blatt 1 2.6 Dust
Decomposition temperature	:	> 392 °F / > 200 °C
Viscosity		
Viscosity, kinematic	:	not determined
Explosive properties	:	Not classified
Oxidizing properties	:	Not classified
Molecular weight	:	268.44 g/mol

SECTION 10. STABILITY AND REACTIVITY

Reactivity	:	None reasonably foreseeable.
Chemical stability	:	Stable under normal conditions.
Possibility of hazardous reactions	:	None known.
Conditions to avoid	:	Heating in air.
Incompatible materials	:	Strong oxidizing agents
Hazardous decomposition products	:	Emits acrid smoke and fumes when heated to decomposition.

SECTION 11. TOXICOLOGICAL INFORMATION

Acute toxicity

Harmful if swallowed.

Product:

Acute oral toxicity : LD50 Oral (Rat): 893 mg/kg

Acute dermal toxicity : LD50 Dermal (Rabbit): > 7,940 mg/kg

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Acute oral toxicity : LD50 Oral (Rat): 893 mg/kg

Acute dermal toxicity : LD50 Dermal (Rabbit): > 7,940 mg/kg

Skin corrosion/irritation

Not classified based on available information.

Product:

Species : Rabbit
Exposure time : 72 h
Result : No skin irritation

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Species : Rabbit
Exposure time : 72 h
Result : No skin irritation

Serious eye damage/eye irritation

Not classified based on available information.

Product:

Species : Rabbit
Result : slight
Exposure time : 72 h

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Species : Rabbit
Result : slight
Exposure time : 72 h

Respiratory or skin sensitization

Skin sensitization

May cause an allergic skin reaction.

Respiratory sensitization

Not classified based on available information.

Product:

Test Type : Skin sensitization
Species : Guinea pig
Result : May cause sensitization by skin contact.

Test Type : Human experience
Result : May cause sensitization by skin contact.

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Test Type : Skin sensitization
Species : Guinea pig
Result : May cause sensitization by skin contact.

Test Type : Human experience
Result : May cause sensitization by skin contact.

Germ cell mutagenicity

Not classified based on available information.

Product:

Genotoxicity in vitro : Test Type: Mutagenicity - Bacterial
Metabolic activation: +/- activation
Method: Bacterial Reverse Mutation Assay
Result: negative

Metabolic activation: +/- activation
Method: In vitro Mammalian Chromosome Aberration Test
Result: positive

Genotoxicity in vivo : Test Type: various
Species: Rat
Result: negative

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Genotoxicity in vitro : Test Type: Mutagenicity - Bacterial
Metabolic activation: +/- activation
Method: Bacterial Reverse Mutation Assay
Result: negative

Metabolic activation: +/- activation
Method: In vitro Mammalian Chromosome Aberration Test

		Result: positive
Genotoxicity in vivo	:	Test Type: various Species: Rat Result: negative

Carcinogenicity

Not classified based on available information.

Product:

Species	:	Rat, male and female
Application Route	:	Ingestion
Method	:	OECD Test Guideline 451
Remarks	:	Based on available data, the classification criteria are not met.

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Species	:	Rat, male and female
Application Route	:	Ingestion
Method	:	OECD Test Guideline 451
Remarks	:	Based on available data, the classification criteria are not met.

IARC	No ingredient of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
OSHA	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.
NTP	No ingredient of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

Reproductive toxicity

May damage fertility or the unborn child.

Product:

Effects on fertility	:	Species: Rat, male Application Route: Oral General Toxicity Parent: NOAEL: 60 mg/kg/day General Toxicity F1: NOAEL: 60 mg/kg/day Fertility: NOAEL: 60 mg/kg/day Early Embryonic Development: NOAEL: 20 mg/kg/day Method: OECD Test Guideline 443 Species: Rat, female Application Route: Oral General Toxicity Parent: NOAEL: 60 mg/kg/day General Toxicity F1: NOAEL: 60 mg/kg/day Fertility: NOAEL: 7 mg/kg/day Early Embryonic Development: NOAEL: 20 mg/kg/day Method: OECD Test Guideline 443

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Effects on fertility : Species: Rat, male
Application Route: Oral
General Toxicity Parent: NOAEL: 60 mg/kg/day
General Toxicity F1: NOAEL: 60 mg/kg/day
Fertility: NOAEL: 60 mg/kg/day
Early Embryonic Development: NOAEL: 20 mg/kg/day
Method: OECD Test Guideline 443

Species: Rat, female
Application Route: Oral
General Toxicity Parent: NOAEL: 60 mg/kg/day
General Toxicity F1: NOAEL: 60 mg/kg/day
Fertility: NOAEL: 7 mg/kg/day
Early Embryonic Development: NOAEL: 20 mg/kg/day
Method: OECD Test Guideline 443

STOT-single exposure

Not classified based on available information.

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Assessment : Not classified

STOT-repeated exposure

Not classified based on available information.

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Assessment : Not classified

Repeated dose toxicity

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Species : Rat, male and female
NOAEL : 20 mg/kg
Application Route : by gavage
Exposure time : 28 days

Species : Rat, male and female
NOAEL : 13.5 mg/kg
Application Route : in feed
Exposure time : 2 year

Aspiration toxicity

Not classified based on available information.

Product:

Not classified

Experience with human exposure

Product:

Inhalation	:	Remarks: None known.
Skin contact	:	Remarks: May cause an allergic skin reaction.
Eye contact	:	Remarks: None known.
Ingestion	:	Remarks: Harmful if swallowed.

SECTION 12. ECOLOGICAL INFORMATION

Ecotoxicity

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Toxicity to fish	:	LC50 (Oryzias latipes (Japanese medaka)): 0.028 mg/l Exposure time: 96 h
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Daphnia magna (Water flea)): 0.13 mg/l Exposure time: 48 h Remarks: Read-across from a similar material
Toxicity to algae/aquatic plants	:	EC50 (Pseudokirchneriella subcapitata (green algae)): 0.335 mg/l Exposure time: 72 h Remarks: Read-across from a similar material NOEC: 0.23 mg/l Exposure time: 72 h Remarks: Read-across from a similar material
Toxicity to fish (Chronic toxicity)	:	NOEC (Oryzias latipes (Japanese medaka)): 0.0037 mg/l Exposure time: 30 d
Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity)	:	NOEC (Daphnia magna (Water flea)): 0.007 mg/l Exposure time: 21 d Remarks: Read-across from a similar material

Persistence and degradability

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Biodegradability	:	Method: Ready Biodegradability: Modified MITI Test (I) Remarks: Not readily biodegradable.

Stability in water : Degradation half life: 2.9 h
Hydrolysis: at 24 °C

Bioaccumulative potential

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Bioaccumulation : Bioconcentration factor (BCF): 569
Remarks: Bioaccumulation is unlikely.

Partition coefficient: n-octanol/water : log Pow: 4.68 (68 °F / 20 °C)

Mobility in soil

Components:

N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine:

Distribution among environmental compartments : log Koc: 3.45
Method: QSAR model

Other adverse effects

No data available

SECTION 13. DISPOSAL CONSIDERATIONS

Disposal methods

Waste from residues : Dispose of in accordance with local regulations.

SECTION 14. TRANSPORT INFORMATION

International Regulations

IATA-DGR

UN/ID No. : UN 3077
Proper shipping name : Environmentally hazardous substance, solid, n.o.s.
(N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine)
Class : 9
Packing group : III
Labels : Miscellaneous
Packing instruction (cargo aircraft) : 956
Packing instruction (passenger aircraft) : 956

IMDG-Code

UN number : UN 3077
Proper shipping name : ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S.
(N-1,3-Dimethylbutyl-N'-phenyl-p-phenylenediamine)

Class	:	9
Packing group	:	III
Labels	:	9
EmS Code	:	F-A, S-F
Marine pollutant	:	yes

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

Not applicable for product as supplied.

Domestic regulation

49 CFR

Not regulated as a dangerous good

Remarks : Shipping in package sizes of less than 5 L (liquids) or 5 KG (solids) may lead to a non-regulated classification.

Special precautions for user

Remarks : Shipping in package sizes of less than 5 L (liquids) or 5 KG (solids) may lead to a non-regulated classification.

The transport classification(s) provided herein are for informational purposes only, and solely based upon the properties of the unpackaged material as it is described within this Safety Data Sheet. Transportation classifications may vary by mode of transportation, package sizes, and variations in regional or country regulations.

SECTION 15. REGULATORY INFORMATION

CERCLA Reportable Quantity

This material does not contain any components with a CERCLA RQ.

SARA 304 Extremely Hazardous Substances Reportable Quantity

This material does not contain any components with a section 304 EHS RQ.

SARA 302 Extremely Hazardous Substances Threshold Planning Quantity

This material does not contain any components with a section 302 EHS TPQ.

SARA 311/312 Hazards : Respiratory or skin sensitization
Reproductive toxicity
Acute toxicity (any route of exposure)

SARA 313 : This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

California Prop. 65

This product does not contain any chemicals known to the State of California to cause cancer, birth, or any other reproductive defects.

