June 2025

Exploring Solutions for Tire Wear Pollution

Workshop Summary

The California Ocean Protection Council (OPC) convened a workshop on March 25 and 27, 2025, on tire wear pollution in coordination with the California Ocean Science Trust (OST) to fulfill the goals of sector-specific workshops as part of the Statewide Microplastics Strategy. The workshop was intended to collaboratively understand a range of perspectives on tire wear pollution to explore potential solutions. Approximately 50 representatives from the tire industry, state agencies, federal agencies, advocacy groups, and research institutions attended the workshop.

Event Goals

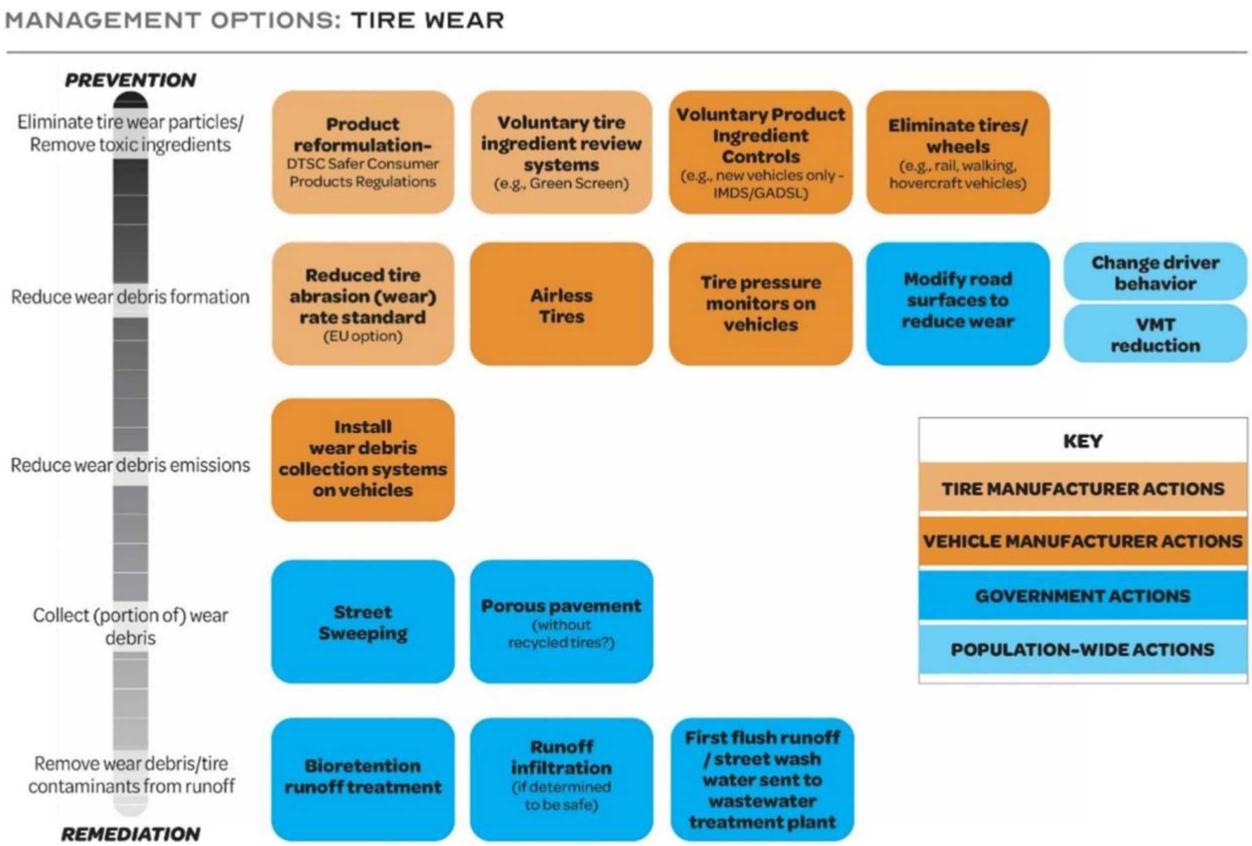
- Identify immediate recommendations that could be enacted in the vehicle tire sector to reduce plastic pollution (e.g., voluntary solutions already in place that can be scaled for broader adoption/implementation).
- Identify long-term policy needs to advance the recommendations, including the removal of barriers to scaling recommendations, identified in the workshop.

- Identify impactful research needs and recommend research priorities.
- Maintain a focus on pollution prevention over remediation, although remediation and intervention approaches were discussed.

Process

Prior to the workshop, participants were offered a survey to solicit ideas on solutions or strategies to inform the agenda. The survey and the workshop agenda were informed by Figure 4 (below) from Mayer et al. (2024)[1], which offered a starting framework for management options to reduce tire wear pollution. Following the survey, organizers integrated the solutions raised into remediation, reduction, and prevention categories for the workshop, which was hosted virtually over two 4-hour sessions. During the discussion of each solution, participants were asked to offer their perspective on perceived challenges or barriers, opportunities, potential state roles, and research needs.

[1] Paul M. Mayer et al., "Where the Rubber Meets the Road: Emerging Environmental Impacts of Tire Wear Particles and Their Chemical Cocktails," *Science of The Total Environment* (2024): 171153, https://doi.org/10.1016/j.scitotenv.2024.171153.



Tires and Tire Wear Pollution Background

The San Francisco Estuary Institute (SFEI) provided background context on tire wear pollution research and issues in California for the workshop participants, which is briefly summarized below:

California has a large population with many vehicles (including over 31 million registered motor vehicles) and generates over 60 million waste tires annually. As tires are used, they wear down, releasing tire wear particles and bits of road material into the environment. Studies estimate that each year, 15 to 19 million kilograms of tire wear particles are produced in the Bay Area, while 100 to 120 million kilograms are produced in the entire state.[2] For scale, the amount

[2] Kelly D. Moran et al., *Tire Wear: Emissions Estimates and Market Insights to Inform Monitoring Design*, SFEI Contribution No. 1109 (Richmond, CA: San Francisco Estuary Institute, 2023), https://www.sfei.org/documents/tire-wear-emissions-estimates-and-market-insights-inform-monitoring-design.

of tire wear produced per person per year is roughly equivalent in mass to the size of a small cat. Most of the mass of tire emissions are 30-100 micron particles, but a greater number of particles in the smaller submicron range are produced in total. Tire wear nanoparticles could be a special concern because they have a large surface area and can pass through cell membranes, which could carry implications for the environment and human health.

While most tire wear mass falls near roads, smaller particles can become airborne and travel farther. Most of California's water management systems direct stormwater to surface waters without treatment, except for San Francisco, which has a combined wastewater and stormwater treatment system. Stormwater is a significant source of tire wear pollution and contributes an estimated 5 trillion tire particles to the San Francisco Bay Area annually[3]. Tire particles can carry chemicals into the environment, and some of these chemicals can be toxic. For example, 6PPD-quinone (6PPD-Q), a transformation product of the tire chemical 6PPD, is acutely toxic to coho salmon. There is a growing body of evidence indicating that some salmonid species may be similarly affected, while other salmonids are not susceptible. Besides 6PPD-Q, other tire-related chemicals, such as other antioxidants and vulcanization agents, have been detected in the San Francisco Bay and its watersheds. There are many potential management options to mitigate tire wear pollution that will "take a village" to solve.

Resources and SFEI Publications:

- Tires and Water Quality Factsheet[4]

[3] Rebecca Sutton et al., *Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region*, SFEI Contribution No. 950 (Richmond, CA: San Francisco Bay Regional Monitoring Program for Water Quality, 2019), https://www.sfei.org/documents/understanding-microplastic-levels-pathways-and-transport-san-francisco-bay-region.

[4] Kelly D. Moran and Ruth A. Askevold, *Microplastics from Tire Particles in San Francisco Bay Factsheet*, SFEI Contribution No. 1074 (Richmond, CA: San Francisco Estuary Institute, 2022), https://www.sfei.org/documents/microplastics-tire-particles-san-francisco-bay-factsheet.

- OPC Report: Microplastic Sources and Pathways to Urban Runoff[5]
- Tire Emissions Estimate Report[2]
- Tian et al. 2020[6]
- Peter et al. 2024[7]
- Mayer et al. 2024[1]

The U.S. Tire Manufacturers Association (USTMA), which is a national trade association for tire manufacturers in the US, provided background on the tire industry, summarized below:

The USTMA represents 11 member companies with 55 tire manufacturing facilities across 16 states, generating over $27 billion in annual sales and supporting more than a quarter million US jobs. USTMA's mission is to advance a sustainable tire manufacturing industry through thought leadership and science-based public policy advocacy, striving to strengthen the competitiveness, societal impact, and reputation of the US tire manufacturing industry while ensuring safe, sustainable mobility for the future.

