

Tyre emissions from the latest electric vehicles *Concepts and results*

Nick Molden
Founder & CEO, Emissions Analytics
Honorary Research Fellow, Imperial College London

19 September 2023

Our Belief

When it comes to the pursuit of emissions reduction, we believe in the power of clarity, transparency and integrity. With real-world data we can meet emissions challenges – instilling trust and confidence in our industry partners and public.

It's with our commitment and independence we are able to make a significant contribution toward positive change and to achieve enduring results.

Agenda

- Defining tyre emissions
- Regulatory trends
- Experimental approach
- BEVs and trade-offs
- Tyre emissions test programme
- Conclusion and the future



The image shows four tires stacked on a paved road. A semi-transparent blue horizontal bar is overlaid across the middle of the tires. The background is a blurred outdoor scene with trees and a bright sky.

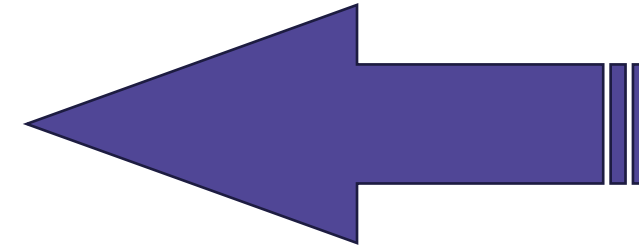
Defining tyre emissions

ASSURED | INDEPENDENT | RESPONSIVE

What are tyre emissions?



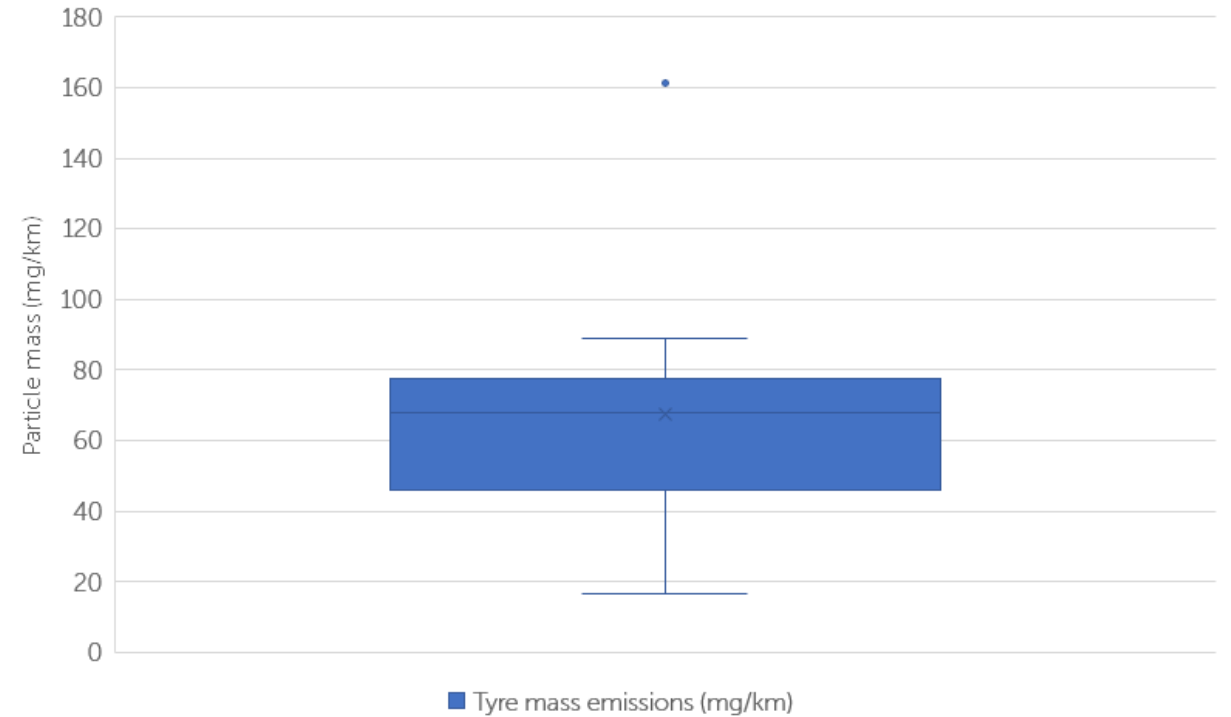
- “Sustainability”: reducing carbon emissions during production
- Alternative materials
- In-use pollution
- Larger and nano-particles
- Off-gassing volatile organics
- End-of-life tyres and recycling
- Rubber crumb
- Fuel source



Tyre mass emissions

- 18 different models of tyre
- Tested from new
- Public highway
- Majority motorway by distance
- Average total distance ~5,000 km