The ingredients of this product are reported in the following inventories:

TCSI : On the inventory, or in compliance with the inventory

TSCA : All substances listed as active on the TSCA inventory

AIIC	:	On the inventory, or in compliance with the inventory
DSL	:	All components of this product are on the Canadian DSL
ENCS	:	On the inventory, or in compliance with the inventory
ISHL	:	On the inventory, or in compliance with the inventory
KECI	:	On the inventory, or in compliance with the inventory
PICCS	:	On the inventory, or in compliance with the inventory
IECSC	:	On the inventory, or in compliance with the inventory
NZIoC	:	On the inventory, or in compliance with the inventory
TECI	:	On the inventory, or in compliance with the inventory

TSCA list

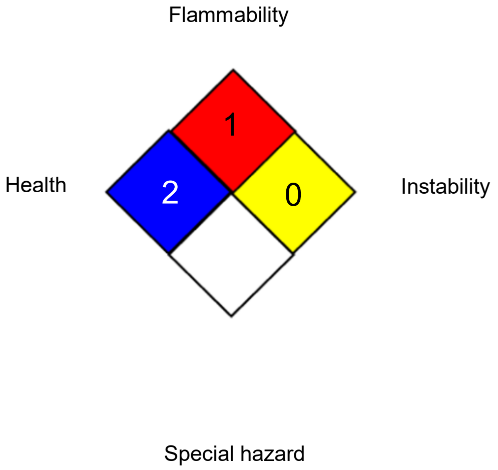
No substances are subject to a Significant New Use Rule.

No substances are subject to TSCA 12(b) export notification requirements.

SECTION 16. OTHER INFORMATION

Further information

NFPA 704:



HMIS® IV:

HEALTH	*	2
FLAMMABILITY		1
PHYSICAL HAZARD		0

HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. The "*" represents a chronic hazard, while the "/" represents the absence of a chronic hazard.

Full text of other abbreviations

AIIC - Australian Inventory of Industrial Chemicals; ASTM - American Society for the Testing of Materials; bw - Body weight; CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN - Standard of the German Institute for Standardisation; DOT - Department of Transportation; DSL - Domestic Substances List (Canada); ECx - Concentration associated with x% response; EHS - Extremely Hazardous Substance; ELx - Loading rate associated with x% response; EmS - Emergency Schedule; ENCS - Existing and New Chemical Substances (Japan); ErCx - Concentration associated with x% growth rate response; ERG - Emergency Response Guide; GHS - Globally Harmonized System; GLP - Good Laboratory Practice; HMIS - Hazardous Materials Identification System; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; IBC - International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk; IC50 - Half maximal inhibitory concentration; ICAO - International Civil Aviation Organization; IECSC - Inventory of Existing Chemical Substances in China; IMDG - International Maritime Dangerous Goods; IMO - International Maritime Organization; ISHL - Industrial Safety and Health Law (Japan); ISO - International Organisation for Standardization; KECI - Korea Existing Chemicals Inventory; LC50 - Lethal Concentration to 50 % of a test population; LD50 - Lethal Dose to 50% of a test population (Median Lethal Dose); MARPOL - International Convention for the Prevention of Pollution from Ships; MSHA - Mine Safety and Health Administration; n.o.s. - Not Otherwise Specified; NFPA - National Fire Protection Association; NO(A)EC - No Observed (Adverse) Effect Concentration; NO(A)EL - No Observed (Adverse) Effect Level; NOELR - No Observable Effect Loading Rate; NTP - National Toxicology Program; NZIoC - New Zealand Inventory of Chemicals; OECD - Organization for Economic Co-operation and Development; OPPTS - Office of Chemical Safety and Pollution Prevention; PBT - Persistent, Bioaccumulative and Toxic substance; PICCS - Philippines Inventory of Chemicals and Chemical Substances; (Q)SAR - (Quantitative) Structure Activity Relationship; RCRA - Resource Conservation and Recovery Act; REACH - Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals; RQ - Reportable Quantity; SADT - Self-Accelerating Decomposition Temperature; SARA - Superfund Amendments and Reauthorization Act; SDS - Safety Data Sheet; TCSI - Taiwan Chemical Substance Inventory; TECI - Thailand Existing Chemicals Inventory; TSCA - Toxic Substances Control Act (United States); UN - United Nations; UNRTDG - United Nations Recommendations on the Transport of Dangerous Goods; vPvB - Very Persistent and Very Bioaccumulative

Revision Date : 05/04/2022

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

US / Z8

Appendix D

Survey Concerning 6PPD Alternatives Sent to Consortium Members

Consortium Survey

Background

In order to assist the consortium in preparing an Alternative Analysis in California on behalf of the consortium members, the consortium members are required to respond to information surveys. Companies that joined the consortium when it was first formed have already completed this survey. We now ask that companies that have newly joined complete the survey as well.

The DTSC Safer Consumer Products Regulations define "alternative" to mean any of the following:

- "Removal of Chemical(s) of Concern from a Priority Product, with or without the use of one or more replacement chemicals;
- Reformulation or redesign of a Priority Product and/or manufacturing process to eliminate or reduce the concentration of Chemical(s) of Concern in the Priority Product;
- Redesign of a Priority Product and/or manufacturing process to reduce or restrict potential exposures to Chemical(s) of Concern in the Priority Product; or
- Any other change to a Priority Product or a manufacturing process that reduces the potential adverse impacts and/or potential exposures associated with the Chemical(s) of Concern in the Priority Product, and/or the potential adverse waste and end-of-life effects associated with the Priority Product."

As part of the alternatives analysis process, the consortium is required to assess all aspects of the definition of alternative listed above. Since information regarding removal of 6PPD, reformulation, or redesign may be considered confidential business information, outside counsel is assisting us in collecting and aggregating information to ensure consortium member proprietary data and information remains confidential.

Individual company responses to survey questions, submitted to outside counsel, will not be shared with USTMA. Outside counsel will summarize the information received from companies and will then work with individual companies to obtain approval for the anonymized summary responses to each question. Summary, genericized responses will be shared with USTMA and consortium members.

Please provide responses to the survey questions below in Microsoft Word. **Please send your responses to [contact information] by [DUE DATE]**. Please do not copy any USTMA staff on your response to outside counsel.

Categorizing Possible Alternatives

The Consortium Alternatives Analysis Working Group has identified a preliminary list of possible alternatives. The Working Group has also been working to identify and collect information regarding the performance and toxicity of these potential alternatives. Based on the information the working group was able to identify in the public domain regarding performance and toxicity, the working group has grouped possible alternatives into four categories (based on information regarding chemical performance):

1. Data/information confirms these chemicals are not suitable alternatives
2. Chemical structure confirms these chemicals are not suitable alternatives
3. Chemical structure of these chemicals indicates they may be possible alternatives but there is no performance or toxicity data/information to confirm
4. Chemical structure and initial data/information for these chemicals demonstrates they could be possible alternative

Survey Questions

For survey questions 1-4, please consult list of potential alternatives in responding to the questions below.

1) **Chemical Alternative Approach: An addition of a different chemical or chemicals in place of 6PPD.**
    a. Category 3 and Category 4 may be possible alternatives. Please review the Category 3 and Category 4 chemicals listed in the attached. Category rankings are found in column I:

    [Attachment containing list of chemicals under consideration from Gradient]

    b. Please provide any data/information on chemicals on the alternatives list or related compounds that would change the conclusion of Category 3 or Category 4.
    c. Please provide any data/information on chemicals that are on the alternatives list, or related compounds that would **support** the overall conclusion of Category 3 or Category 4.
    d. Please provide any data/information on chemical toxicity of the chemicals on the alternatives list or related compounds that would change or support the overall conclusion of Category 3 or Category 4.
    e. In general: If known, please provide any data/information on other chemical approaches that are a lower hazard, **available, functionally acceptable, and technically feasible** alternative that would eliminate the need for 6PPD.

2) **The Safer Consumer Products Regulations require the consortium to consider whether 6PPD can be <u>removed</u> from tires, with or without the use of one or more replacement chemicals.**
    a. Please review the list of potential alternatives and add any additional chemicals that your company recommends the consortium consider as part of the alternatives analysis. Note, alternatives should have a lower hazard profile and should be functionally acceptable, technically feasible, and economically viable.
    b. Does your company have any information/data that demonstrates that 6PPD can be removed from tires?
    c. Please review the list of potential alternatives and provide any information that would change the categorization of the potential alternative.
    d. For possible alternative chemicals that have the needed chemical structure and that have initial data/information on performance and/or toxicity which demonstrates these chemicals may be possible alternatives - please provide any additional information your company might have regarding performance and/or toxicity of these chemicals.

3) The Safer Consumer Products Regulations require the consortium to consider whether tires can be reformulated or redesigned to eliminate or reduce the concentration of 6PPD in tires.

a. Please provide any data and/or information that your company has regarding the ability to reformulate tires to reduce the amount of 6PPD used in tread or sidewall (not including saturated polymers).
   i. What worked? What did not work?
   ii. Is it currently used in production or planned for future production? If planned for future production, what is the timing for that launch?

b. Please provide any data/information on reformulation approaches using SATURATED polymers that reduce the amount of 6PPD used in tread or sidewall.
   i. What worked? What did not work?
   ii. Is it currently used in production or planned for future production? If planned for future production, what is the timing for that launch?