The frictional grip between tires and road surfaces causes abrasion, leading to wear, and results in particles worn from tire treads mixed with road wear, dust, and other substances found on the road. USTMA prefers the term Tire and Road Wear Particles (TRWP), which refers to a particle that is a combination of tire tread, road pavement material, and other materials (e.g., break wear) that is produced in real-world scenarios. Approximately 50% of TRWP originate from tire treads, while the remaining 50% come from other materials. The terminology tire wear particles (TWP), on the other hand, is less specific and can include tire

[5] Kelly D. Moran et al., *A Synthesis of Microplastic Sources and Pathways to Urban Runoff*, SFEI Contribution No. 1049 (Richmond, CA: San Francisco Estuary Institute, 2021), https://www.sfei.org/documents/synthesis-microplastic-sources-and-pathways-urban-runoff.
[6] Zhenyu Tiam et al., "A Ubiquitous Tire Rubber–Derived Chemical Induces Acute Mortality in Coho Salmon," *Science* 371, no. 6525 (2021): 185–89, https://doi/10.1126/science.abd6951.
[7] Katherine T. Peter et al., "Storms Mobilize Organophosphate Esters, Bisphenols, PFASs, and Vehicle-Derived Contaminants to San Francisco Bay Watersheds," *Environmental Science: Processes & Impacts* 26, no. 10 (2024): 1760–79, https://doi.org/10.1039/D4EM00117F

particles generated in laboratory settings. SFEI noted that these terms are not used consistently in the literature.

It should be stressed that the amount of TRWP released into the environment is heavily dependent on several factors, including driving behavior, roadway materials, and vehicle characteristics. The US tire market is dominated by passenger and light truck tires, which can be categorized into original equipment tires and replacement tires. Replacement tires are designed to perform well on a wide range of vehicles, and consumer demand in the US typically focuses on optimized tread wear and wet traction performance.

Tire design is a balance, and improving one tire performance characteristic typically affects others. Designing tires for sustainability requires considering consumer needs, vehicle demands for safety and performance, and environmental impacts. Stakeholders beyond the tire industry, such as vehicle manufacturers, state and local departments of transportation, and others, must collaborate to help identify, test, and implement solutions.

The sections below capture participant pre-workshop survey results, discussion, and comments on potential solutions to tire wear pollution. They are organized into remediation, reduction, and prevention categories. Each section describes a potential solution and its associated opportunities, state roles, challenges, and research gaps. Opportunities may include existing programs that are being tested for implementation in other states or regions that may be relevant for California, research to watch, resources, and strategy co-benefits. State roles include participant suggestions on policy needs or actions that state agencies may consider or explore, if appropriate. Challenges articulate technical or policy barriers, or otherwise capture information about limits in effectiveness or feasibility of the solution under discussion. Finally, research gaps capture knowledge gaps that would support an improved understanding of tire wear pollution and how to address it.

Remediation Strategies

Background: Stormwater Best Management Practices[8]

Stormwater Best Management Practices (BMPs) are "strategies for controlling the quality and quantity of water that runs off the land,"[9] that include a suite of technologies engineers often refer to as a "toolbox of solutions". Stormwater BMPs is a broad term and includes green infrastructure, low-impact development, nature-based solutions, and grey infrastructure. The term BMP is increasingly known as stormwater control measures (SCMs) in states other than California. BMPs can be non-structural (e.g., programs preventing runoff from coming in contact with pollutants, such as street sweeping) or structural (e.g., constructed devices that induce pollutant removal mechanisms and/or promote runoff to soak into the ground instead of discharging into receiving waters).

Structural BMPs that induce pollutant removal mechanisms encompass technologies including vegetated or bio-swales, retention or extended detention basins, constructed wetlands (an engineered basin with slowly moving water, substrate, and biological systems[10]), biofiltration systems including rain gardens and planters, permeable pavement and sand filters[11]. Structural BMPs that divert large volumes of runoff into the ground without specifically inducing treatment mechanisms include dry wells, infiltration trenches, basins, and galleries. Each of these types of BMPs is typically built-in-place. In contrast, a range of manufactured

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[8] This section summarizes content from the pre-workshop survey and a presentation by the Southern California Coastal Water Research Project.

[9] "Stormwater BMPs," Southern California Coastal Water Research Project, accessed April 8, 2025, www.sccwrp.org/about/research-areas/stormwater-bmps/.

[10] R.B.E. Shutes et al., "The Design of Vegetative Constructed Wetlands for the Treatment of Highway Runoff," *Science of the Total Environment* 235, nos. 1–3 (1999): 189–97, https://doi.org/10.1016/S0048-9697(99)00212-0.

[11] "Green Infrastructure and Groundwater Protection," United States Environmental Protection Agency, accessed April 8, 2025, www.epa.gov/green-infrastructure/green-infrastructure-and-groundwater-protection.

treatment devices, ranging from hydrodynamic separators to multi-media filtration systems to baffle boxes to tree filters, are available as pre-constructed systems. There is no universally recognized classification of “green” infrastructure versus “gray” infrastructure, but generally, “greener” infrastructure operates at smaller scales.

BMPs to manage urban runoff are built to comply with requirements of the federal Clean Water Act under the National Pollutant Discharge Elimination System (NPDES), and which may include Total Maximum Daily Loads (TMDLs). NPDES is a federal permit program implemented in California by the State Water Resource Control Board and the Regional Water Quality Control Boards. NPDES requires BMP implementation to mitigate runoff from new and redevelopment projects, i.e., to introduce water quality treatment as a preventative measure as land use changes. These BMPs are intended to manage a broad range of mostly conventional pollutants, e.g., sediments, nutrients, heavy metals, and fecal indicator bacteria. The cost of BMP implementation is typically borne by the property owners developing or redeveloping parcels of land (including many private land owners as well as public agencies, etc.). In contrast, TMDLs are intended to clean up legacy pollution, target specific pollutants in specific watersheds, and are mostly paid for by public funding. Conventional pollutants like heavy metals, nutrients, and trash are typically covered by NPDES requirements for new and redevelopment, but contaminants of emerging concern (CECs), such as microplastics, PFAS, and pesticides, are not currently regulated at the federal level. TMDLs are developed to manage pollutants only after the beneficial uses of a waterway are deemed impaired, i.e., TMDLs are a pathway for BMP implementation once a water quality problem for a specific water body has been identified.

Choosing the “right” BMP to remove or reduce contaminant concentrations depends on matching the appropriate pollutant removal mechanism (treatment type) to the specific form of contaminant. Microplastics and tire wear particles are considered forms of particulate matter; particulates are fairly well understood to be removed by filtration-based BMPs, though the lower density of microplastics may require special design considerations for removal by sedimentation-type BMPs. Tire-wear degradates such as 6PPD-Q are dissolved contaminants that may be removed by sorption (sticking) to appropriate filtration media, and thus are likely only to be removed by filtration-type BMPs with particular media compositions (i.e., not all filter media components may be "sticky enough" to remove 6PPD-Q). Infiltration-type BMPs like galleries and dry wells will "remove" runoff from drainage pathways, essentially redirecting contaminants to the soil beneath the BMP. Rather than choosing the "best" BMP for the pollutants of concern at a given location, the type of BMP that is implemented at a site is often dictated by physical opportunities and constraints. For example, BMPs along transportation corridors must fit into the right-of-way, while the size or footprint of a BMP is directly proportional to the extent of land area draining to it. BMPs must be located at low points in the topography so that runoff flows downhill, by gravity to the treatment system. It is increasingly recognized that the "best" BMP in any location is one that is most likely to be regularly maintained, regardless of any other consideration.

While design features to address microplastics and tire wear particles are not specifically identified in current California BMP design manuals, particulates are removed by many types of BMPs. BMP design guidance manuals are issued by multiple jurisdictions across California, often (but not exclusively) according to NPDES permittee. OPC is currently funding research by the Southern California Coastal Water Research Project (SCCWRP) to understand if existing filtration-based BMPs can contribute to microplastic mitigation and to explore design elements or conditions that support microplastic retention. Research is active in Washington State to identify appropriate filter media materials to effectively remove 6PPD-Q.

Stormwater Best Management Practices - General

Opportunities:

- Develop intentional cross-sector collaborations or convenings to share information between the tire industry, stormwater management communities, and state and local government transportation agencies. These could be convened by the state or by other entities.

- There may be opportunities to learn from research underway by Washington (WA) State, which is funding over 20 stormwater BMP research projects[12] to address 6PPD-Q. Topics include: bioretention, sorbent media, unamended soils, grassy swales, floating wetlands, proprietary treatment devices, street sweeping, decant facilities, granular activated carbon, etc.
- For 6PPD-Q removal, a participant reported that BMPs are most effective when several remediation strategies are combined. For example, slowing down the flow rate of water, reducing the surface area of impervious surfaces, reducing the number of tires on the road, and having some kind of sorbent media in the SCM can all be important to reducing 6PPD-Q below toxic levels.
- Develop incentives to implement BMPs to capture and treat runoff from existing roadways.
- Generally, strategies that slow down water and allow it to soak through natural or engineered media (e.g., permeable pavement, soils, bioretention, and sand filters) show promise for remediation.
- Prioritization of BMPs co-benefits (such as simultaneous removal of nutrients and heavy metals[13]; increasing urban green spaces; climate resiliency to increased flooding, precipitation, drought; etc.) can reduce costs of repair or otherwise benefit local communities.
- Hydrodynamic separators that use centripetal force to remove total suspended solids were raised by a participant as a grey infrastructure strategy,

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[12] Washington Department of Ecology, "6PPD Stormwater Best Management Practices Research," Committees, Boards, and Workgroups, accessed June 5, 2025, https://www.ezview.wa.gov/site/alias__1962/40944/6ppd_stormwater_best_management_practices_research.aspx.