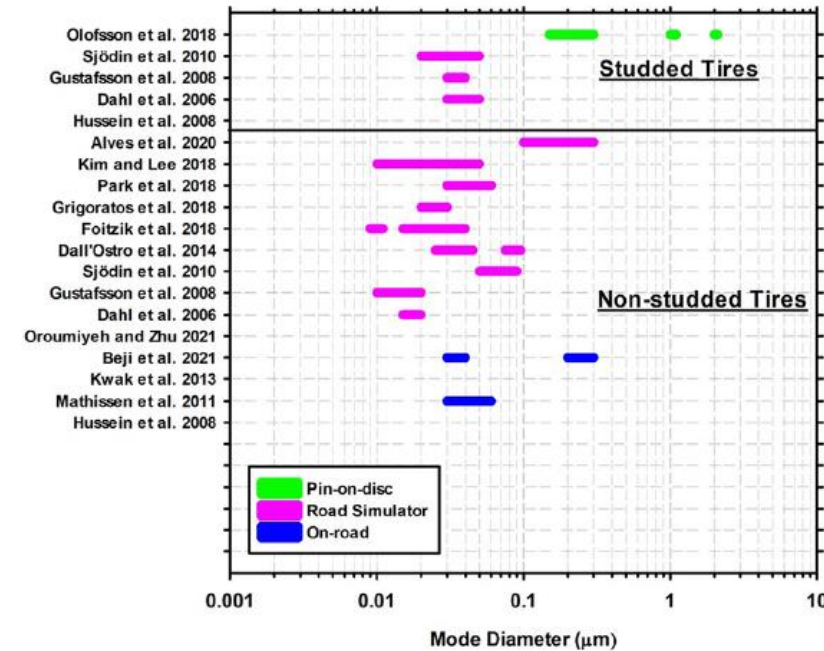
- 67 mg/km mean
- Inter-quartile range: 46-77 mg/km
- Outliers
- Suggests limit value ~80 mg/km



Particle mass vs number

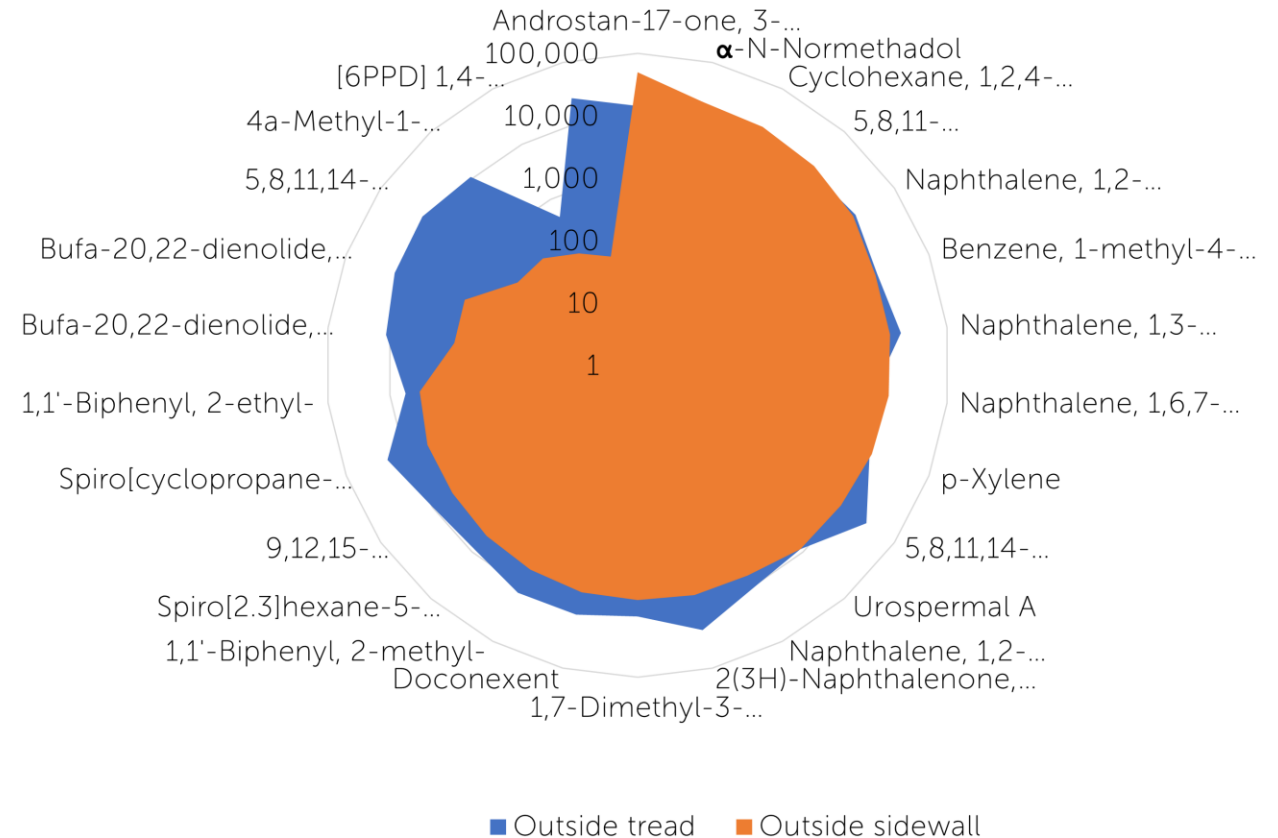
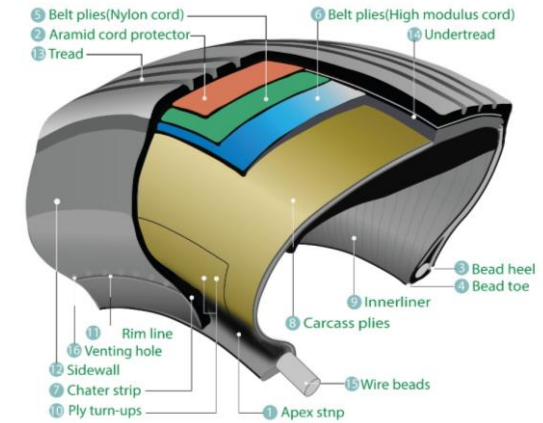
- On-road test with 'normal' dynamics
 - 11% of fine particle mass is below 2.5 μm diameter
 - This mass accounts for almost 100% of particle number
 - And ultrafines account for 92% by number
 - Other potential source of ultrafines is from combustion, but influence from other vehicles eliminated
 - Results borne out in academic literature
- Tyres are simultaneously a problem for air, soil and water

c) Tire wear particle number distribution



Secondary pollutants

- Secondary organic aerosol formation from off-gassed VOCs reacting in air
- Mainly from tyre sidewall, which can be different chemical composition from tread
- SOA Yield of $4.01 \mu\text{g}/\text{m}^3$ from toluene in recent research in Shanghai