4) The Safer Consumer Products Regulations require the consortium to consider whether tires can be redesigned to reduce or restrict potential exposures to 6PPD. This may include a change to the configuration or construction of a tire to reduce or eliminate the need for 6PPD.

a. Please provide any data/information on a construction feature that would eliminate or reduce the amount of 6PPD used in a tire.
   i. What has worked? What has not worked?
   ii. Is it currently used in production or planned for future production? If planned for future production, what is the timing for that launch?

5) Other Approaches

a. Please share any data/information regarding any other approaches beyond those listed above that can be used to reduce/eliminate/reformulate/reconfigure tires to remove/reduce 6PPD. For example - exterior coating or veneer applications, improved tread wear/lower skid, other sidewall solutions that may not work for tread.

6) Use of 6PPD

a. USTMA has gathered preliminary information regarding the use of 6PPD. Please review the statement below and provide any recommended edits based on the use of 6PPD by your company.
   i. “Some consortium members began using 6PPD in tire manufacturing in the mid 1960’s and early 1970’s. However, as tire wear life increased in the 1990s, 6PPD became more widely used by consortium members in the early 2000s.”

Appendix E

Derivation of Estimated Tire Shipments into the State of California

Derivation of Estimated Tire Shipments into the State of California

The SCP regulations require companies preparing an AA to include data on the number of product units sold in the State of California. Consortium members do not have data on products sold in California because products are typically sold by third parties. USTMA does collect data on total US shipments of tires by year, but data are not available at the statewide level. This data nonetheless allows us to approximate tire shipments to the State of California, which can be used as a proxy for tire sales. The USTMA shipment data for 2022 are shown below.

Table E.1 USTMA US Tire Shipments for 2022

Vehicle Category	US Tire Shipments in 2022 (Excluding Exports)
Passenger cars/Light Truck	298,847,000
Heavy-duty Truck/Bus	33,139,000
Total	331,986,000

Notes:
US = United States; USTMA = U.S. Tire Manufacturers Association.
Source: U.S. Tire Manufacturers Association (USTMA) Factbook 2024

To determine what percentage of total US tire shipments are attributable to California, 2022 passenger car, bus, and motorcycle vehicle registrations for the US and California were obtained directly from the Federal Highway Administration (FHWA)

Table E.2 FHWA Motor Vehicle Registration Data for 2022

Jurisdiction	Automobiles	Buses	Trucks[1]	Motorcycles	All Vehicles
California	13,796,109	95,965	16,424,539	802,500	31,119,113
US Total	99,946,870	954,119	172,932,334	9,567,664	283,400,986

Notes:
FHWA = Federal Highway Administration; US = Unites States.
(1) Trucks as described by the FHWA includes light duty trucks, heavy duty trucks, vans, and sport vehicle utilities (SUVs).
Source: US Dept. of Transportation (US DOT), Federal Highway Administration (FHWA). 2022. "Highway Statistics 2022." Accessed on March 6, 2024 at https://www.fhwa.dot.gov/policyinformation/statistics/2022/.

The FHWA motor vehicle registration data reports total "trucks" registrations to include heavy duty trucks, light duty trucks, vans, and SUVs; whereas USTMA separates data for heavy duty and light duty trucks. The total number of "trucks" reported in the FHWA data use percentages from a US National Highway Traffic Safety Administration (NHTSA) report, which provided more detailed classifications (*i.e.*, passenger cars, light duty trucks, large trucks, motorcycles, and busses) but only at the national level. The latest publicly available vehicle registration data from NHTSA is from 2021, published in 2023 (NHTSA, 2023). Unfortunately, 2022 data is not yet publicly available.

Table E.3 Latest NHTSA US Motor Vehicle Registration Data (2021)

Vehicle Type	2021 US Motor Vehicle Registrations	Percent of Total
Passenger cars	107,934,093	35.65%
Light duty trucks	170,108,546	56.19%
Large trucks (*i.e.,* heavy duty trucks)	13,859,181	4.58%
Motorcycles	9,881,414	3.26%
Buses	939,219	0.31%
Calculations:		
Combined light and heavy duty trucks	183,967,727	60.77%
Percent of light duty trucks out of combined truck numbers		92.5%
Percent of heavy duty out of combined truck numbers		7.5%

Notes:
NHTSA = National Highway Traffic Safety Administration; US = United States.
Source: US Dept. of Transportation (US DOT), National Highway Traffic Safety Administration (NHTSA), National Center for Statistics and Analysis (NCSA). December 2023. "Traffic Safety Facts 2021: A Compilation of Motor Vehicle Crash Data." DOT HS 813 527. 225p. Accessed on March 20, 2024 at https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813527.

The abovementioned NHTSA data indicates that light duty trucks were 92.5% of the combined truck number and heavy duty trucks were 7.5% of the total truck number. These percentages were applied to the FHWA reported California "truck" registrations to allocate these trucks to the proper category. The passenger car/light duty truck (again, including vans and SUVs) and heavy duty truck/bus combined categories, were then constructed by adding the appropriate numbers. The California percentage of national vehicle registrations in each category was then multiplied against US tire shipments in those categories to arrive at California specific estimates of tires that were shipped and likely to be used in California.

Table E.4 Estimated Annual Shipments of the Priority Product in California

Vehicle Category	Vehicle Registrations in 2022			USTMA Tire Shipments in 2022	
	US	CA	CA% (calc.)	US	CA (est.)
Passenger/Light Duty Truck	259,909,278	28,988,808	11.2%	298,847,000	33,332,000
Heavy Duty Truck/Bus	13,924,044	1,327,805	9.5%	33,139,000	3,160,000
Total	273,833,322	30,316,613	11.1%	331,986,000	36,492,000

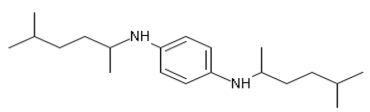
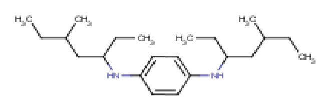
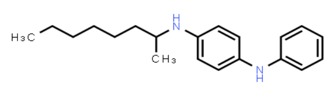
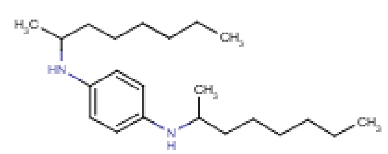
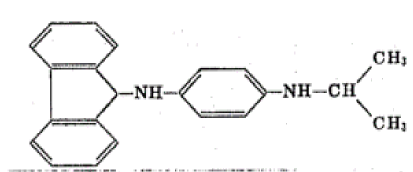
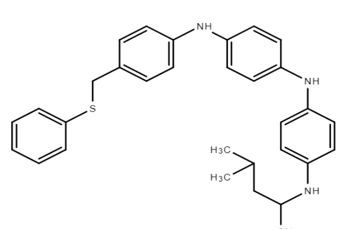
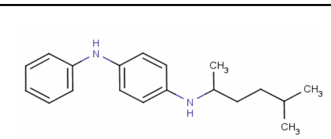
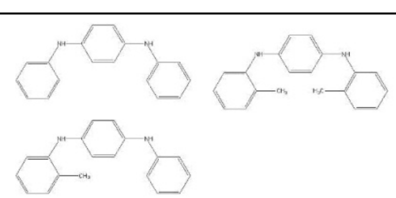
Notes:
CA = California; calc. = Calculated; est. = Estimated; US = United States; USTMA = U.S. Tire Manufacturers Association.

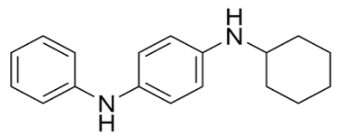
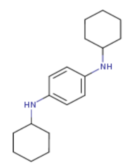
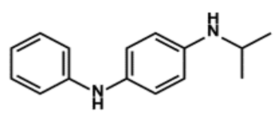
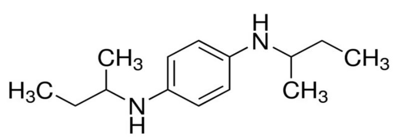
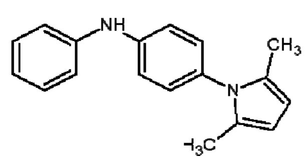
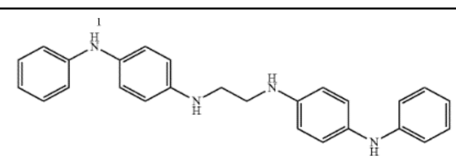
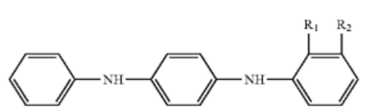
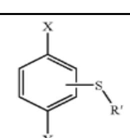
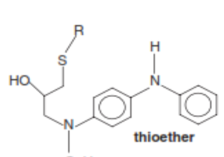
As indicated in the table above, an estimated 33,332,000 passenger car/light duty truck tires were shipped to California in 2022 and an estimated 3,160,000 heavy duty truck and bus tires were shipped to California in that year, for an estimated total number of tires shipped to California in 2022 at 36,492,000 units. Data on motorcycle tires are not included in this count because USTMA does not collect data on motorcycle tires. As shown above in the NHTSA data, motorcycle tires represent a very small portion of the overall vehicle fleet and this would not be expected to significantly different for California.