[13] Ilka Gehrke et al., "Review: Mitigation Measures to Reduce Tire and Road Wear Particles," *Science of The Total Environment* 904 (2023): 166537, https://doi.org/10.1016/j.scitotenv.2023.166537.

State Roles:

- There are opportunities for the state to support improvement of BMP design specifically for microplastics and TRWP, and to facilitate updates to design manuals to better address microplastics and 6PPD-Q. BMP design manuals are known to lag behind research advances, often by decades. There may be opportunities to track or learn from WA State, which is in the process of compiling BMP research to create guidance. Likewise, OPC and SCCWRP are actively pursuing BMP research with cooperation from the Southern California Stormwater Monitoring Coalition, focusing on advancing design for pollutant mitigation.
- State-driven research to identify "hotspots" of tire wear pollution may be an effective prioritization tool for the implementation of remediation strategies. For example:
    - An ongoing state mapping project developed by the California Department of Transportation (Caltrans) and the State Water Resource Control Boards aims to identify high traffic locations that coincide with receiving waters that may have sensitive salmon populations to evaluate 6PPD-Q risk. This work could be expanded.
    - Caltrans could explore identifying areas where more TRWP are likely to be generated and target appropriate BMPs placement and type to capture TRWP (not just 6PPD-Q). Road drainage areas and Annual Average Daily Traffic (AADT) are factors that could be considered.
    - Engagement with Tribal Nations and community groups could help to inform a prioritization framework. For example, some metrics to be considered for prioritization could include Tribal treaty rights, environmental justice, co-benefit potential of BMPs, salmon recovery, habitat recovery, water quality improvement, etc.
- Develop funding mechanisms to support routine BMP maintenance, so that pollutant removal is effective throughout the life-cycle of the BMP.

Research Gaps:

- Identification of “hotspots” for TRWP emission may help prioritize stormwater management placement (see State Roles above).
- Research is needed to confirm characterization of TRWP in urban runoff and evaluate where improvements may be gained in BMP design to address size fractions, morphology, or polymer types of particular concern. Understanding of bridge stormwater pathways for TRWP is also needed.
- The fate of TRWP removed from stormwater, what happens when chemicals are released from trapped particles, and whether or not they are introduced into drinking water or plants should be examined. However, answering these types of questions may be time-intensive (10+ years).
- There is a need to better quantify maintenance needs of green infrastructure in order to ensure on-going successful capture of tire-wear particles and 6PPD-Q.
- As the circular economy gains traction, there may be opportunities to research BMPs that use other media.
- Research into green infrastructure’s ability to reduce airborne tire particles is needed, even though they are likely to be a tiny fraction of total particles, because airborne particles may cause adverse health effects.

Challenges and Barriers:

- Neither microplastics nor tire wear pollution are recognized at a federal level as contaminants of concern under the current Clean Water Act.
- Currently, neither tire wear particles nor microplastics are specifically targeted by jurisdictional BMP design manuals across California. Updates to design manuals tend to lag many years behind research advances.
- The effectiveness of BMPs is highly dependent on local conditions (land-use, slope, soil condition, etc.), expertise of the designer, and experience of the contractor. There is no one-size-fits-all solution.

- The effectiveness and efficacy of stormwater management strategies have not yet been determined for TRWP, although research is underway to understand their potential for general microplastic removal.
- The South Coast Air Quality Management District is researching whether and how tire particles may contribute to cancer risks.
- Generally, BMPs and green infrastructure strategies are expensive and time-intensive to install and maintain.
    - Although green infrastructure maintenance is costly, it must be prioritized to remediate contaminants because the sediment buildup from high-traffic roads is very common and reduces the effectiveness of these systems.
- Some green infrastructure requires irrigation, which places an additional burden on California's limited water resources.

Stormwater Management - Permeable Pavement

Permeable or porous pavement, such as porous asphalt, pervious concrete, permeable interlocking pavers (PICP), permeable friction course, and other systems[14], can allow water to infiltrate and evaporate, potentially capture TRWP, capture other pollutants, and reduce stormwater runoff while doubling as surfaces for driving and parking. Permeable pavements are increasingly used in states including North Carolina, Texas, and Washington, as well as the EU, but are not yet widespread in California.

Opportunities:

- There may be lessons learned from the successful implementation of permeable pavement (called ZOAB, which stands for "Zeer Open Asfalt Beton" or Very Open Asphalt Concrete) in the Netherlands.

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[14] The terminology "porous", "pervious", or "permeable" is used interchangeably across the industry.

- While green infrastructure needs to be irrigated, permeable pavement does not require irrigation, which is an important consideration given California's water availability challenges.
- While there is limited expertise in permeable pavement construction, there are training programs to increase skill levels, which may aid in implementation. For example, the SCCWRP is working with the Concrete, Masonry, and Hardscapes Association on permeable pavement training for designers.

Research Gaps:

- The effectiveness of permeable pavement for microplastic and tire particle removal is currently unknown.
- Information is needed on how the permeable pavement surface, which is typically rougher than conventional asphalt, might impact tire wear rates and particle formation.

Challenges and Barriers:

- As with all BMPs, permeable pavement will lose effectiveness over time without maintenance or surface "cleaning" to maintain infiltration rates. The particulate loading rate and filter media size in the aggregate bed beneath the surface determines the rate of clogging. SCCWRP offers a publicly available report summarizing recent information and techniques on maintaining permeable pavement[15].

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[15] Ryan J. Winston and Elizabeth Fassman-Beck, *Permeable Pavement Maintenance: A Review of Literature to Assess Clogging, Predict Maintenance Frequency, and Compare Maintenance Techniques*, Technical Report 1280 (Southern California Coastal Water Research Project, 2022), https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1280_PermeablePavementMaintenance.pdf.

Stormwater Management - Street Sweeping

Street sweeping improvements, such as more frequent street sweeping or optimizing the use of advanced street sweeping strategies and technologies (e.g., regenerative air sweepers that combine air pressure and vacuum), were discussed as a potential TRWP reduction strategy.

Opportunities:

- Once more research is completed, there may be opportunities to develop best practices for street cleaning for TRWP collection, such as optimizing frequency or timing around rain events, or different technologies and strategies (e.g., regenerative airstreet sweepers instead of mechanical sweepers).
- Street sweeping may have co-benefits beyond capturing TRWP, including removing other macroplastics and stormwater pollutants, keeping bike lanes clear, and helping to reduce airborne TRWP exposure to the communities near roads and populated urban areas.
- Participants shared a method developed by SCCWRP[16] to measure the impact of street sweeping on runoff water quality. The method will be deployed 2025-2027 in research conducted by the Southern California Stormwater Monitoring Coalition, the Rio Hondo Watershed Area Steering Committee, the Upper Los Angeles River Watershed Area Steering Committee, and SCCWRP.
- Participants shared research underway by the City of Santa Barbara and funded by OPC to study street sweeping and microplastics, including what gets captured in the sweepers. Partners on this project include SFEI, the University of California Los Angeles, and the University of California Santa Barbara.

[16] Elizabeth Fassman-Beck et al., *Development of a Method to Measure the Impacts of Street Sweeping on Wet Weather Runoff Water Quality*, Technical Report 1411 (Southern California Coastal Water Research Project, 2024), https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1411_DevelopmentMethodStreetSweeping.pdf.

- Following WA State's research on effective strategies for 6PPD-Q and other contaminant removal from street sweeping waste could yield lessons learned.
- Participants noted a study finding that more frequent cleaning (3x per week) of main roads and intersections reduces the tire abrasion input into the sanitary sewer system by 42% and 36%, respectively, versus sweeping streets once per week (Venghaus et al., 2021 in Gehrke et al., 2023)[13].
- Street sweeping is included as a non-structural BMP in many NPDES permits across California. It may be one of the more cost-effective BMPs to expand (e.g., increased coverage or frequency), in comparison to building more structural BMPs.

Challenges and Barriers:

- Street sweeping likely has limited ability to collect small particles, decreasing the efficiency of this method for TRWP remediation. However, more research is needed.
- Street sweeping only collects particles on the street, while many tire particles also end up on other impervious surfaces near roads (e.g., sidewalks).
- California has limited ability to create requirements for street sweeping under the current stormwater management permitting system.
- Street sweeping strategies need to consider how to process and dispose of waste material after collection, which can be challenging.

Research Gaps:

- Additional research is needed to understand how existing and new street sweeping technologies and strategies impact the efficiency of tire particle removal or possibly reintroduce small tire wear particles.

Stormwater Management - Tire-based Infrastructure

Some stormwater management strategies use media derived from tires. For example, some stormwater galleries have tire shreds and horizontal perforated pipes underground within permeable fill material and are designed to rapidly infiltrate stormwater runoff and prevent flooding, while also supporting groundwater replenishment. In California, some infrastructure uses particles derived from tires, including a CalRecycle program, Water Quality and Tire-Derived Aggregate (TDA)[17] in civil engineering applications.

State Roles:

- Participants identified a state role in advancing research on the environmental impacts of tire-derived stormwater management strategies.
- CalRecycle has conducted some research on both TDA and rubberized pavement, and will continue this work with regard to environmental concerns in the future.

Research Gaps:

- Well-designed, peer-reviewed studies with robust chemical analysis are needed to understand the chemical leaching from all tire reuses, including stormwater infrastructure and pavements made with tire-derived components. Relatedly, labs capable of conducting the 6PPD-Q analyses needed for this type of research are challenging to find.