Regulatory trends

ASSURED | INDEPENDENT | RESPONSIVE

Emerging regulation – EU

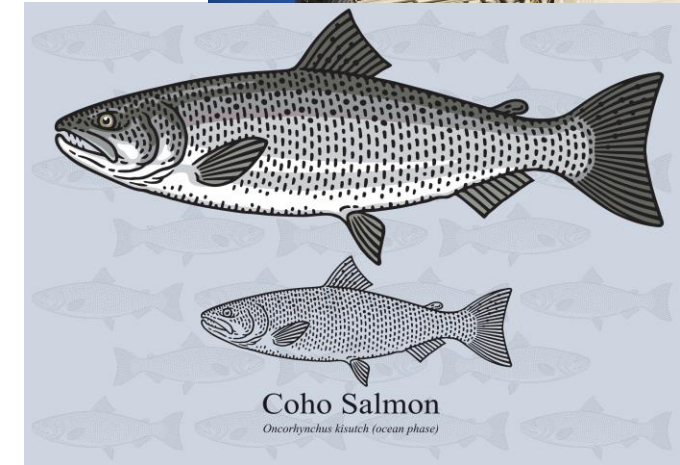


- “Euro 7” proposes to set limit values for distance-specific mass emissions
- More details required on how this would be enforced for replacement tyres
- Test method being developed by Task Force on Tyre Abrasion at UNECE
- Earliest introduction 2025, but more likely 2026/27, or as late as 2028-
- Nothing approved yet
- Conceptual issues such as inclusion of ice tyres
- Major potential loophole if limit value set on mg/km per tonne basis

- REACH already limits 8 polycyclic aromatic hydrocarbons

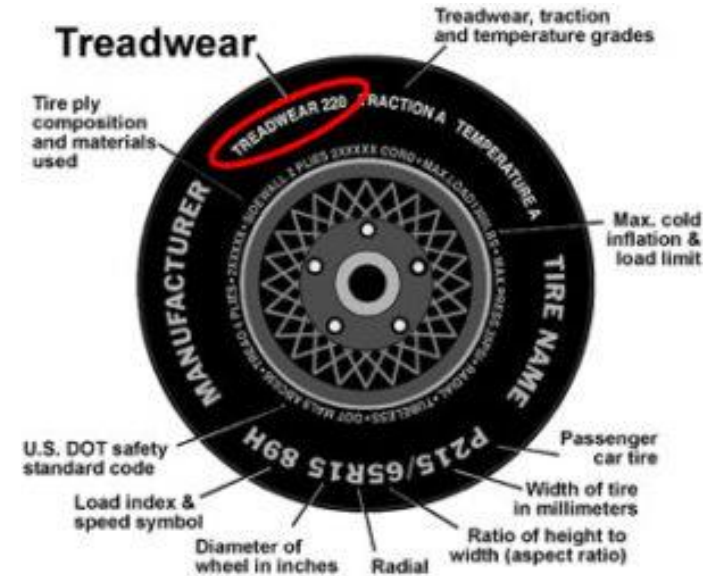
Emerging regulation – US (1)

- California 6PPD rule introduced in 2023
 - To address mass die-off of coho salmon (<https://www.emissionsanalytics.com/news/fishy>)
 - Forces tyre manufacturers to investigate alternatives to 6PPD
 - Or remove from sale
 - Accelerated timeline – November 2023
 - One-off review only
-
- Other West Coast states planning to follow, with more prescriptive direction



Emerging regulation – US (2)

- California replacement tyre rule is...
- “...designed to ensure that tires sold in the state are at least as energy efficient, on average, as tires sold in the state as original equipment on new passenger cars and light-duty trucks.”
- Replacement tyres currently have 21% greater rolling resistance than new, original tyres
- 5* rating system – by manufacturers, for use at point of sale
- Must not affect safety, durability and end-of-life
- Maximum rolling resistance coefficient of 9.0 from 2026
- Falling to 7.0 from 2028