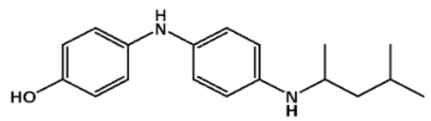
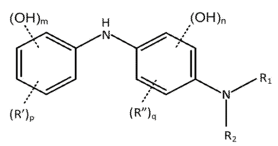
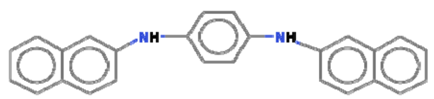
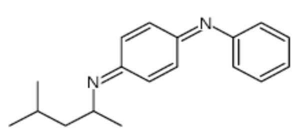
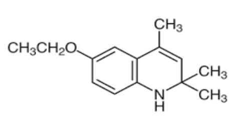
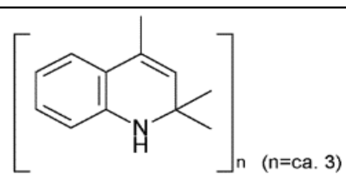
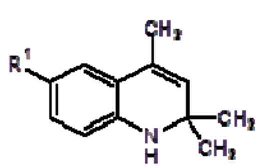
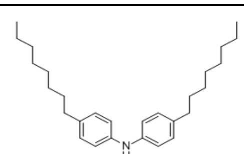
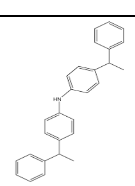
Appendix F

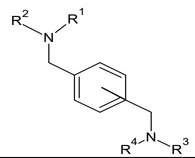
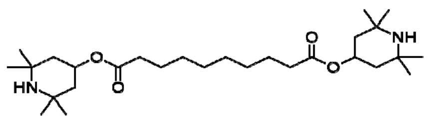
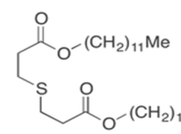
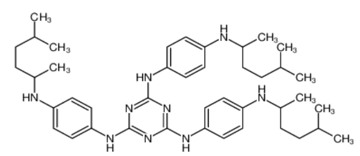
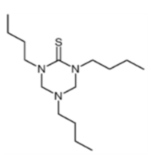
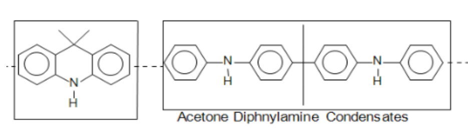
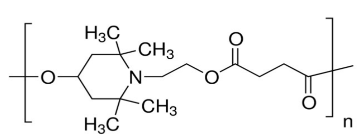
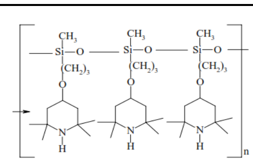
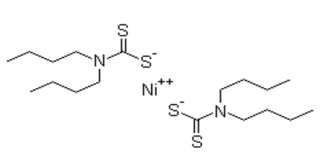
List of All Candidate Alternatives Identified and Reviewed by the Consortium

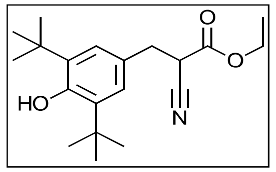
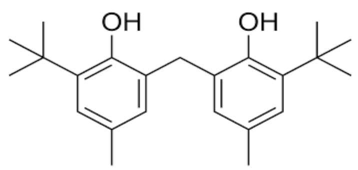
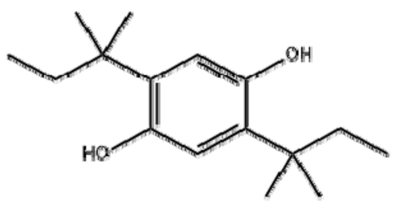
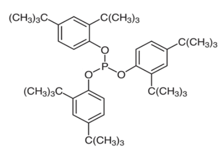
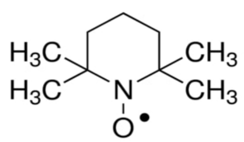
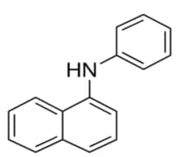
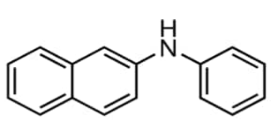
Appendix F. List of All Candidate Alternatives Identified and Reviewed by the Consortium

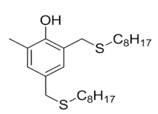
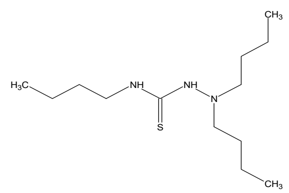
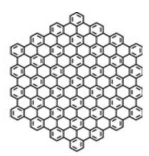
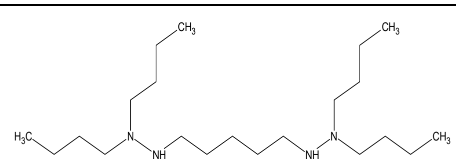
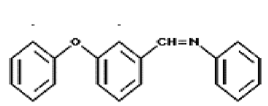
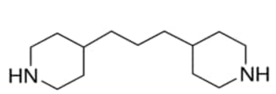
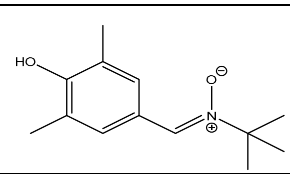
Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Phenylene Diamine		77PD	N,N'-Bis(1,4-dimethylpentyl)-phenylenediamine; Tenamene 4; Santoflex 77; Antioxidant 4030; 1-N,4-N-Bis(5-methylhexan-2-yl)benzene-1,4-diamine; UOP 788	3081-14-9	CC(C)CCC(C)NC1=CC=C(C=C1)NC(C)CCC(C)C	Fatigue Oxygen Ozone	1	1	2	Yes	Migrates faster than 6PPD, so not as effective in long term protection.	7, 8
Phenylene Diamine		Flexzone 8L UOP 88 DEMPD	N,N'-Bis(1-ethyl-3-methylpentyl)-p-phenylenediamine	139-60-6	CCC(C)CC(CC)NC1=CC=C(C=C1)NC(CC)CC(C)CC	Fatigue Oxygen Ozone	No data but expected to perform similar to 77PD	N/A	1	Probable	Expected to migrate faster than 6PPD. Reported as a commercial antiozonant in the 1970s.	91, 92, 95
Phenylene Diamine		UOP 688	N-1-Methylheptyl-N'-phenyl-p-phenylenediamine	15233-47-3	CCCCCCC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	Fatigue Oxygen Ozone	No data but expected to perform similar to 7 PPD	N/A	2	Probable	Expected to migrate faster than 6PPD. Reported as a commercial antiozonant in the 1970s.	90, 92
Phenylene Diamine		UOP 288	Di-2-octyl-p-phenylenediamine Elastozone 30	103-96-8	CCCCCCC(C)NC1=CC=C(C=C1)NC(C)CCCCCC	Fatigue Oxygen Ozone	No data but expected to perform similar to 7 PPD	N/A	2	Probable	Expected to migrate faster than 6PPD. Reported as a commercial antiozonant in the 1970s.	92,125
Phenylene Diamine		N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	N' -Phenyl.N-Fluorenyl-Para-Phenylenediamine	Not available	C1=C(NC(C=CC2)=CC=2)C=CC(=C1)NC(C(C1=CC2)=CC=2)C(=CC=C2)C1=C2	Fatigue Oxygen Ozone	4	3	3	Probable	In static ozone tests the compound was equivalent to 77PD	93
Phenylene Diamine		N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	N-(p-phenylthiomethylphenyl)-N'-(1,3 dimethyl-butyl)-p-phenylenediamine	Not available	C1=CC=C(C=C1)SCC1C=CC(=CC=1)NC1=CC=C(C=C1)NC(C)CC(C)C	Fatigue Oxygen Ozone	4	4	3	Probable	Equivalent to 6PPD in dynamic ozone testing - similar in other tests.	94
Phenylene Diamine		7PPD	N-(1,4-Dimethylpentyl)-N'-phenyl-p-phenylendiamine	3081-01-4	CC(C)CCC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	Fatigue Oxygen Ozone	4	Unclear, maybe 1	1	Probable	Similar antiozonant properties to 6PPD; virtually equivalent dynamic ozone in ESBR.	9, 122
Phenylene Diamine		DAPD BENPAT Wingstay 100	Wingstay 100; 1,4-Benzenediamine,N,N'-diphenylj-methyl derivatives; 1,4-Benzenediamine, N,N'-mixed tolyl and xylyx derivatives; Hydroquinone,o-toludine,xylidine condensate	68478-45-5	N/A, Multi-Constituent	Fatigue Oxygen Ozone	1	1	1	Yes	Slower to migrate than 6PPD; not as effective an antiozonant as 6PPD.	1, 10, 138, 118, 119