Challenges and Barriers:

- Participants commented on perceived and evidence-based concerns about using tire chips and tire-derived aggregates due to potential contaminants leaching from tire material into environmental settings.
- Using recycled tires in stormwater systems in areas with current or historical salmonid runs (coho, steelhead, cutthroat, etc.) could leach 6PPD-Q, which causes salmonid mortality and potentially has sublethal effects.

Other Remediation Strategies

- Street washing programs, where a "first flush" of water is sent for treatment, are currently in limited use outside of the US and could be considered for California. However, this strategy may present a challenge for water use.

[17] California Department of Resources Recycling and Recovery (CalRecycle), "Tire-Derived Aggregate (TDA)," 2025, https://calrecycle.ca.gov/tires/tda/.

- Although stormwater is expected to contribute significantly more TRWP to marine environments than wastewater, wastewater treatment strategies for TRWP remediation may also be considered as a strategy for combined sewer systems. In California, there are only two wastewater treatment plants that accept stormwater and wastewater, which is a relatively small portion.

Reduction Strategies

Optimizing Tire Pressure

Research estimates that tire pressure optimization can reduce tire wear rates by 5-17%[18]. Tire Pressure Monitoring Systems (TPMS) notify drivers when tires are underinflated. They exist in many newer vehicles and are a federal requirement[19] for vehicles made after 2007. Additionally, hub tire pressure monitors are available for purchase post-production. Next generation TPMS may have advanced signaling and analysis to provide more nuanced information to drivers. For example, different color light indicators where green is optimal, yellow is safe yet wear is increased, and red is unsafe. New technology can leverage wireless connectivity for sensors, chips, and tags to transmit real-time information such as tire temperature, pressure, and tread wear for fleet and tire life cycle management (for example, see RL automotive sensors[20]). A public information campaign may aim to increase awareness of the benefits of tire pressure optimization, for example, the Don't Wait to Inflate[21] behavior change campaign encourages people to properly and regularly inflate their tires. In California, a 2012 tire inflation regulation

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[18] ExxonMobil Chemical, "Electric Vehicle Tires," accessed June 17, 2025, https://www.exxonmobilchemical.com/en/products/butyl/electric-vehicle-butyl-campaign/electric-vehicle-tires.

[19] Federal Motor Vehicle Safety Standards; Tire Pressure Monitoring Systems, 70 Fed. Reg. 53,037 (September 7, 2005), https://www.federalregister.gov/documents/2005/09/07/05-17661/federal-motor-vehicle-safety-standards-tire-pressure-monitoring-systems.

[20] RL Automotive, "Home," accessed June 17, 2025, https://www.rlautomotive.net.

[21] Puget Sound Starts Here, *Don't Wait to Inflate* (2023), https://www.pugetsoundstartshere.org/DontwaittoInflate/.

from the California Air Resources Board (CARB) mandates auto shops check pressure when the vehicle is in for service. Gas stations are required to provide free air. These regulations are part of greenhouse gas (GHG) reduction programs and aim to improve fuel economy, though there are certainly co-benefits for reducing tire wear.

Opportunities:

- Optimizing tire pressure to reduce tire wear provides carbon emission reduction co-benefits. Higher-resolution monitoring systems will be needed for tire pressure optimization to be effective at reducing wear rates.
- The telemetry of newer cars can include improved air pressure data, and a rebate program could be explored to incentivize drivers to maintain proper pressure.

State Roles:

- The State could consider regulating and standardizing air pressure sensors in passenger cars. However, this may put undesirable burdens on consumers and motor vehicle manufacturers. A few participants noted that if a system is mandated in California but not nationwide it will be especially challenging for vehicle manufacturers.
- The State could explore opportunities to support TPMS affordability to reduce barriers to replacement.
- The State could explore supporting information campaigns on air pumps, in multiple languages, that explain the benefits of proper tire inflation, although the effectiveness of communications campaigns should be considered.
- The State could explore incentives for proper tire inflation, such as a small reward for checking tire pressure at an optimal frequency.
- The State could explore adding public service announcements to car registration mailers about the benefits of monitoring and optimizing tire pressure.

Research Gaps:

- Data on tire depressurization could help justify making free air more accessible at convenient locations, given the general limitations of the existing TPMS.

Challenges and Barriers:

- Per federal regulations, current TPMS systems alert drivers if pressure is ~25% underinflated, which is based on safety and not environmental impact. TPMS can be limited in the utility of the information they provide (in terms of relevancy to tire wear). For example, some vehicle designs may show when tire pressure is imbalanced between tires, but will not show that tire pressure is below a certain limit. A participant commented that these issues should be addressed by the vehicle manufacturing industry and not car owners.
- A few participants shared personal experience that cost was a barrier to replacing malfunctioning TPMS.
- Generally, optimizing tire pressure puts the burden on individual drivers, thus the effectiveness of communication campaigns needs to be considered.
- A participant commented that heavier vehicles, including electric vehicles (EVs), may require more tire pressure maintenance.

Optimizing Tire Care

In addition to tire pressure, tire tread, rotation, and alignment can also impact tire wear. For example, misaligned wheels can lead to uneven, rapid tread wear and should be corrected by a professional.

Opportunities:

- Resources are available from the industry to support drivers in optimizing tire care to reduce wear, safety, and performance (e.g., Tire Care Essentials from the U.S. Tire Manufacturers Association[22]).

[22] U.S. Tire Manufacturers Association, *Tire Care Essentials* (2025), https://www.ustires.org/tire-care-essentials.

State Roles:

- Information campaigns could be used to increase driver/vehicle owner awareness. However, the effectiveness of information campaigns should be considered.

Challenges and Barriers:

- Generally, optimizing tire care puts the burden on individuals, which may limit the effectiveness of this strategy.
- Cost can be a barrier to following tire care best practices.

Airless Tires

Airless tires are an emerging technology that could theoretically reduce tire wear because they avoid tire pressure optimization issues and reduce the maintenance burden on car owners. Similar to pneumatic tires, airless tires also utilize rubber tread compounds and are required to meet the same federal motor vehicle safety regulations. However, airless tires are typically heavier than pneumatic tires. Examples from this technology are available from the industry (e.g., Michelin airless tire[23]) and government-funded research and development. For example, the EU-Horizon2020 funded Leon-T project[24] aims to develop and construct prototypes for airless heavy goods vehicle (HGV) tires that reduce noise and particulate emissions.

Research Gaps:

- Quantify the wear rates of airless versus traditional tires to determine emission rates to examine the claim that airless tires have less wear.

Challenges and Barriers:

- All tires are going to have friction and will generate TRWP emissions, regardless of their construction.
- Availability of this technology is limited and costly.

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[23] Michelin, "Michelin UPTIS," accessed June 17, 2025, https://michelinmedia.com/michelin-uptis/.

[24] LEONT Project, "Home," accessed June 17, 2025, https://www.leont-project.eu/.

Changing Driver Behavior

Research shows that rapid acceleration, hard cornering, and braking increase TRWP generation and emissions. Strategies to reduce tire wear via driver behavior include: reducing and enforcing speeds on roads and highways, acceleration limiters, and awareness campaigns focused on driver cornering, turns, and sudden deceleration (which has more impact than speed alone).

Opportunities:

- Develop a curriculum and educate drivers about tire wear and driving best practices to reduce wear (e.g., explore if California driving schools and driver's license tests could include information about tire wear and how to reduce it).
- New "smart" technologies in cars could potentially support real-time driver behavior changes (e.g., scanning road signs and displaying the speed limit on the dashboard as a visible reminder; notifying the driver of changes to roads, speed of traffic; etc.). Autonomous vehicles (AVs) could optimize driving to reduce tire wear.
- Include flyers in vehicle or driver's license renewal notices from the California Department of Motor Vehicles (DMV) to remind drivers about tire maintenance and driving best practices to optimize tire wear, fuel efficiency/battery life, and tire safety.
- WA State's integration of bioswales/rain gardens into roadway planning to both slow traffic and capture stormwater pollutants could potentially reduce tire wear pollution, depending on what infrastructure it is replacing. However, steering to maneuver around these objects could increase tire abrasion rates on these streets.

State Roles:

- Caltrans has methods for sharing information with drivers, such as amber alerts, and it could be valuable to explore if there are opportunities to use infrastructure and systems like these to convey messages that encourage driver behavior to reduce tire wear.
- WA State employs local access only roads, which are aimed at reducing vehicle traffic and increasing safety. California could also explore the implementation of "salmon-safe"

streets or ”water quality ensured” streets that are closed off to only local access if the road is likely to have significant water quality impacts.

Research Gaps:

- Quantifying tire-wear reductions as driving behavior changes from aggressive (hard acceleration and braking) to gentle and eco driving (gradual acceleration and braking) would inform managers of the effectiveness of these solutions.

Challenges and Barriers:

- The effectiveness of awareness campaigns should be considered before investing in these types of strategies.

Rubber Modified Asphalt

Rubber modified asphalt (RMA) pavement surfaces (including from scrap tires) can reduce tire wear as compared to concrete pavements. One study suggests rubber-modified asphalt can reduce tire wear by up to 50 percent[25].

Opportunities:

- There may be opportunities to learn from resources shared on RMA, e.g., USTMA’s State of the Knowledge Report for Rubber Modified Asphalt[26].