Experimental approach

ASSURED | INDEPENDENT | RESPONSIVE

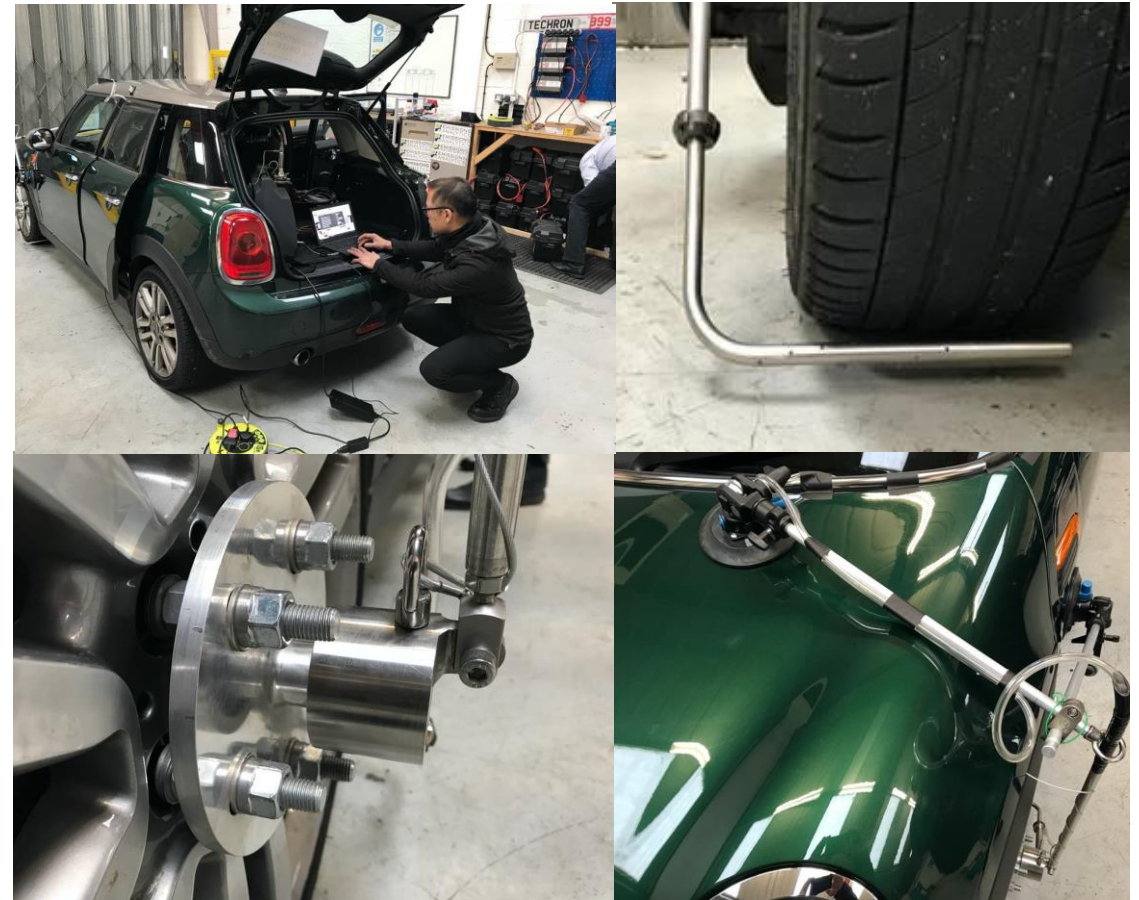
Concept

$$\begin{aligned} & \textit{Tyre wear rate} \\ & \times \\ & \textit{Chemical speciation} \\ & \times \\ & \textit{Compound hazard} \\ & = \\ & \textit{Potential environmental impact} \end{aligned}$$



On-vehicle sampling – principles

- Universal fitment across vehicles
 - Fits to any and all wheels on a vehicle
 - No vehicle modification required
 - Articulates as the vehicle steers
 - Safe and road-legal
 - Can be coupled with any detector
 - And collecting plates/receptacle
 - Patent-pending
- Mass, number and physical collection



Chemical fingerprinting

- Two-dimensional gas chromatography with mass spectrometry
- INSIGHT flow modulator from SepSolve Analytical for separation
- BENCH-TOF time-of flight mass spectrometer
- Multi-stage pyrolysis method



Hazards

Hazard code	Description
H300	Fatal if swallowed
H301	Toxic if swallowed
H302	Harmful if swallowed
H303	May be harmful if swallowed
H304	May be fatal if swallowed and enters airways
H305	May be harmful if swallowed and enters airways

- Globally Harmonized System of Classification and Labelling of Chemicals (GHS) – United Nations’ standardised system
- Compounds identified CAS Registry Number, unique identifier assigned by US Chemical Abstracts Service
- European Chemicals Agency database of manufacturer disclosures
- ‘Hazard codes’ describe different effects, from irritants to carcinogens
- Each compound can have multiple hazard codes
- Which can be weighted together using a severity index

$$\sum_{i=1}^n \text{Compound concentration in sample } (\mu\text{g}/\text{mg})_i$$

Overall toxicity factor =
Number of hazard codes;
Compound concentration in sample ($\mu\text{g}/\text{mg}$)_i



BEVs and trade-offs

ASSURED | INDEPENDENT | RESPONSIVE

The battery electric vehicle challenge

- Does the extra weight and torque on BEVs lead to higher tyre emissions?
- Due to very low tailpipe pollution on modern cars, tyre emissions could be x1,850 higher (<https://www.emissionsanalytics.com/news/gaining-traction-losing-tread>)
- Various studies shows BEV tyre emissions 10-25% higher (<https://www.emissionsanalytics.com/news/do-no-harm>, <https://www.michelin.com/en/publications/morgan-stanley-trwp-state-of-knowledge-investor-presentation/>)



However...



- The comparator vehicles matter – should the equivalence be on payload, power, maximum speed, cost, or something else?
 - Factor in regenerative braking or not? Torque control?
 - The comparator tyres matter – original or replacement?
 - What about toxicity?
- Chasing the perfect like-for-like comparison is impossible
- To correlate to changes in aggregate emissions, actual consumer choices must be followed – hence Tesla Y vs Kia Niro
(<https://www.emissionsanalytics.com/news/do-no-harm>)

Trade-offs: higher loads require bigger tyres

Each extra 100 kg of passenger car kerb weight leads on average to...