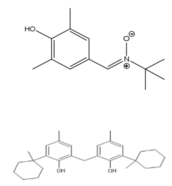
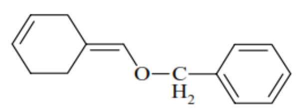
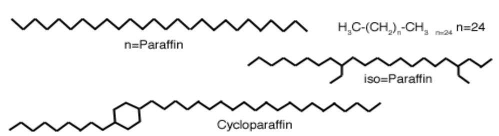
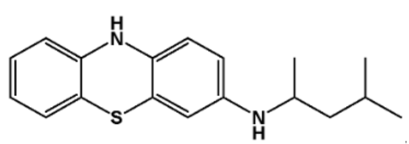
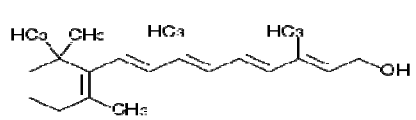
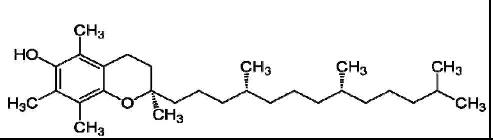
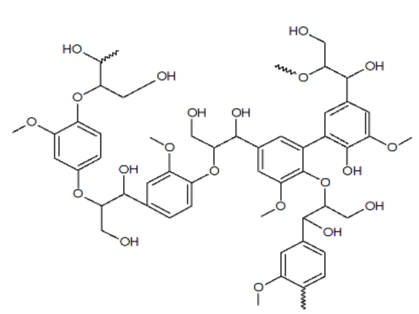
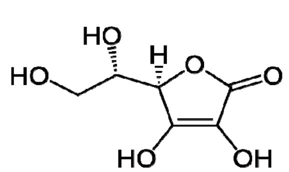
Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Phenylene Diamine		Flexzone 6H Vulkacit 4010 CPPD	N-Cyclohexyl-N'-phenyl-p-phenylenediamine	101-87-1	C1CCC(CC1)NC2=CC=C(C=C2)NC3=CC=CC=C3	Fatigue Oxygen Ozone	3	Unclear, maybe 1	2	Probable	Antioxidant and antiozonant similar to 6PPD.	55,56,57,123
Phenylene Diamine		UOP 26 CCPD	N,N'-Dicyclohexyl-p-phenylenediamine	4175-38-6	C1CCC(CC1)NC2=CC=C(C=C2)NC3CCCCC3	"Although no specific uses for N,N'-Dicyclohexyl-4-phenylenediamine (CCPD) were identified, based on similarity to other phenylenediamines, it is presumed to be used as an antioxidant / antiozonant, fuel additive, and in monomer distillation" ref. 77 p. i	3	Unclear	2	Probable	Not commonly used as a polymer stabilizer. Expected to have characteristics similar to 7,7 PD.	76,77
Phenylene Diamine		IPPD	N-Isopropyl-N'-phenyl-1,4-phenylenediamine; Stanguard IPPD	101-72-4	CC(C)NC1=CC=C(C=C1)NC2=CC=CC=C2	Fatigue Oxygen Ozone	4	1	1	Yes	More water soluble than 6PPD; quinone formation probable.	1,2
Phenylene Diamine		N,N'-Di-sec-butyl-p-phenylenediamine 44PD	4,4 PD Antioxidant 22 Santoflex 44 UOP 5	101-96-2	CCC(C)NC1=CC=C(C=C1)NC(C)CC	Fatigue (probable) Oxygen Ozone (not good after heat aging)	1	3	1	Probable	Used as an antioxidant in gasoline and has been reportedly used as an antioxidant and antiozonant in SBR.	74, 74a
Phenylene Diamine		None	4-(2,5-Dimethyl-1H-pyrrol-1-yl)-N-phenylaniline; N-Phenyl-4-(2,5-dimethyl-1H-pyrrole-1-yl)aniline	Not available	C1=CC=C(C=C1)NC1C=CC(=CC=1)N(C1C)C(=CC=1)C	Fatigue (probable, not known) Oxygen (probable, not known) Ozone	4	3	3	Probable, but predicted to be much less than 6PPD	Shown to be an effective antiozonant in rubber. May have less tendency to form quinone because of aromatic pyrrole substructure.	2 (Table 6.2), 14, 15
Phenylene Diamine		None	N,N - (Ethane-1,2-diyl) bis (N-phenylbenzene-1 4-diamine; 1-N-[2-(4-anilinoanilino)ethyl]-4-N-phenylbenzene-1,4-diamine	Not available	C1C=CC=C(C=1)NC(C=CC1NCCNC(C=CC2NC(=CC=C3)C=C3)=CC=2)=CC=1	Fatigue Oxygen Ozone	4	2	3	Probable, but size of quinone molecule may affect toxicity	This and similar materials were shown to be as effective as 6PPD for ozone protection of nitrile rubber. Quinones from this material may be less toxic due to size of molecule.	24,25, 98 (Note the patents contain references to similar materials)
Phenylene Diamine		None	4-N-(2,3-Dimethylphenyl)-1-N-phenylbenzene-1,4-diamine- R1 and R2 are methyl	Not available	C1=CC=C(C=C1)NC1=CC=C(C=C1)NC(C1)=C(C(C)=CC=1)C	Fatigue Oxygen Ozone	3	5	2	Probable	No comment	99
Phenylene Diamine	 X and Y are NH-Aryl and R' is alkyl or aryl	None	N,N'-Diphenyl-2-(butylthio)-p-phenylenediamine if R' is n-butyl	Not available	C1C=C(C=CC=1)NC(C=C1)=C(C=C1NC(C=CC1)=CC=1)SCCCC	Fatigue Oxygen Ozone	1	3	3	Possible	Data indicates poorer performance for dynamic ozone	100, 101
Phenylene Diamine (Kruger)		RU997 Irgazone 997	Reaction product of N-phenyl-N'-(1,3 dimethylbutyl)-p-phenylenediamine with an alkyl glycidylthioether.	444992-04-5	C1=CC(=CC=C1)NC1C=CC(=CC=1)N(CC(O)CSC(C)(C)CCCCCCCCC)C(CC(C)C)C	Fatigue Oxygen Ozone	3	5	3	Probable	Non-staining and had been approved for some food use in Europe.	46,47,48