State Roles:

- The State can explore support for research into potential chemical leaching, toxicity, or other impacts from tire reuses, including asphalt and stormwater management.

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[25] Jonathan O. Allen, Olga Lexandrov, and Kamil E. Kaloush, “Tire Wear Emissions for Asphalt Rubber and Portland Cement Concrete Pavement Surfaces,” Arizona Department of Transportation, April 1, 2025, https://rosap.ntl.bts.gov/view/dot/20267 (accessed June 17, 2025).

[26] U.S. Tire Manufacturers Association, “Rubber-Modified Asphalt,” May 27, 2021, https://www.ustires.org/system/files/files/2024-05/Rubber-Modified-Asphalt_5-27-2021-FINAL.pdf.

Research Gaps:

- Research is needed to understand what roadway surfaces (e.g., asphalt, concrete, RMA, etc.) lead to the least amount of TRWP.
- Research is needed to understand the effects of RMA on both tire particles and chemical releases. Available literature is not definitive.
- There are still significant data gaps about the chemicals and microplastics emitted from RMA under different conditions.

Challenges and Barriers:

- The potential for chemical leaching from tire-based rubberized pavement material in roads has not been adequately researched.

Modifying Road Surfaces and Design

Modifying road surfaces can reduce tire wear. For example, asphalt has a lower rate of tire wear than concrete, abrasion-resistant materials like quartzite can be used, or resurfacing and maintenance of roads can create a smoother surface. Roadway planning and design can also reduce the tire abrasion that occurs during braking, acceleration, or turning. One study found that the lateral load caused by cornering maneuvers contributes 63% of tire wear but only 5% of tire mileage, suggesting the importance of road design for minimizing wear.[27]

Opportunities:

- A “permeable friction course” or ”open graded permeable asphalt”, a retrofitted surface layer that allows water to pass through and is installed on the surface of conventional

[27] D.O. Stalnaker et al., “Indoor Simulation of Tire Wear: Some Case Studies,” *Tire Science and Technology* 24, no. 2 (1996): 94–118, https://doi.org/10.2346/1.2137517.

driving surfaces, has been shown to have promising water quality benefits[28,29]. Caltrans has design guidance[30] on this technology, and research is underway into its effectiveness for 6PPD-Q removal.

- Examples of roadway planning and design that may reduce tire abrasion include roundabouts instead of intersections with stop signs or traffic signals and angled parking instead of 90 degree or parallel parking.

State Roles:

- State agency coordination on road surface and design modification strategies to reduce TRWP pollution is needed. CARB, CalRecycle, Department of Toxic Substance Control (DTSC), California Energy Commission, Caltrans, and California Highway Patrol were identified as a starting list of agencies with relevant mandates to road modifications, but this coordination is needed across potential TRWP strategies. This broad inclusion of agencies recognizes that the State has multiple roles.

Research Gaps:

- Quantifying the reduction in tire wear from road surface modifications in California would shed light on the effectiveness of this strategy.

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[28] Bradley J. Eck et al., "Permeable Friction Course for Sustainable Highways," in *Green Streets and Highways 2010: An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes*, 2010, https://doi.org/10.1061/41148(389)17.

[29] Bradley J. Eck et al., "Water Quality of Drainage from Permeable Friction Course," *Journal of Environmental Engineering* 138, no. 2 (2012): 174–81, https://doi.org/10.1061/(ASCE)EE.1943-7870.0000476.

[30] California Department of Transportation, *Open-Graded Friction Course* (2020), accessed June 17, 2025, https://dot.ca.gov/-/media/dot-media/programs/design/documents/open-graded-friction-course-dg-a11y.pdf.

Challenges and Barriers:

- Participants commented that road surface modification will likely have a high implementation cost, which could limit adoption.
- Implementing road design is also challenging in a city planning context.

Install Wear Debris Collection Systems on Vehicles

TRWP collection devices installed on vehicles can collect TRWP as they are generated and could be emptied as part of regular vehicle maintenance. Companies like Nexen Tire, Gelbiko Environmental Solutions, and Tyre Collective are working to offer these devices. The Tyre Collective[31] is active in California and is at mid-stage research and development on a fleet of commercial vehicles in Yosemite's shuttle buses. There are opportunities to work with the vehicle industry to put these systems in passenger cars over the long term.

Opportunities:

- Several participants expressed support for this solution as the best option for reducing environmental pollution when tire reformulating or other prevention strategies are not possible, or worthy of investment, while longer-term solutions are in development.
- Participants expressed interest in this strategy's feasibility and the potential to capture the most harmful "air pollution and small particles with high surface area".
- Efforts are underway to explore integration of collection devices into new vehicles directly, potentially with the aim of creating a car part that mechanics would empty and reset during regular maintenance.

State Roles:

- In the technology development phase, the State could support research and development by direct funding, involving State vehicle fleets as partners in pilots to test efficiency and feasibility, including the technology in bids for State fleets, or supporting

[31] The Tyre Collective, accessed June 17, 2025, https://thetyrecollective.com/.

engagement with vehicle manufacturers with the technology to reduce barriers to future adoption.

- Once the technology is developed, State policies could provide incentives for adoption and, if feasible,
- The State could explore the opportunities to and potential impacts of recycling collected TRWP, such as recycling into new tires.

Research Gaps:

- Scaling up pilots and testing of this technology in California, including measuring the effectiveness of TRWP collection in different contexts (e.g., snow), would inform managers of the effectiveness of this strategy.
- Research to understand which vehicle classes emit the most TRWP and which particles (e.g., particle sizes) are the most impactful to capture would be valuable to inform the prioritization of vehicles to target for implementation of this technology.
- Research exploring reuses would address challenges related to the collected particles.
- Research exploring how collection devices can be combined with tire and vehicle improvements would be valuable.
- Understanding the cost of installing systems and the impact on the vehicle mass and fuel economy could help address scaling questions and barriers.
- If implemented at a large scale, waste management of captured material would come into question; research should address if leaching of tire chemicals of concern from concentrated deposits of tire wear microparticulate (i.e., what's captured from multiple collection devices) is of significant concern compared to other existing concerns (end-of-life tires and tire wear deposited on streets).

Challenges and Barriers:

- Disposing of the collected TRWP at scale, including pick-up and drop-off, could be a barrier. Participants reported that initial research into recycling TRWP particles from collection devices is technologically feasible, although logistical questions remain.

- The impact of these devices depends on their ability to capture particle sizes that are most likely to release chemicals or harm the environment (i.e., smaller particles are more likely to release chemicals of concern like 6PPD-Q because of their large surface area to volume ratio, and collection devices may struggle to collect small particles).
- Automotive companies and consumer buy-in to use these devices will be needed to implement them at scale.

Optimizing Vehicle Design

Participants discussed how car design factors like weight, torque, and braking can impact tire wear rates. Vehicle manufacturers were identified as an important perspective to engage on this topic, yet one that was missing from the workshop.

Opportunities:

- Innovations in EV design would help minimize forces that impact tire abrasion, such as using low-density materials or lower weight, higher energy density batteries (e.g., solid state batteries, which have higher energy density and are lighter than liquid-based lithium-Ion batteries).
- One participant raised a potential policy solution related to vehicle design: a State program that charges extra registration or other fees for high-weight, high-torque, non-commercial vehicles that contribute disproportionately to TRWP. These fees could be used as a mitigation fund.

State Roles:

- Engage with vehicle and tire manufacturers to understand how vehicle design constraints and opportunities could impact the generation of TRWP. This opportunity is also relevant to other solutions in this report (e.g., tire collection devices, changing driver behavior).

Challenges and Barriers:

- As EV adoption increases, TRWP may also increase because EVs are heavier than internal combustion engine vehicles, have higher acceleration torque, and their braking systems tend to result in higher tire abrasion rates than conventional (friction) braking systems.
- Participants discussed the complexity of tire size and design and how that impacts wear rates. Tires are designed to carry vehicle load, and the three main variables in tire sizes are rim diameter, aspect ratio, and section width. Changes in these variables' dimensions impact rotations per mile, so relating tire size to TRWP emissions may not be straightforward.

Tire Abrasion Standards

Tire abrasion standards are a regulatory approach to limiting tire wear. In a first regulation of its kind, the EU is pursuing new rules on emission limits for tire abrasion and braking for cars, vans, and heavy-duty vehicles as part of the Euro 7 standard[32]. Test procedures and limits are under development[33]. Once abrasion limits are set at the UN level, the EU will transpose the abrasion limits into Euro 7 regulation for new tire types for passenger cars in 2028, light commercial vehicles in 2030, and heavier commercial vehicles in 2032. A UN Task Force on Tyre Abrasion[34]

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[32] Council of the EU. 12 April 2024 12:30. Press release Euro 7: Council adopts new rules on emission limits for cars, vans and trucks, accessed June 18, 2025 https://www.consilium.europa.eu/en/press/press-releases/2024/04/12/euro-7-council-adopts-new-rules-on-emission-limits-for-cars-vans-and-trucks/

[33] United Nations Economic Commission for Europe, "World Forum for Harmonization of Vehicle Regulations (WP.29)," UNECE Vehicle Regulations, accessed June 5, 2025, https://unece.org/transport/vehicle-regulations/world-forum-harmonization-vehicle-regulations-wp29.