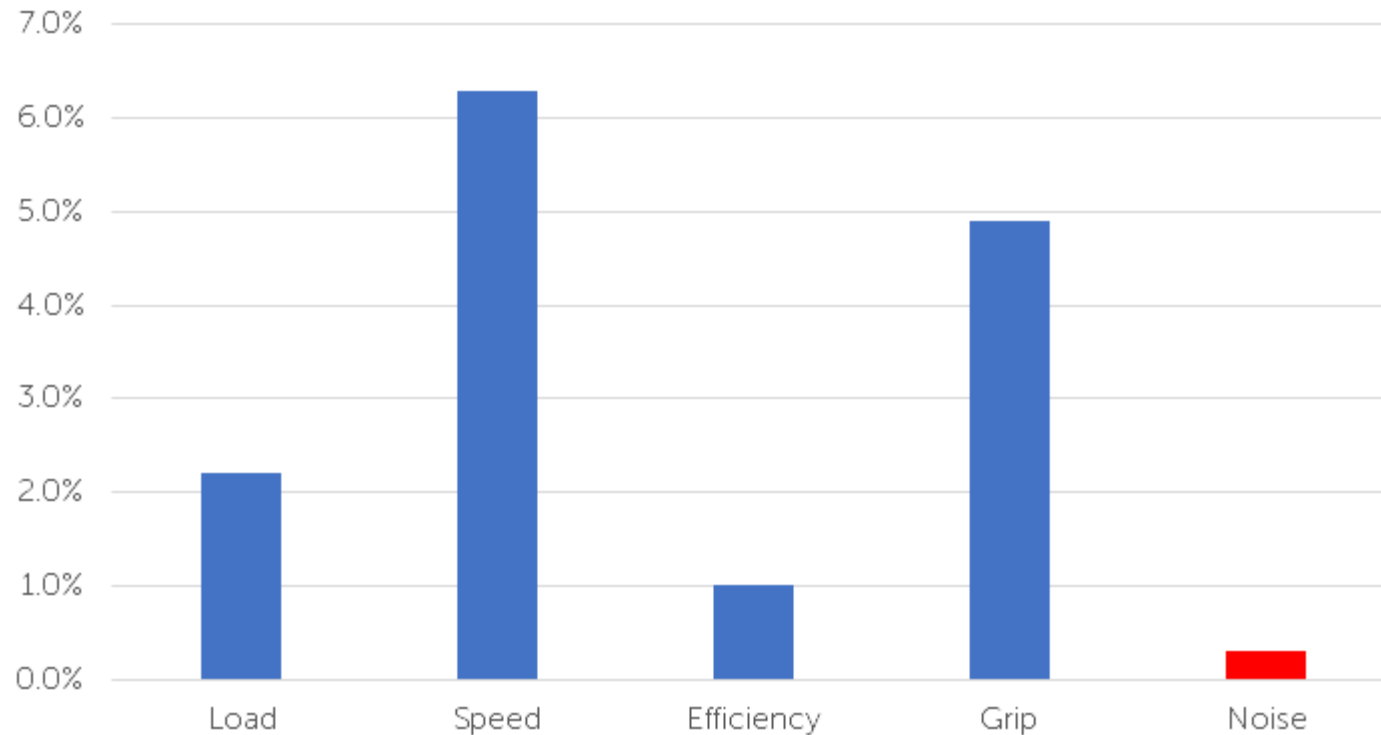
- 4.8mm extra width (+2%)
- 0.27" extra rim size (+2%)
- Slightly lower profile – aspect ratio
- 0.032 m² surface area (+4%)

Leading to extra tyre emissions...

- 2.2 mg/km mass wear (+3%)
- 2.8 µg/minute off-gassing VOCs (+4%)



Trade-offs: bigger tyres have better performance...