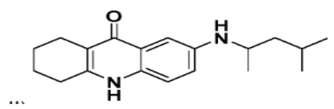
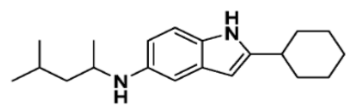
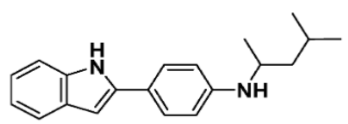
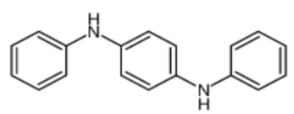
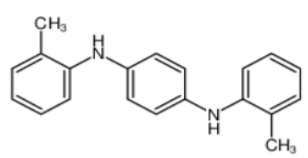
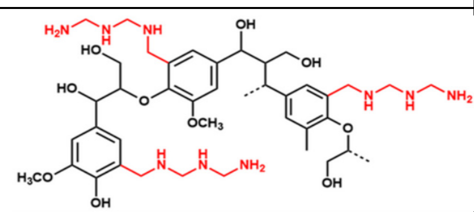
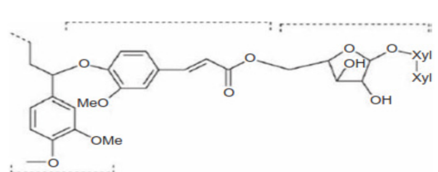
Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Phenylene diamine		4-[4-(4-Methylpentan-2-ylamino)anilino]phenol	Not available	Not available	C1(O)=CC=C(C=C1)NC1=CC=C(C=C1)NC(C)CC(C)C	Oxygen but also claimed as antiozonant	3	3	5	Probable	Prediction of performance based on bond strength; no ozone data.	117, 124
Phenylene diamine		This is a class of compounds - Reference uses case where R1 and R2 are methyl; n,p and q are zero and m=1 and is in the para position	Reference example is 4-((4-(dimethylamino)phenyl)amino)phenol	Reference compound is 6358-22-1	CN(C)C1=CC=C(C=C1)NC2=CC=C(C=C2)O	Fatigue Oxygen Ozone	3	2	2	Probable	Recent patent - good static and dynamic ozone resistance in natural rubber black compound.	78,79
Phenylene diamine		N,N'-Di-2-naphthyl-p-phenylenediamine	DNPD; AgeRite W	93-46-9	C1=CC=C2C=C(C=CC2=C1)NC3=CC=C(C=C3)NC4=CC5=CC=CC=C5C=C4	Fatigue Oxygen Ozone	3	5	2	Probable	Listed in a review article as an early commercial antiozonant.	86,87
Phenylene Diamine related		6QDI	N-4-(1,3-Dimethylbutyl)imino-2,5-cyclohexadien-1-ylidene benzenamine; 4-N-(4-methylpentan-2-yl)-1-N-phenylcyclohexa-2,5-diene-1,4-diimine	52870-46-9	CC(C)CC(C)N=C1C=CC(=NC2=CC=CC=C2)C=C1	Fatigue Oxygen Ozone	4	2	2	Yes	Forms 6PPD during use. Partially attaches to polymer on mixing and in service.	2,12
Dihydroquinoline		Ethoxyquin	Ethoxyquin; 6-Ethoxy-2,2,4-trimethyl-1,2-dihydroquinoline; Santoquin; Antioxidant EC; Santoflex AW	91-53-2	CCOC1=CC2=C(C=C1)NC(C=C2C)(C)C	Fatigue Oxygen Ozone	1	3	1	Yes	Used as very early antiozonant; heavily staining; used in fish food as an antioxidant but the authorization for that application has been suspended in the EU. Not as effective as 6PPD.	4,5,6
Dihydroquinoline		TMQ	2,2,4-Trimethyl-1*H* -quinoline	26780-96-1	N/A Polymer	Oxygen Ozone (in combination with 6PPD)	1	Unclear, maybe 1	1	Unlikely	Very low antiozonant activity by itself but acts synergistically with 6PPD.	1,2
Dihydroquinoline		N,N-diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	N,N-Diethyl-2,2,4-trimethyl-1H-quinolin-6-amine (R= N(C2H5)2	Not available	C1(C)(C)C=C(C)C(C2N1)=CC(=CC=2)N(CC)CC	Fatigue (?) Oxygen Ozone	4	4	3	Probable	Amino derivatives of ethoxyquin have been shown to be better antiozonants than ethoxyquin in lab testing.	29, 30, 31 (for morpholine derivative), 32 (comparison of amine derivatives in lab tests)
Diphenyl amine		Dioctyl diphenylamine DOPD	Vanox ODP; Standguard ODP	101-67-7	CCCCCCCCC1=CC=C(C=C1)NC2=CC=C(C=C2)CCCCCCCC	Oxygen	2	5	1	Unlikely	Used in chloroprene rubber for improved flex resistance. Would not be expected to perform as an antiozonant.	71,72,73;80(comparison of AOZ activity with other candidates in SBR)
Diphenyl amine		Wingstay 29	4-(1-Phenylethyl)-*N* -[4-(1-phenylethyl)phenyl]aniline	68442-68-2	CC(C1=CC=CC=C1)C2=CC=C(C=C2)NC3=CC=C(C=C3)C(C)C4=CC=CC=C4	Oxygen	2	5	1	Unlikely	Good antioxidant, but minimal antiozonant activity.	11, 126

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Hindered amine		Mixed xylene diamines	N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine and N,N'-Dibenzyl-m-xylene-alpha,alpha'-diamine perform the best	N,N'-Dibenzyl-p-xylene-alpha,alpha'-diamine- 25790-41-4	N/A Mixture	Fatigue (not known, probably low) Oxygen (not known) Ozone	4	3	2	No, unless R groups are phenyl	Patent claims better crack growth inhibitor than PPDs on exposure to ozone. Quinone formation much less likely than with 6PPD. Best performance was with N,N'-dibenzyl-m,p-xylylenediamine.	16, 17 , 18
Hindered amine (HALS)		Tinuvin 770	Bis(2,2,6,6-tetramethyl-4-piperidyl) sebacate	52829-07-9	CC1(CC(CC(N1)(C)C)OC(=O)CCCCCCCCC(=O)OC2CC(NC(C2)(C)C)(C)C)C	Oxygen	2	5	1	No	These are based on 2,2,6,6-tetramethylpiperidine and are used as light stabilizers. They have no ability to protect against ozone.	48, 49, 81, 127
Sulfur compound		DLTDP	Dodecyl 3-(3-dodecoxy-3-oxopropyl)sulfanylpropanoate	123-28-4	O=C(OCCCCCCCCCCCC)CCSCCC(=O)OCCCCCCCCCCCC	Oxygen (synergist used with other antioxidants)	2	5	1	No	Does not act as an antiozonant.	13
Triazine		Durazone 37 TAPDT	2,4,6-Tris-(N-1,4-dimethylpentyl-para-phenylenediamino)-1,3,5 triazine; TAPDT	121246-28-4	CC(C)CCC(C)NC1=CC=C(C=C1)NC2=NC(=NC(=N2)NC3=CC=C(C=C3)NC(C)CCC(C)C)NC4=CC=C(C=C4)NC(C)CCC(C)C	Fatigue (unknown) Oxygen (not known, but expected to be good) Ozone	4	Unclear, maybe 1	1	Probable, but size of quinone molecule may affect toxicity	Good solubility in natural rubber but limited solubility in butadiene rubber and SBR. Works as antiozonant at low levels in sidewall with phenolic resin but no comparison to 6PPD. Most likely to migrate too slowly.	19, 20
Triazinethione		Tetrahydro-1,3,5-tri-n-butyl-(S)-triazinethione	Tetrahydro-1,3,5-tri-n-butyl-(S)-triazinethione	Not available	N1(CCCC)NN(C(C[C@H](CCCC)C1=S)CCCC	Oxygen Ozone	1	3	3	No	Used as a non-staining antiozonant. Extremely scorchy.	27, 28
Polymeric antioxidant		ADPA (not to be confused with p-aminodiphenyl-amine)	Acetone-Diphenylamine condensate; Accinox BL 75S	68412-48-6	CC(=O)C.C1=CC=C(C=C1)NC2=CC=CC=C2	Fatigue Oxygen Ozone (poor)	2	5	1	Unknown	Mainly used as an antioxidant in lower cost applications. Poor antiozonant.	26, 80, 137
Polymeric antioxidant		Poly(4-hydroxy-2,2,6,6-tetramethyl-1-piperidineethanol-alt-1,4-butanedioic acid)	2-(4-Methoxy-2,2,6,6-tetramethylpiperidin-1-yl)ethyl 4-oxopentanoate; Photo-stabilizer BW-10LD	65447-77-0	CC(=O)CCC(=O)OCCN1C(CC(CC1(C)C)OC)(C)C	Ozone Hindered amine light stabilizer (HALS)	2	5	2	No	Reference reports compound as an antiozonant for polybutadiene but only data shown was on polypropylene. Unlikely to be effective in diene based polymers.	38, 128
Polymeric siloxane		Uvasil 299	Poly-methylpropyl-3-oxy [4(2,2,6,6-tetramethyl)piperidinyl] siloxane	164648-93-5	N/A Polymer	Oxygen	2	5	3	No	This is a hindered amine light stabilizer and is not expected to have any antiozonant activity.	50,51
Metal dithiocarbamate		Nickel dibutyl dithiocarbaname	Perkacit NDBC; Naugard NBC	13927-77-0	CCCCN(CCCC)C(=S)[S-].CCCCN(CCCC)C(=S)[S-].[Ni+2]	Oxygen Ozone	1	3	1	No	Reasonable antiozone activity but extremely scorchy, making it impractical in tire compounds. Contains high level of nickel.	26, 52, 53 ,54

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Hindered phenolic		None	2-Cyano-3-(3,5-ditert-butyl-4-hydroxyphenyl)propionic acid ethyl ester	132631-62-0	CCOC(=O)C(CC1=CC(=C(C(=C1)C(C)(C)C)O)C(C)(C)C)C#N	Oxygen Ozone	2	5	2	Probable	Paper claims antiozonant activity similar to IPPD and DPPD but only looks at carbonyl formation during ozonation.	41, 42
Bisphenol		AO2246	2,2'-Methylenebis(6-tert-butyl-4-methylphenol)	119-47-1	CC1=CC(=C(C(=C1)C(C)(C)C)O)CC2=C(C(=CC(=C2)C)C(C)(C)C)O	Oxygen	2	5	1	Probable	Does not act as antiozonant but is a common antioxidant used as a raw polymer stabilizer; not typically used in final compound.	43,44, 82, 129
Hydroquinone		Santovar A	2,5-Di-tert-amylhydroquinone	79-74-3	CCC(C)(C)C1=CC(=C(C=C1O)C(C)(C)CC)O	Oxygen	2	5	1	Yes	Does not act as antiozonant but is a common antioxidant used as a raw polymer stabilizer; not typically used in final compound.	45,82,83,130
Phosphite		Irgafos 168	Tris(2,4-ditert-butylphenyl)phosphite	31570-04-4	CC(C)(C)C1=CC(=C(C=C1)OP(OC2=C(C=C(C=C2)C(C)(C)C)C(C)(C)C)OC3=C(C=C(C=C3)C(C)(C)C)C(C)(C)C)C(C)(C)C	Fatigue Oxygen	2	5	1	Unlikely	Used as raw polymer stabilizer. Highly hindered phosphites have some antifatigue activity, although most phosphites are decomposed during vulcanization.	61,62,84 131
Nitroxyl compounds		TEMPO	2,2,6,6-Tetramethylpiperidine 1-oxyl,	2564-83-2	CC1(CCCC(N1[O])(C)C)C	UV protection	2	5	2	Not from TEMPO but potentially from other HALS compounds depending on the structure	TEMPO is not used as a polymer stabilizer - it is a precursor to a hindered amine light stabilizer. The nitroxyl species is not an antiozonant.	67,68, 132
Phenylnaphthyl amines		N-Phenyl-1-naphthylamine	1-Anilinonaphthalene Phenyl-α-naphthylamine	90-30-2	C1=CC=C(C=C1)NC2=CC=CC3=CC=CC=C32	Fatigue Oxygen Ozone	3	5	2	Probable	Used in neoprene but not common with diene rubbers used in tires.	64, 65
Phenylnaphthyl amines		N-Phenyl-2-naphthylamine	2-Anilinonaphthalene; Phenyl-β-naphthylamine	135-88-6	C1=CC=C(C=C1)NC2=CC3=CC=CC=C3C=C2	Fatigue Oxygen Ozone	4	Unclear, maybe 1	2	Possible	An early antiozonant	63, 66
Ether		Vulcazon AFS	3,9-Dicyclohex-3-enyl-2,4,8,10-tetraoxaspiro[5.5]undecane	6600-31-3	C1CC(CC=C1)C2OCC3(CO2)COC(OC3)C4CCC=CC4	Ozone (for chloroprene rubber)	Ineffective with tire elastomers - does not have antiflex properties	3	1	No	Shown to be effective in chloroprene and claimed for "natural latex" but unlikely to perform in other diene rubbers.	21,22,23,88