[34] United Nations Economic Commission for Europe, "Task Force on Tyre Abrasion (TF TA)," UNECE Wiki, March 8, 2022, https://wiki.unece.org/pages/viewpage.action?pageId=160694352.

aims to develop draft requirements for finalization and translation in June 2025 and present them for discussion in September 2025 at the UN committee meeting.

Opportunities:

- Reformulating to limit wear seems feasible from the perspective that existing tires have a range of emissions, and lower-abrading tires are already on the market.
- The United Nations Economic Commission for Europe (UNECE) has adopted tire abrasion measurement test methods, and an International Organization for Standardization (ISO) standard is also in development, with the ultimate goal to correlate between on-vehicle tests and wheel tests.
- Broad stakeholder and government engagement in the UN task force convened as part of the Euro 7 process is encouraged because of the importance of landing on a good threshold and methodology that could be seen as a baseline for potential global use. Industry is already heavily engaged.

State Roles:

- Generally, the UNECE process will reveal lessons learned on setting abrasion standards that may be relevant for California policies. Some state agencies are already involved in the tire task force and encourage others to join the collaborative proceedings.
- There are also opportunities for the State to convene industry, scientists, engineers, and other stakeholders and experts to explore tire abrasion in California.
- In the future, California could subsidize the cost of lower-abrasion tires, since they may be more expensive, to incentivize adoption.
- There may be lessons learned for abrasion standard development from the state regulatory effort underway from AB 844 (Gipson, 2023), in which the California Energy Commission aims to create a minimum performance standard for rolling resistance for energy efficiency gains.
- If abrasion standard methods are determined and validated for US tires, California could consider adopting tire abrasion test standards.

Research Gaps:

- A landscape analysis should be conducted to understand what technology is readily available (not proprietary, does not require research and development) to reduce tire abrasion.
- Before moving forward with reformulation for reduced abrasions, research on the toxicity of potential replacement chemicals is needed to avoid regrettable substitutions.
- While the EU tyre abrasion standard is focused on particulate matter, it is still important to understand gaseous emissions and the fate and transport of airborne particles that tires emit during their lifetime.
- Research into potential tradeoffs between setting tire abrasion standards and tire lifecycle concerns (e.g., rolling resistance, toxicity, durability) is needed.
- Research is needed on the emitted particle size distribution of low-abrasion tires compared to conventional tires (e.g., do they, on average, produce smaller particles that have potentially increased toxicity concerns?).

Challenges and Barriers:

- Participants discussed the complexity of tire engineering and raised concerns about one-size-fits-all solutions, given that wear processes vary by tire type and application (e.g., winter tires). Abrasion standards will require examining material innovation, tread design changes, and torque management, all in the context of the safety of the tire. The effectiveness of abrasion standards may be limited by grip needs and safety concerns.
- Setting abrasion standards may be difficult without new innovations (e.g., coupling agents, nano-scale materials), which themselves may have tradeoffs. Tire tread engineering must balance rolling resistance, wet grip, and durability.
- Extensive testing would be necessary to understand the full potential suite of safety concerns of low-abrasion tires on different roadways..
- Lack of transparency in the chemical make-up and composition of all types of plastics, including tires, is a challenge for understanding the impacts of reformulation for lower

abrasion. This is often driven by proprietary concerns and could potentially be addressed via research.

- While participants agreed that lessons can be learned from the Euro 7 process, they also highlighted key differences between American and European tires. A participant commented that while American tires are engineered for longer mileage, EU tires are engineered for high traction, high speed, and handling.

Prevention Strategies

Labeling and Disclosure

Labeling tires with information on abrasion rates or toxicity could potentially provide incentives for consumers to choose tires with lower environmental impacts. There are both government-backed efforts and consumer protection labeling initiatives to consider as models. For example, the Automobile Club of Germany produces biannual reports rating different tires available on the European market. The EU requires tire labels with information on fuel efficiency, wet grip, and noise emissions. Through Proposition 65, California's Office of Environmental Health Hazards Assessment (OEHHA) maintains a list of chemicals that businesses are required to provide warnings to Californians about significant exposures to chemicals.

Opportunities:

- There is a regulatory precedent in AB 844 and the California Energy Commission, which, in addition to creating a minimum performance standard for rolling resistance, also aims to create a label rating system for tires on rolling resistance for energy efficiency, and could provide useful lessons on the feasibility and impact of tire labeling. However, factors like noise emissions and tire wear are outside of the California Energy Commission mandate at present.

- There may be value in following listing and labeling criteria requirements for plastic products, including tires, that may be included in the ongoing UN Plastics Treaty negotiations[35].

Research Gaps:

- Social science research to understand the effectiveness and feasibility of labeling could be useful before investing in this strategy. For instance, it may be helpful to understand the average consumer's familiarity with tire emissions and associated compounds of concern, how consumers respond to labeling information, and what consumer education is needed for proper label interpretation.

Challenges and Barriers:

- For tires, labeling is feasible in theory, but is still very difficult, in part because of the challenge that tires use numerous chemicals, many of which are proprietary.
- Efficacy may be a challenge for this strategy; it is unclear if labeling would lead to substantive and impactful changes in consumer choice on a broad scale. Consumer labels may need to be very simple.
- Labeling for 6PPD may not be feasible in the near term because it is likely that all tires will have 6PPD until an alternative is found.

Voluntary Reformulation - Industry innovation, Ingredient controls, and review systems

Voluntary measures to prevent the use of harmful substances in tires include voluntary tire ingredient review systems and voluntary product ingredient controls. Examples of the former include: A) the US EPA Hazard Comparison tool[36], which enables users to search and compare

[35] United Nations Environment Programme, "Intergovernmental Negotiating Committee on Plastic Pollution," April 3, 2025, https://www.unep.org/inc-plastic-pollution.

[36] U.S. Environmental Protection Agency. (n.d.). ChemInformatics Analysis Modules Resource Hub. Retrieved June 18, 2025, from https://www.epa.gov/comptox-tools/cheminformatics-analysis-modules-resource-hub

a variety of chemical and hazard information to evaluate potential health effects of chemicals; B) the GreenScreen for Safer Chemicals[37], which is a comprehensive hazard assessment tool that is transparent, scientifically based, and promotes the design and use of safer chemicals via informed substitution; C) lifecycle assessment tools or services; and D) ChemFORWARD[38], a nonprofit working to provide hazard data and safer alternatives. Examples of voluntary product ingredient controls include the International Global Automotive Declarable Substance List[39] (GADSL) and other similar resources that the automotive industry can refer to.

Opportunities:

- Shifting formulation at the global level may be more impactful than at the state level, which points to the value of engaging in and tracking the UN Plastics Treaty process.
- Some participants expressed a positive sense that innovations in toxicology technologies may accelerate learning and testing and could potentially address reformulation challenges, while others expressed concern about the environmental impacts of applying AI to this purpose.
- Increased EV adoption could drive voluntary tire reformulation, or, at minimum, tracking EV car design evolution and potential changes of associated TRWP formation could be valuable.

State Roles:

- A potential State role could be to support or advance green chemistry tools or advice for tire manufacturers. However, existing state mandates limit the ability of the DTSC to engage in outreach on green chemistry, provide grant money for research, or otherwise

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[37] Clean Production Action. (2025). GreenScreen® for Safer Chemicals. https://www.greenscreenchemicals.org/

[38] CHEMFORWARD. (2025). ChemForward. https://www.chemforward.org/

[39] American Chemistry Council, Inc. (2025). Global Automotive Declarable Substance List (GADSL). https://www.gadsl.org/

support evaluation of chemicals and alternatives. WA State's programs could be a model.

- A State role, more generally, could be to facilitate research funding to fill data gaps (see below).

Research Gaps:

- Completing the toxicology testing research needed for the many chemicals in these green chemical resources would make them more robust.
- Research is needed on transformation products from many tire ingredients. Transformation products are new molecules formed as a result of a chemical reaction or transformation process, which may have differing toxicity properties, e.g., 6PPD in tires transforms into 6PPD-Q.

Challenges and Barriers:

- Voluntary measures are unlikely to be effective in driving changes in tire reformulation.
- There is a perception that these tools (e.g., voluntary tire ingredient review systems and voluntary product ingredient controls) are not currently in wide use at present and, additionally, that some may risk federal funding cuts, but agreed there could be potential to promote more use.
- Voluntary reformulation is complicated by the fact that chemical suppliers have a role in shaping the chemical product market, not just tire manufacturers.
- Reformulation is complex because tires are engineered, composite products designed to meet safety requirements and often involve proprietary information. Transparency into compounds and chemicals used is limited. There are 15-20 different rubber compounds and many chemicals used, each with a specific performance capability. When one chemical is changed, it can affect the others.
- It is important to avoid regrettable substitutions in this and other tire formulation and abrasion discussions, with the recommendation that full toxicology and degradation byproduct testing be completed before alternatives are adopted.

- Research on transformation products from many tire ingredients is complex and challenging. There are dozens of transformation products from 6PPD alone, and thousands more chemicals from tire wear leachate. A challenge is connecting funders with the researchers who have the tools for these robust analyses.
- Encouraging "safer formulations" may make it more challenging to track the compounds in use in tires at any time point, which would further complicate toxicology work and could foster regrettable substitutions.