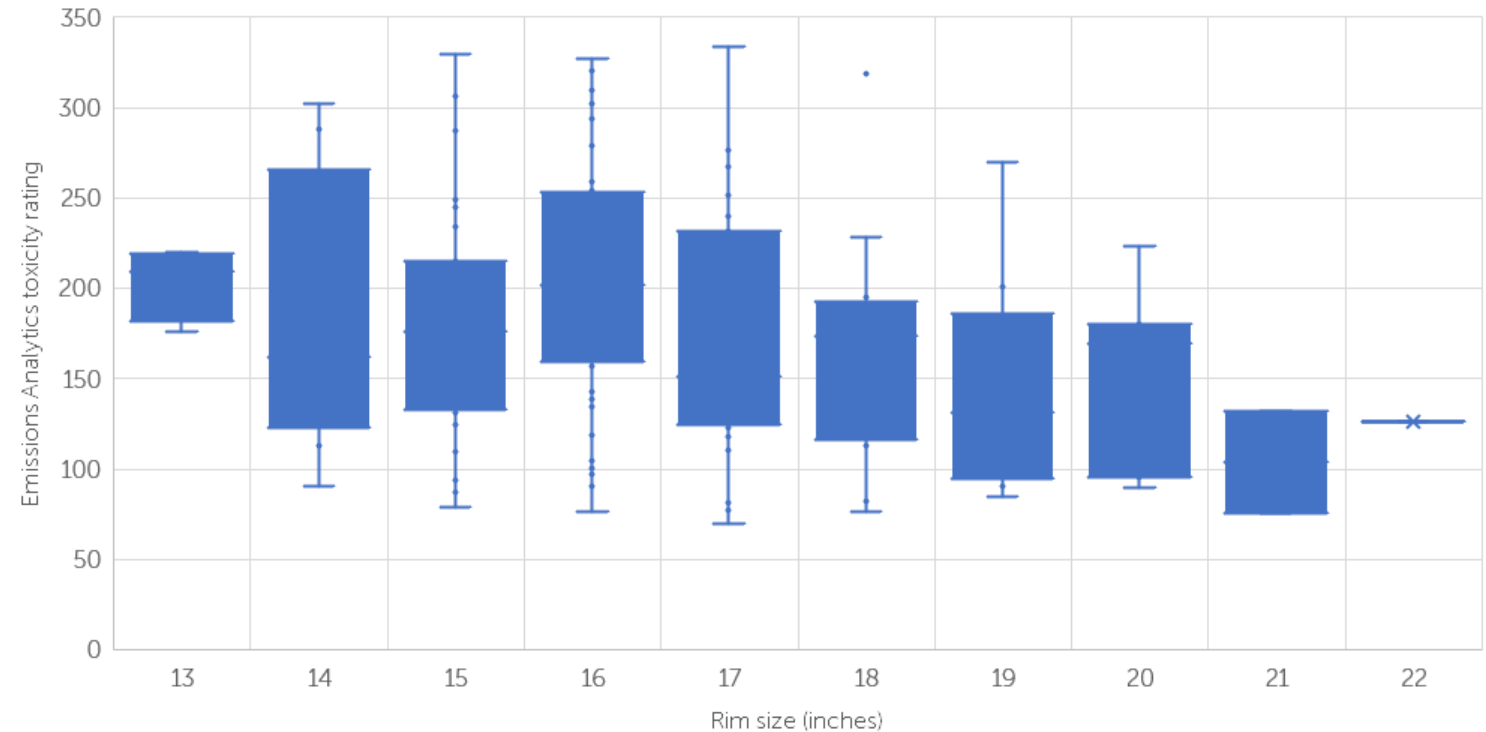
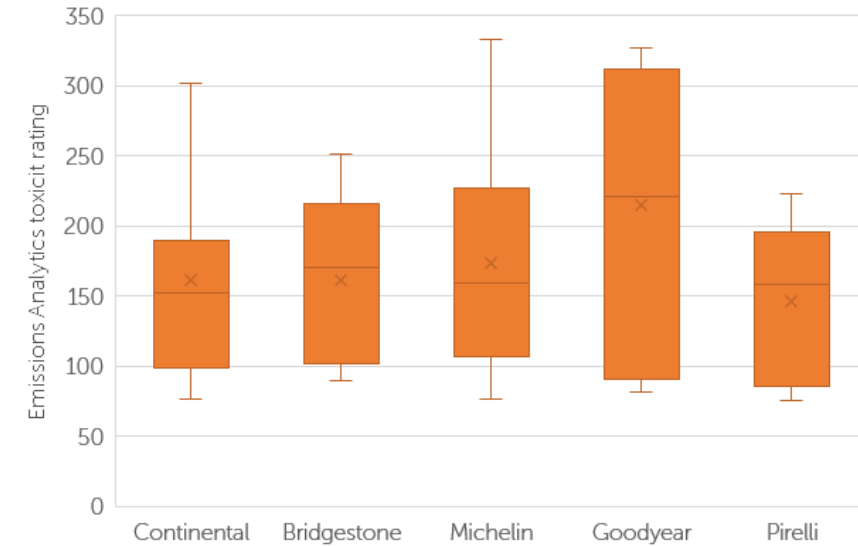


Almost a Pareto improvement, but...

- Slightly worse noise
- Cost premium
- Toxicity?

Trade-offs: ...and reduce toxicity

- 4.3% lower potential toxicity, on Emissions Analytics' normalised scale
- 9.5% lower aromatics concentrations
- But significant variation between makes and models



Trade-offs: US formulations are different

- Heavier duty tyres are wider and taller, with larger rims
- Are also less toxic overall
- Due to much lower aromatics, offset by higher alkanes
- US tyres are typically less toxic than European tyres

	Europe	North America	Variance
Tyres analysed	16	39	
Average aromatics concentration (ng/mg)	95,142	64,122	-33%
Human toxicity potential	26	21	-20%
Marine toxicity potential	2	2	14%
Average alkanes concentration (ng/mg)	133,963	100,328	-25%
Human toxicity potential	26	34	34%
Marine toxicity potential	4	4	13%