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Ether + Phenol	 	Vulcazon AFS/ Irganox 1520 blend	3,9-Dicyclohex-3-enyl-2,4,8,10-tetraoxaspiro[5.5]undecane (Vulcazon AFS) and 2-Methyl-4,6-bis((octylthio)methyl)phenol (Irganox 1520)	6600-31-3 (Vulcaazon AFS) and 110553-27-0 (Irganox 1520)	N/A Mixture	Ozone	4	3	1	Not Vulcazon AFS but probable with Irganox 1520	Shown to be effective in chloroprene and claimed for "natural latex". Shown to be effective in sidewall formulation in combination with Irganox 1520 phenolic antioxidant.	21,22,23,85, 88
Thiosemicarbazide		1,1,4 Tributyl thiosemicarbazide	1,1,4 Tributyl thiosemicarbazide	Not available	CCCCN(NC(=S)NCCCC)CCCC	Fatigue (unknown) Oxygen (unknown) Ozone	1	4	3	No	Trialkyl thiosemicarbazides have antiozonant properties but are extremely scorchy. Better reaction with ozone than substituted thioureas.	33
Inorganic		Graphene	Prophene™	1034343-98-0	N/A	Fatigue (unknown) Oxygen Ozone	2	3	2	No	Reported to reduce 6PPD when used as a filler in rubber compounds.	34
Inorganic	Al2O3	Alumina (in combination with 6PPD)	Alumina (in combination with 6PPD)	1344-28-1	[O-2].[O-2].[O-2].[Al+3].[Al+3]	Ozone	2	5	1	No	All examples had 6PPD in the formulation. Unlikely to be effective without 6PPD.	39, 133
Inorganic	MnO2	Manganese dioxide	Dioxy magnesium	1313-13-9	O=[Mn]=O	None in rubber. Acts to promote oxidation. Ligated manganese salts have been shown to decompose ozone, but no work has been done in rubber.	2	5	1	No	Literature exists on manganese complexes to decompose ozone, but it is know that manganese salts promote oxidation of rubber compounds.	75,76, 134
Hydrazine		1,1' -Pentamethylenebis(2,2-Di-n- Butylhydrazine)	1,1' -Pentamethylenebis(2,2-Di-n-Butylhydrazine)	Not available	CCCCN(CCCC)NCCCCCNN(CCCC)CCCC	Fatigue (unknown) Oxygen (unknown) Ozone	3	3	3	No	Shown to be an antiozonant in dynamic testing of rubber but not compared to conventional antiozonants.	35
Imine		N-phenyl-meta-phenoxyphenylmethaneimine; 1-(3-phenoxyphenyl)-N-phenylmethanimine	N-Phenyl-meta-phenoxyphenylmethaneimine; 1-(3-phenoxyphenyl)-N-phenylmethanimine	Not available	C1(/C=N/C(C=CC2)=CC=2)=CC(=CC=C1)OC(C=CC1)=CC=1	Fatigue (unknown) Oxygen (unknown) Ozone	1	5	3	Unlikely	Reported as an antiozonant in rubber.	36
Diamine		1,3-Bis(4-piperidyl)propane; 4-(3-piperidin-4-ylpropyl)piperidine	1,3-Bis(4-piperidyl)propane; 4-(3-piperidin-4-ylpropyl)piperidine	16898-52-5	C1CNCCC1CCCC2CCNCC2	Fatigue (unknown) Oxygen (unknown) Ozone	2	5	2	Depends on structure	Shown to be improve crack resistance in static ozone tests on SBR.	37, 135
Nitrone		α- C-4- Hydroxy- 3,5-dimethylphenyl-N-tert. butyl nitrone	α- C-4- Hydroxy- 3,5- dimethylphenyl-N-tert. butyl nitrone	Not available	C1(/C=[N+](\[O-])C(C)(C)C)=CC(C)=C(C(C)=C1)O	Fatigue Oxygen (unknown) Ozone	4	2	3	Depends on structure, but probable from a phenolic nitrone	Compared to IPPD - reasonable ozone performance, some antifatigue activity, synergistic with phenolic antioxidants. May be able to replace some 6PPD with this material.	40

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Nitrone + Phenolic AO		α- C-4- Hydroxy- 3,5- dimethylphenyl - N-isopropyl nitrone and Lowinox WSP	α- C-4- Hydroxy- 3,5- dimethylphenyl - N-tert. butyl nitrone and Lowinox WSP	Lowinox WSP - 77-62-3; No CAS number for nitrone	N/A Mixture	Fatigue Oxygen Ozone	4	2	Nitrone - 3 Lowinox WSP-1	Probable for both the nitrone and the Lowinox WSP	Blend of two materials gave ozone protection equal to IPPD in static ozone testing. A film was noted on ozone treated rubber.	40, 89
Enol ether		Cyclohexen-3-ylidenemethyl benzyl ether Vulkazon® AFD	Benzyl-3-cyclohexen-1-ylidenemethyl ether	22428-48-4	C1CC(=COCC2=CC=CC=C2)CC=C1	Ozone	2	5	3	Unlikely	Claimed to be a good antiozonant for light colored rubber. Not as good as PPD for fatigue. Primarily used with chloroprene.	69,70,136
Hydrocarbon		microcrystalline wax paraffinic wax	Nochek (blend of waxes for tires)	Not available	CCCCCCCCCCCCCCCCCCCCCCCCCC.CCCCCCCCC(CC)CCCCCCCCCC(CC)CCC.C1(CCCCCCCCC)CCC(CC1)CCCCCCCCCCCCCCCCCCC	Ozone (static)	1	1	1	No	Blends of microcrystalline and paraffin waxes are used in combination with 6PPD. Waxes alone only provide static ozone protection.	58,59,60
Phenothiazine		N-(4-methylpentan-2-yl)-10H-phenothiazin-3-amine	3-(1,3-Dimethylbutylamino)phenothiazine	Not available	C1=CC(=CC(=C1NC1=CC2)SC1=CC=2)NC(C)CC(C)C	Ozone	3	5	3	Unlikely	Reported as an antiozonant in rubber but no data in patent.	96,97
Unsaturated alcohol		Vitamin A	Retinol	11103-57-4	CC1=C(C(CCC1)(C)C)C=CC(=CC=CC(=CCO)C)C	Weak food antioxidant; important to biochemical processes	2	5	1	Unlikely	The material would be expected to be decomposed by ozone reacting with the double bonds in the molecule.	102
Phenolic		Vitamin E	α-Tocopherols (all isomers)	59-02-9	CC1=C(C2=C(CCC(O2)(C)CCCC(C)CCCC(C)CCCC(C)C)C(=C1O)C)C	Food antioxidant; important in biochemical processes	2	5	1	Probable	As a phenolic, this material would not be expected to act as an effective antiozonant, and there is no data indicating it works in rubber in that capacity. It has been used as an antioxidant in plastics.	103, 104
Conventional lignin		Lignin	Not available	9005-53-2 (other "lignins" may occur as different CAS numbers)	N/A polymer	Mild antioxidant. Has been used in rubber as a filler and a stabilizer. No known antiozonant properties.	2	5	1	Probable, but the quinone would have very high molecular weight	Lignin is complex polymeric phenolic material which also occurs in a sulfonated form with different metal ions which can play a large role in its antioxidant and filler properties. It was compared to octylated diphenyl amine in nitrile rubber. No known antiozonant properties.	105, 106, 107
Alcohol/Acid		Vitamin C	Ascorbic acid	50-81-7	C(C(C1C(=C(C(=O)O1)O)O)O)O	Mild antioxidant but important in biochemical processes. Has been used as an antiozonant for plants.	2	5	1	No	Used in plants but not expected to have any antiozonant activity in compounded rubber.	108, 109