Reformulation through Regulation

Regulatory strategies that enforce tire product contents were also discussed, e.g., in the past, the EU limited Polycyclic aromatic hydrocarbons (PAH) contents[40] in oils used to manufacture tread, and over time, the tire industry shifted towards manufacturing processes that used oils with lower PAH contents. In 2023, California's DTSC finalized a regulation under the Safer Consumer Products (SCP) Regulations to list 6PPD in tires as a new Priority Product chemical combination after USTMA's petition. Subsequently, USTMA has established its 6PPD Alternatives Analysis Consortium to meet regulatory obligations under DTSC, which includes 36 tire companies. Washington State is also assessing alternatives for 6PPD[41] and has developed hazard criteria[42].

[40] Health and Safety Authority, "PAHs in Extender Oils in Tyres," accessed June 17, 2025, https://www.hsa.ie/eng/Your_Industry/Chemicals/Legislation_Enforcement/REACH/Restriction/Restricted_Chemicals/PAHs_in_extender_oils_in_tyres.pdf.

[41] Washington State Department of Ecology, *6PPD Action Plan and Alternatives Assessment Progress Report and Recommendations* (October 2024), https://apps.ecology.wa.gov/publications/documents/2404053.pdf.

[42] Washington State Department of Ecology, "Washington's Sustainable Management of Used Tires: 2023 Report to the Legislature," April 2023, https://apps.ecology.wa.gov/publications/SummaryPages/2304036.html.

Opportunities:

- There may be value in following efforts in WA State's investments in research related to replacing 6PPD in tires, monitoring, and tire recycling; California's DTSC SCP program for lessons learned; and in tracking the UN Plastic Treaty for any international decisions on reformulation.

State Roles:

- DTSC has established 6PPD in tires as a product-chemical combination, which requires all tire manufacturers selling tires in the state to conduct an alternatives analysis compliance or discontinue selling tires containing 6PPD in the state. Final alternatives analysis reports are due to DTSC in August 2026.
- DTSC has proposed adding microplastics to their candidate chemical list, which is a list of chemicals they may regulate.

Research Gaps:

- Research is needed to understand the toxicity of any replacement chemicals used to meet abrasion or reformulation standards, including any degradation byproducts or transformation products.
- Research is needed to understand the effects of tire wear, including the relative size distribution of particles emitted and the impacts associated with size, e.g., there may be lower wear but a higher proportion of smaller particles, which could increase inhalation and human health impacts.

Challenges and Barriers:

- Currently, there are no available substitutes for 6PPD that offer comparable tire performance and safety. Once a potentially suitable alternative has been identified, USTMA estimates that it could take a minimum of 4 to 6.5 years for the tire research and development, design, and performance testing process for adding a new ingredient to a tire with existing commercially-produced materials known to perform as necessary. In the case of 6PPD, once a new candidate alternative is identified, a minimum of an additional 4 years of limited-scale field testing will be required to ensure continued performance as a tire ages[43].

- Generally, replacing chemicals in tires is complex and difficult. With potential replacements, it is also important to avoid regrettable substitutions. Tire performance is critical for safety and is subject to regulation by the Federal Motor Vehicle Safety Standards on dimensions, test ratings, loading, etc. In the EU, PAHs seemed relatively less complex to lower via reformulation, although a participant shared that the process took over 10 years. Antioxidant protections like 6PPD may be more difficult and time-intensive to reformulate.
- Mandatory reformulations with sufficient product and toxicity testing may require research funding.

Eliminating Tires and Wheels, Reducing Vehicle Miles Travelled

Eliminating the use of tires and wheels and reducing Vehicle Miles Traveled (VMT) will also reduce TRWP formation from vehicle tires. Examples of this strategy include: public and mass transit availability and incentives (e.g., UK low emission zone[44]); regional and local development planning (i.e., walkable and bikeable cities); trains, cable cars, or other public transportation methods that do not use rubber tires; scooter and bike municipal rentals; rideshare and carpool incentives (e.g., a program in South America requires carpool on certain roads on certain days); or incentivizing or regulating VMT reductions. CARB is running a statewide program to reduce VMT, which was implemented over 10 years ago as part of the SB 375 (Steinberg, 2008) sustainable communities program. This required the state government to work with local

[43] "Preliminary (Stage 1) Alternatives Analysis Report Motor Vehicle Tires Containing N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD)," U.S. Tire Manufacturers Association, prepared for USTMA by Gradient Corp., March 24, 2024, https://www.ustires.org/resources/preliminary-stage-1-alternatives-analysis-report-motor-vehicle-tires-containing-n-13.

[44] Transport for London, "Ultra Low Emission Zone," accessed June 17, 2025, https://tfl.gov.uk/modes/driving/ultra-low-emission-zone.

planning agencies to develop regional GHG reduction goals. As a result, substantial VMT reduction is already happening with passenger cars. However, for commercial vehicles, VMT is increasing, although heavy-duty VMT is only 10% of total statewide VMT.

Opportunities:

- The primary benefits of these strategies would be seen in urban areas.
- There is value in exploring the co-benefits of these strategies (e.g., carbon dioxide emissions reduction, improving vehicle or tire lifespan, health benefits associated with walkability) and there may be opportunities to integrate or communicate the benefits of TRWP reduction into broader city and regional planning efforts that seek to eliminate tires and wheels for other reasons.
- Study best practices from other countries on mass transit planning, regulations, and incentives to reduce VMT (e.g., limiting freight trucks in cities or residential areas).

State Roles:

- Participants suggested that the State implement programs that support remote and telework opportunities as much as possible, such as requiring companies with over a certain number of employees to offer hybrid or remote options for workers to reduce commute frequency and thus VMT.
- State agency coordination and communication around the co-benefits of reducing VMT and eliminating wheels could be valuable, potentially involving CARB’s VMT reduction programs.
- State agency roles include taking more steps to support all strategies in this category, including ride sharing, HOV lanes, mass transit, and high-speed rails, which could drastically reduce vehicle tire wear within and between highly populated areas in the San Francisco Bay Area and Los Angeles.

Research Gaps:

- The extent of tire wear pollution in rural areas is unknown. If rural areas have high impervious surfaces with low to moderate traffic, this could potentially cause high environmental 6PPD-Q concentrations.
- Most of the strategies discussed here are focused on passenger vehicles and research could explore opportunities to reduce VMT for freight trucks.

Challenges and Barriers:

- Many of these solutions are more challenging to implement in rural areas where personal vehicles and driving are required.
- Most Californians are highly reliant on cars and personal vehicles. Public transportation costs and inconvenience are barriers for commuters.
- Participants raised that trains and other mass transit technologies can produce metal particulates from the tracks or brake wear emissions. With this in mind, it is important to consider how feasible it is to regulate some contaminants over others, e.g., in Washington State, it is easier to mitigate metal pollution from light rail than 6PPD-Q pollution.

Research Gaps Prioritization

Participants discussed the many research gaps that emerged during the workshop and engaged in an exercise of arranging them on a feasibility and impact matrix. Impact was defined as the potential to lead to the implementation of solutions with positive environmental impacts and reduced TRWP pollution in California. Feasibility was defined as the cost and time to complete the research in California with State resources. This could help the State prioritize its efforts in the TRWP pollution space.

Themes from Discussion:

- Efficiency gains may be realized by pursuing cross-cutting research needs that help the State prioritize between the many possible TRWP pollution intervention strategies for maximum impact.
- Participants discussed the importance of considering what questions can lead to impactful and feasible upstream solutions (prevention or reduction). For example, many gaps related to specific downstream stormwater management strategies should be deprioritized because these strategies can be costly, hard to maintain, and prohibitive in space-constrained urban areas. However, an exception to this is research gaps that help prioritize “hotspots” for stormwater management or address the impacts from chemicals like 6PPD with no known replacement.
- Questions related to the toxicity and impacts of TRWP are important, but our current understanding is enough to know that emissions should be reduced. However, prioritizing research on toxicology and its impacts will help California avoid regrettable substitutions, especially in the context of new reformulation or abrasion policies.
- California is one of the few places with the leadership and resources to implement research and large-scale piloting studies of tire wear collection devices. Very few other specific intervention strategies were associated with cautiously optimistic interest from most participants.
- In contrast, prioritized research questions for other specific solutions were related to understanding their potentially negative impacts (i.e., tire reuse, regrettable substitutions in abrasion standards setting or reformulation) or prioritizing hotspots for remediation actions (i.e., stormwater management). These other solutions do not seem ready to consider scaling yet, and more research and development are necessary first.
- Fundamental methods and standards development for measuring TRWP will advance tire research as a whole. Efforts are underway at the international level on some of these standardization questions, and California can learn from them.

Summarized research gaps are shared below:

High Impact, High Feasibility

Tire reuse:

- Given that the available literature is not definitive, multiple high-quality, peer-reviewed studies from reliable independent sources are needed to investigate the effects of rubber-modified asphalt on both tire particle and chemical releases, potentially in different conditions. Trust is very important for this issue to be resolved.
- Beyond RMA, additional high-quality, independent, peer-reviewed studies with robust chemical analysis are needed to understand the potential for chemical leaching from all tire reuses, such as on crumb rubber fields, playgrounds, and consumer products.

Methods and Standards:

- Research is needed to develop scientifically valid methods to estimate quantities of TRWP emissions. The literature on emissions factors, which is the particle weight relative to particle size per unit distance, says they are highly variable based on climate and road. Developing this standard will enable researchers to compare across studies.