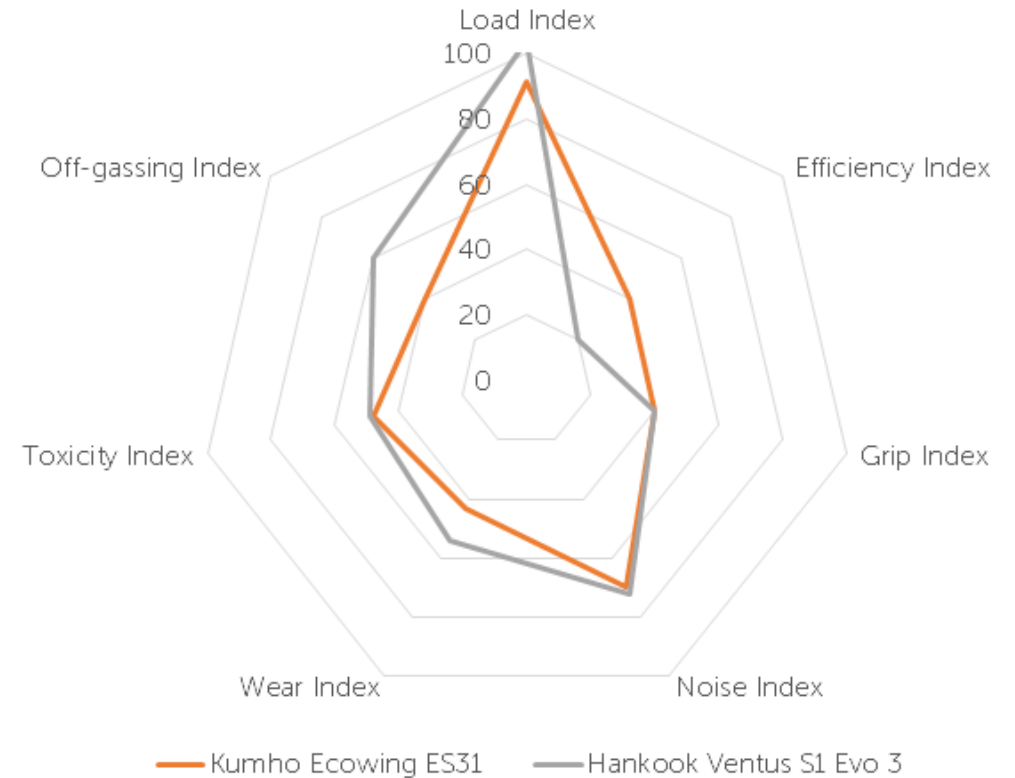


Tyre emissions test programme

ASSURED | INDEPENDENT | RESPONSIVE

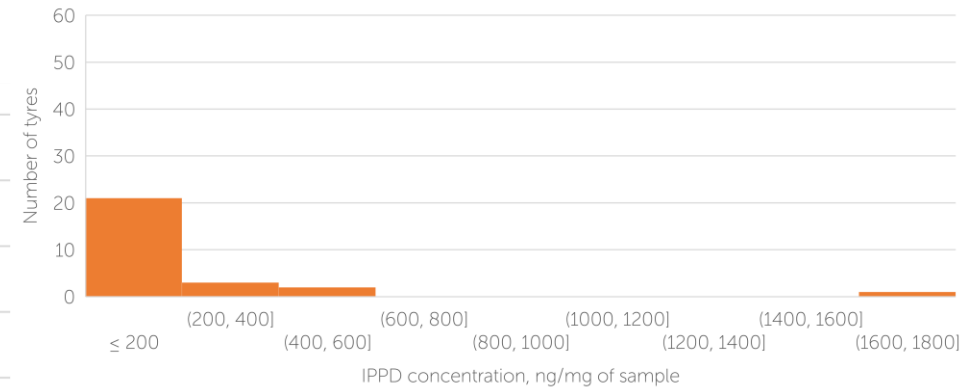
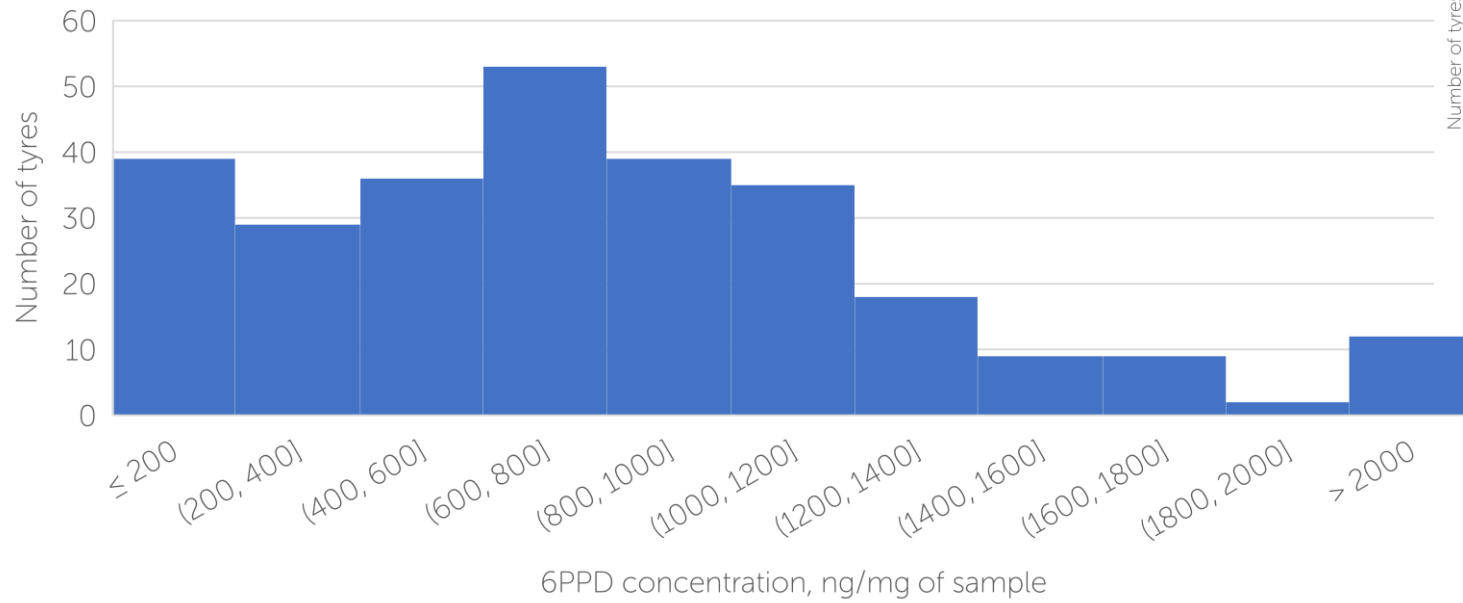
Ratings

- 7 dimensions
 - Load index, related to...
 - 3 performance criteria
 - 3 pollutants
 - Smaller values are better
-
- Added load required for Hankook on Tesla Y leads to worse emissions in all dimensions
 - And noisier, but more efficient



Target compound tracking: 6PPD and alternatives

- 6PPD is in 100% of tyres tested so far
- Modal concentration ~700 ng per mg of sample
- 10% of tyres contain IPPD as partial substitute



The image shows four tires stacked on a road surface. A blue horizontal bar is overlaid on the tires, containing the text 'Conclusion and the future'. Below this bar, the words 'ASSURED | INDEPENDENT | RESPONSIVE' are written in white. The background is a blurred outdoor scene with trees and a bright sky.