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Amine		7-(4-Methylpentan-2-ylamino)-2,3,4,10-tetrahydro-1H-acridin-9-one	Not available	Not available	C1C=C(C=C(C=1N1)C(=O)C(=C1CC1)CC1)NC(C)CC(C)C	Patent claims antiozonant activity but only compared with 6PPD in simple oxidation test - no ozone data.	4	4	3	Unknown	Compound has better oxidation onset temperature than 6PPD, but no ozone data.	110, 115,116
Amine		2-Cyclohexyl-N-(4-methylpentan-2-yl)-1H-indol-5-amine	Not available	Not available	C1CCC(CC1)C1=CC2=CC(=CC=C2N1)NC(CC(C)C)C	Patent claims antiozonant activity but compared with 6PPD in simple oxidation test and compounding after air aging.	4	4	3	Unknown	Compound has better oxidation onset temperature than 6PPD, but no ozone data.	111, 112
Amine		4-(1H-Indol-2-yl)-N-(4-methylpentan-2-yl)aniline	Not available	Not available	C1C=C2C=C(NC2=CC=1)C1C=CC(=CC=1)NC(CC(C)C)C	Patent claims antiozonant activity but compared with 6PPD in simple oxidation test.	4	4	3	Unknown	Compound has better oxidation onset temperature than 6PPD, but no ozone data.	113, 114
Phenylene Diamine		DPPD	1-N,4-N-Diphenylbenzene-1,4-diamine	74-31-7	C1=CC=C(C=C1)NC2=CC=C(C=C2)NC3=CC=CC=C3	Fatigue Oxygen Ozone	4	3	1 (as mixture)	Probable	Part of CAS 68478-45-5. Low solubility in rubber; not as good as an antiozonant as 6PPD.	75, 76, 118, 1
Phenylene Diamine		DTPD	1-N,4-N-Bis(2-methylphenyl)benzene-1,4-diamine 1,4-Benzenediamine, N,N'-bis(2-methylphenyl)-	68953-84-4 for mixture	CC1=CC=C(C=C1)NC2=CC(=CC=C2)NC3=CC=C(C=C3)C	Fatigue Oxygen Ozone	4	3	1 (as mixture)	Probable	Part of CAS 68478-45-5. Low solubility in rubber; not as good as an antiozonant as 6PPD.	119,1
Polymeric amine functionalized lignin		Amine functionalized lignin	Not available	Not available	N/A polymer	Antioxidant Antiozonant	4	2	3	Probable, but would be polymer bound	Ozone testing was static, but comparable to 6PPD. Fatigue was similar to 6PPD. Since there is no blooming or reservoir, it is unlikely to provide long term protection	120
Phenolic	 + Calcium salt	Calcium salt from lignin rice straw black liquor	Not available	Not available	Not available	Antioxidant	2	5	3	Probable, but would be polymer bound	Reference only claims material as antioxidant; no work with ozone was done.	121

Class of Compounds	Compound	Common Name	Other Names	CAS No.	SMILES	Primary Usage Property - Antidegradant	Compound Effectiveness	Quality of Data	Commercial Availability	Quinone Formation on Oxidation/Ozonation?	Comments	References
Gallate related	Not available	Rambutan peel extract	Not available	Not available	N/A complex mixture	Antioxidant Antiozonant	4	2	2	Unknown	Ozone testing showed comparable crack resistance to 6PPD	139

Notes:
BR = Butadiene Rubber; CAS No. = Chemical Abstracts Service Number; ESBR = Emulsion Styrene Butadiene Rubber; HALS = Hindered amine light stabilizer; N/A = Not applicable; SBR = Styrene Butadiene Rubber.

Compound Effectiveness	1. Have data and doesn't work 2. Have no data but chemical molecule will not work 3. Have no data to say either way 4. Have some positive data but not enough to say yes or no
Commercial Availability	1. Multi ton lots 2. Laboratory availability only 3. Not available
Quality of Data	1. Tire data 2. Compounding data (ozone/fatigue) 3. Compounding data (ozone resistance) 4. Chemical data only (reaction with ozone) 5. Listed as an antioxidant or antiozonant; little or no data on ozone

Count	Author Names and Publication Date	Reference List
1	Hong *et al.,* 2016	S. Hong, "Antioxidants and Other Protectant Systems" in Brendan Rodgers' Rubber Compounding Chemistry and Applications, 2nd Ed., CRC Press, 2016 p. 419-459
2	Huntink, 2003	N. Huntink Durability of Rubber Products, PhD Thesis, University of Twente, 2003 (https://ris.utwente.nl/ws/portalfiles/portal/6072556/thesis_Huntink.pdf)
3	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/13101#section=Safety-and-Hazards
4	Stahly, 1968	Comparison of Ethoxyquine with various 6PPD type antiozonants - E.E. Stahly, US Patent 3.391,107, 1968
5	Kristin Hals and Sofia Helena Lindahl, 2020	https://aquafeed.co.uk/entrada/ethoxyquin-ban-in-the-eu-are-there-viable-alternatives-21749
6	Byrne, 2017	Reason for suspending Ethoxyquin authorization in feed - https://www.feednavigator.com/Article/2017/06/12/Ethoxyquin-authorization-suspended-in-the-EU-are-there-viable-alternatives#:~:text=Last%20week%20saw%20the%20European,Official%20Journal%20of%20the%20EU.
7	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/18320
8	ToxServices LLC, 2021	Greenscreen assessment - https://www.ezview.wa.gov/Portals/_1962/Documents/6ppd/GreenScreenExecutiveSummaryFor77PPD.pdf
9	Pubchem, 2024	For a number of patents cited on this material see https://pubchem.ncbi.nlm.nih.gov/compound/92190
10	Lippincott & Peto Inc, 1993	https://www.thefreelibrary.com/Review+of+antiozonants-a014459625
11	Engels *et al.*, 2011	Engels, Hans-Wilhelm, Herrmann-Josef Weidenhaupt, Manfred Pieroth, Werner Hofmann, Karl-Hans Menting, Thomas Mergenhagen, Ralf Schmoll, and Stefan Uhrlandt. "Rubber, 9. Chemicals and additives." Ullmann's Encyclopedia of industrial chemistry (2000). P.24
12	Huntink, 2004	"Addressing Durability of Rubber Compounds" N. Huntink et al, RC&T (2004) 77 (3): 476-511
13	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/31250
14	KR 20090100673A	KR 20090100673A "Tire Sidewall Composition"
15	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/substance/164110485
16	Masatomo *et al.*, 1972	E. Masatomo, *et al*. US 3,634,316 “Sulfur-Vulcanizable Natural, and Synthetic Rubbery Polymers Containing Xylylene Diamines as Antiozonants”
17	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/15320161
18	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/284842
19	Huntink, 2003	N. Huntink Durability of Rubber Products, PhD Thesis, University of Twente, 2003 p. 45 and listed references within (https://ris.utwente.nl/ws/portalfiles/portal/6072556/thesis_Huntink.pdf)
20	Pender, 2008	M. Pender, US 8,329,788 B2, Tire having enhanced ozone resistance
21	Lanxess, 2019	https://lanxess.com/en/Media/Press-Releases/2019/07/Safe-protection-against-oxidation
22	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/98143
23	Bruck *et al.*, 1985	D. Bruck; H. Konigshofen and L. Ruetz, "The Action of Antiozonants in Rubber " Rubber Chemistry and Technology (1985) 58 (4): 728–739.
24	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/129273577
25	Boone *et al.*, 2017	M. Boone *et al*., US Patent US 10 , 428 , 009 B2 Methods of Making Compounds and Mixtures Having Antidegradant and Antifatigue Efficacy 2019
26	PMC Rubber Chemicals, 2021	https://r.search.yahoo.com/_ylt=AwrNYahZZfNlcwQAY3FXNyoA;_ylu=Y29sbwNiZjEEcG9zAzEEdnRpZAMEc2VjA3Ny/RV=2/RE=1711659609/RO=10/RU=https%3a%2f%2fpmcrci.in%2fwp-content%2fuploads%2f2023%2f05%2fPDS_Accinox-BL-75S.pdf/RK=2/RS=eRuCWIHOsDvqjVl6Iauca9vBXu0-
27	Rollick *et al.*, 1991	K. L. Rollick, J. G. Gillick, J. A. Kuczkowski (to The Goodyear Tire & Rubber Co.), May 28, U.S. 5,019,611 (1991)
28	Rollick *et al.*, 1988	K. L. Rollick, J. G. Gillick, J. L. Bush, and J. A. Kuczkowski, \Triazinethiones: A New Class of Nonstaining Nondiscoloring Antiozonants," paper no. 52 Rubber Division, American Chemical Society, October 18{21, 1988
29	Pubchem, 2024	https://pubchem.ncbi.nlm.nih.gov/compound/85841216
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