Tire Wear Collection Devices:

- More and larger pilot projects testing tire wear collection devices in California would shed light on the potential to scale this solution for near-term reductions in TRWP release. A number of factors should be studied, including: A) assessing which particle sizes are most impactful to capture, which particle sizes should be targeted for collection, and the percentage of TRWP captured; B) research to understand which vehicle classes emit the most to inform priorities for tire device deployment; and eventually, to C) understand the feasibility of broader deployment, such as identifying barriers like potential local impacts, impacts to vehicle fuel economy, or costs.

Remediation:

- Research to identify TRWP emission “hotspots” in California, leveraging traffic data, impervious surfaces, proximity to vulnerable ecosystems, and other data, would help prioritize the placement of costly, time-intensive stormwater management strategies.

This could include screening-level geospatial analysis within watersheds to assess the feasibility of placing stormwater BMP strategies that target TRWP or other microplastics. It could also involve local communities and tribes to develop localized prioritization frameworks to increase the co-benefits of green infrastructure.

Toxicology and Impacts:

- Generally, more research is needed to build on existing scientific studies to understand how humans and other species are affected by inhalation and ingestion of tire particles, including how volatile organic compounds, transformation products (beyond 6PPD-Q), combinations of chemicals, and/or exposure to different size particles might interact to cause potential toxicity or harm. This is challenging because there is little transparency into the many chemicals in use.
- These toxicological and human and ecosystem health impact questions are especially relevant to the active policy discussions around abrasion standards or reformulation because any changes to tire manufacturing, formulation, or abrasion should avoid regrettable substitutions or substitutions that cause more harm.
- Research is needed on the relative toxicity of TRWP based on particle size and to understand how potential tire reformulation could shift the particle size distribution. For example, collecting data on the particle size of low-abrasion tires compared to conventional tires and understanding how this relates to toxicity concerns.

High Impact, Low Feasibility

Rubber-Modified Asphalt:

- Research gaps include how much elastomer and microplastics are generated from RMA, the proportion of particles that are from tires on the road versus the RMA, and if there are any trade-offs with tire lifecycle concerns, such as rolling resistance, toxicity, and durability.

Sources:

- Assessment of primary sources of TRWP in California, where and when it is produced, and characterization of particle size distributions could help prioritize both research needs and solutions.

Toxicity and Impacts:

- Research into the impacts of airborne particles from tires on human health is needed.

Tire Wear Collection Devices:

- Research is needed to understand how tire collection devices can be combined with tire and vehicle design improvements.

Stormwater Management:

- A number of research gaps were identified related to the efficiency of specific stormwater management solutions in remediating TRWP, including:
    1) studies on how permeable pavement can affect tire wear rates and formation;
    2) large-scale field evaluations of biofiltration removal of 6PPD-Q from stormwater;
    3) research into space-efficient stormwater tech and vortex separator costs, local benefits, and feasibility to scale, which could lead to implementation of this solution; and
    4) research to understand which stormwater management strategies can also reduce airborne tire wear particles.
- Research into stormwater management strategies using infiltration is needed to understand their potential risk of introducing tire chemicals into groundwater supplies, aquifers, drinking water, and/or into plants.

Reduction Strategies:

- Research into strategies to reduce VMT for freight trucks could be valuable, given that most VMT reduction strategies target passenger vehicles. For example, studies exploring the impact of restricting road access to certain vehicle types (e.g., large commercial truck bans on arterial or residential roads) would help understand the potential impact of this solution.

- Research investigating how different road surface compositions like concrete, RMA, or other surfaces affect tire wear would clarify what surfaces to prioritize for TRWP reduction.

High Feasibility, Low Impact

Sources:

- Research to understand if tire wear is getting into food crops grown along roads is needed.

Remediation Strategies:

- Research is needed to understand how California's existing waste maintenance strategies, such as street sweeping, and their frequency, affect the removal of TRWP.
- Stormwater BMP design development is needed to promote microplastic and TRWP removal, which will require field and lab testing for these emerging contaminants.

Toxicity and Impacts:

- Research to understand the leaching behavior (e.g., mobility and bioavailability over time) of compounds of concern (e.g., 6PPD-Q) in different water bodies is needed.

Tire Wear Collection Devices:

- The performance of tire wear collection devices in winter and snowy conditions will need to be understood before deployment in those conditions is considered.

Low Feasibility, Low Impact

Methods and Standards:

- Research is needed to develop scientifically valid methods to estimate quantities of TRWP in the environment.
- A similar, but more difficult science gap to address with California's resources alone is ensuring that all testing and methodology is based on independent, peer-reviewed science.

Sources and Transport:

- Research is needed to understand how much TRWP becomes airborne versus stuck to the road.

Toxicity and Impacts:

- Research is needed to understand if chemicals are released from trapped particles, e.g., if soils and sorbent media release trapped 6PPD-Q over time.
- Research on the extent of tire wear pollution in rural areas is needed. If rural areas have highly impervious surfaces even with low to moderate traffic, this could cause high 6PPD-Q concentrations.

Remediation strategies:

- Research is needed to understand the fate of TRWP filtered out of stormwater, e.g., if they degrade or resuspend out of the system.
- Relatedly, it will be important to investigate appropriate means of managing the waste from stormwater maintenance and to assess if it should be considered as hazardous waste.
- As the circular economy gains traction, research that builds on existing studies into alternative or potentially recycled media used in stormwater BMPs could be considered.

Reduction:

- Research and syntheses are needed to understand what technology is readily available, (i.e., not proprietary and not requiring research or development) to reduce tire abrasion.
- Studies to quantify tire-wear reductions as driving behavior changes from aggressive (i.e., hard acceleration and braking) to gentle and eco-driving (i.e., gradual acceleration and braking) would help assess the potential impact of driver behavior change on tire wear.
- Social science research will likely be needed before pursuing any tire labeling program to understand how consumers would respond to abrasion labels or to understand consumer familiarity with tire emissions and associated components of concern.
- There are many research questions related to airless tires, but they are of lower priority given the currently limited adoption of this technology.

- Research into the feasibility of capturing volatile organic compounds (VOCs) when they are released from tires could advance tire wear collection device capabilities.

Appendix A: Agenda

Day One

Tuesday, March 25, 8:00 am-12:00 pm Pacific Time

I. 8:00 Welcome, 3*0 min*
   Discussion Goals & Framing
   Agenda Overview
   Introductions
II. Tire Wear Pollution - Science and Background (San Francisco Estuary Institute), *15 min*
III. Industry Perspectives (U.S. Tire Manufacturers Association), *10 min*
IV. Overview of Survey Results, *5 min*
V. Solutions & strategies for remediation / removing and collecting wear debris and tire contaminants from runoff, *90 min*
   Group discussion & whiteboard activity
   For each solution, there will be facilitated opportunities to:
   1. Clarify or add detail to the description of the solution under discussion
   2. Share verbally or via the whiteboard your sense of the solution under discussion, i.e., the feasibility, potential impact, research gaps, potential barriers, and/or state policy and support opportunities
   3. ask clarifying questions to better understand the information shared by other participants
   4. Offer additional solutions/strategies that are not currently captured
VI. Solutions & strategies for reducing wear debris formation and emissions, *95 min*

Group discussion & whiteboard activity

For each solution, there will be facilitated opportunities to:

1. Clarify or add detail to the description of the solution under discussion
2. Share verbally or via the whiteboard your sense of the solution under discussion, i.e., the feasibility, potential impact, research gaps, potential barriers, and/or state policy and support opportunities
3. ask clarifying questions to better understand the information shared by other participants
4. Offer additional solutions/strategies that are not currently captured

VII. 11:50 Close & Next Steps

<u>Day Two</u>

Thursday, March 27, 8:00 am-12:00 pm Pacific Time

I. 8:00 Welcome & Recap, *20 min*

II. Reduction Discussion, continued, starting at the abrasion standard frame, *30 min*

III. Solutions and strategies for prevention / eliminating tire wear particles and removing toxic ingredients, *90 min*

Group discussion & whiteboard activity

For each solution, there will be facilitated opportunities to:

1. Clarify or add detail to the description of the solution under discussion
2. Share verbally or via the whiteboard your sense of the solution under discussion, i.e., the feasibility, potential impact, research gaps, potential barriers, and/or state policy and support opportunities
3. ask clarifying questions to better understand the information shared by other participants
4. Offer additional solutions/strategies that are not currently captured

IV. Prioritization of Research needs, *50 min*

Group discussion & whiteboard activity

V. 11:50 Close & Next Steps

Appendix B: Participating Organizations

ACE Laboratories
California Air Resources Board
California Coastkeeper Alliance
California Department of Transportation
California Department of Toxic Substances Control
California Energy Commission
California Ocean Protection Council
California Ocean Science Trust
California State Water Resources Control Board
CalRecycle
Emissions Analytics
Monterey Bay Aquarium
National Oceanic and Atmospheric Administration Marine Debris Program
Ocean Conservancy
Oregon State University
San Francisco Estuary Institute
Smithers
Southern California Coastal Water Research Project
Stantec
Texas A&M University

The Pew Charitable Trusts
The Tyre Collective
U.S. Environmental Protection Agency
U.S. Tire Manufacturers Association
University of California Los Angeles
Virginia Institute of Marine Science
Washington State Department of Ecology