Conclusion and the future

ASSURED | INDEPENDENT | RESPONSIVE

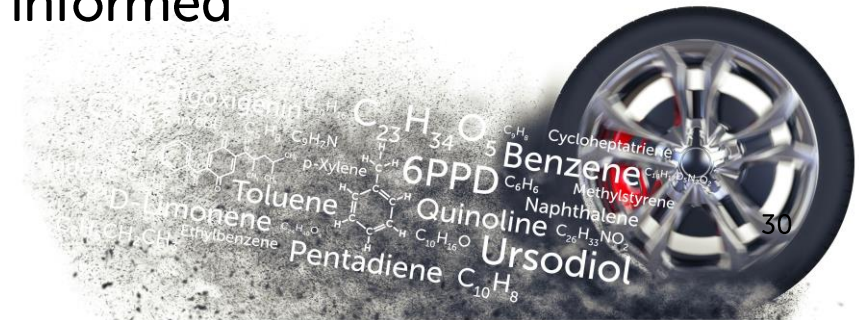
Omnipresence of tyre wear emissions

- 6 million tonnes of tyre wear globally per year
- Or 4 kg per car per year
- Excluding 1-2 billion end-of-life tyres per year
- Larger particles wash into the drainage system
- Fine particles settle on soil close to roadway
- Ultrafine particles are airborne before eventually settling
- Multiple vectors for human inhalation or ingestion
- 135 ng of 6PPD and 6PPD-quinone in urine of average adult per day



Key messages

- Tyre emissions problem is more complex and significant than previously thought
 - It affects vehicles of all types, not just BEVs
 - High variability in chemical composition between brands and models of tyre
 - The combination of vehicle and tyre really matters
 - Testing tyres as installed on new vehicles is a priority
 - Current BEV tyres tend to be higher wearing but less toxic – and at a price
 - Regulating the replacement market is also essential
- Developing regulation must be holistic, and empirically informed



Tyre Emissions Research Consortium



<https://www.linkedin.com/company/tyre-emissions-research-consortium>

RDE subscription database

Budget Mid-market Premium

Alkanes Aromatics Acids

Europe					Asia				
#	Manufacturer	Conc	MoM	YoY	#	Manufacturer	Conc	MoM	YoY
µg/mg					µg/mg				
1	Avon	1683			1	Bridgestone	1583		
2	Barum*	1686			2	Toyo*	1811		
3	Pirelli	1872			3	JK Tyre*	1847		

CalSAFER

For more information about this target list, visit <https://calsafes.dtsc.ca.gov>.

Search:

CAS #	Substance	Formula	Functional Group	Tires found # (% of tyres)	Average concentration µg/mg	Maximum concentration µg/mg
793-24-8	6PPD N(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine	C ₁₈ H ₂₄ N ₂	Aromatics	281 (100.0%)	0.814	3.832
106-42-3	p-xylene	C ₈ H ₁₀	Aromatics	274 (97.5%)	9.323	31.148
108-88-3	Toluene	C ₇ H ₈	Aromatics	267 (95.0%)	7.992	42.333
122-39-4	Diphenylamine	C ₁₂ H ₁₁ N	Aromatics	230 (81.9%)	0.088	0.758
71-43-2	Benzene	C ₆ H ₆	Aromatics	226 (80.4%)	2.919	12.840
100-40-3	4-VCH 4-Vinylcyclohexene	C ₈ H ₁₂	Aromatics	221 (78.6%)	3.355	23.166
129-00-0	Pyrene	C ₁₆ H ₁₀	Aromatics	215 (76.5%)	0.123	0.661
106-87-6	4-Vinyl-1-cyclohexene diepoxide	C ₈ H ₁₂ O ₂	Aromatics	213 (75.8%)	1.666	16.727

- Substances of concern tracking
- For benchmarking, research and development

Emissions Analytics conferences

- Prague, Czechia, 28-29 February 2024
- Newport Beach, CA, USA: 24-25 April 2024
- Pre-sale now on – express interest at conferences@emissionsanalytics.com








Emissions Analytics
TYRE EMISSIONS & SUSTAINABILITY
EUROPE 2024



Emissions Analytics
TYRE EMISSIONS & SUSTAINABILITY
USA 2024

Emissions Intelligence

- Expanded independent EQUA test programme
- Monthly releases of latest results, including tyre wear and chemical toxicity
- Focus on latest products brought to market, with rapid turn-around of results
- Open to all clients and subscribers, plus academics, students and accredited media
- For more information, please express interest at info@emissionsanalytics.com

CaISAFER		
For more information about this target list, visit https://calsafes.dtsc.ca.gov .		
		Search: <input type="text"/>
Tyre	Total concentration	Substances found
	µg/mg	# (% of list)
 BFGoodrich Urban Terrain T/A 235/55 R17 99V	110.296	
 Toyo Toyo R37 225/55 R18 98H	106.376	
 Michelin Agilis + 235/65 R16C 115/113R	85.267	
 Lanvigator Perfor Max 255/65 R16C 109H	82.349	
 Michelin Energy Saver+ 195/55 R16 87H	82.137	

Thank you.

Nick Molden

Chief Executive Officer

nick@emissionsanalytics.com

+44 (0)20 7193 0489

ASSURED | INDEPENDENT | RESPONSIVE

ASSURED | INDEPENDENT | RESPONSIVE

Assured

Emissions testing in real-world conditions brings challenges that experience anticipates and expertise overcomes. We deliver.

Independent

Objectivity and candour are the driving forces in all our work, so you know the facts.

Responsive

We're fast on our feet so we can conduct emissions testing when and where we're needed.