The potential hazards of microplastics to human health and the complexity of assessing risks

Dr Todd Gouin

Dr Stephanie Wright | Imperial College London

Microplastic: How big is the issue?

CNN health Food Fitness Wellness Parenting Vital Signs Edition

You could be swallowing a credit card's weight in plastic every week

By Isabelle Gerretsen, CNN
Updated 2043 GMT (0443 HKT) June 17, 2019

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Microplastics may be stoking antibiotic resistance: Study

BY SHARON UDASIN - 03/11/25 9:40 AM ET

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Chewing Gum Releases Microplastics Into Your Mouth, Scientists Warn

Story by Ian Randall • 6d • 3/25/2025 ead

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MARCH 4, 2025 The GIST Editors' notes

Environmental scientists highlight role of paint in microplastic pollution

by Cynthia Macdonald, University of Toronto

CNN health Food Fitness Wellness Parenting Vital Signs Edition

If you drink bottled water, you could double how many microplastic particles you ingest, study says

By Susan Scutti, CNN
Updated 2038 GMT (0438 HKT) June 5, 2019

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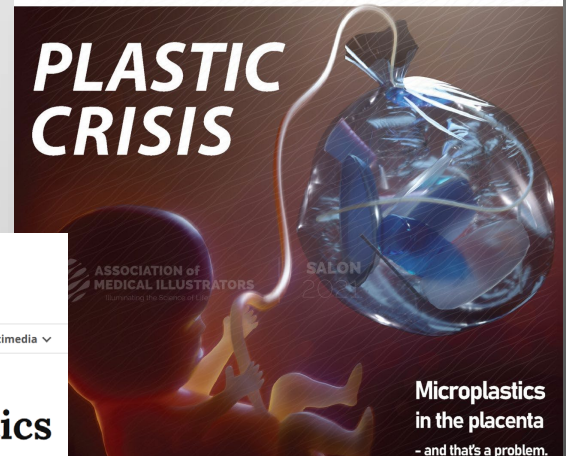

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INTERNATIONAL

Interview on Microplastics

'Never Good News Having Particles in Your Brain'

Microplastics are everywhere, but nobody really knows what dangers they might present once they enter the human body. British toxicologist Rosemary Waring warns our oceans will be inundated with the stuff.

Interview Conducted by Philip Bethge

SCI AM

MARCH 10, 2025 | 3 MIN READ

Microplastics Are Messing with Photosynthesis in Plants

Microplastics can cut a plant's ability to photosynthesize by up to 12 percent, new research shows

BY JOANNA THOMPSON EDITED BY ANDREA THOMPSON

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COLUMNS

A modern health crisis: microplastics

Communication is key

- Comment published in Nature draws attention to the reliability and relevance of data reporting plastic/microplastic particles in human tissues, including concerns related to:
  - Sampling and analysis
  - Exposure and plausibility

Microplastics have been found in oceans, lakes, rivers, soils, food and air.

KEYZAWISSA TARKA/NURPHOTO VIA GETTY

Are microplastics bad for your health? More rigorous science is needed

Jun-Li Xu, Stephanie Wright, Cassandra Rauert & Kevin V. Thomas

Micro- and nanoplastic particles: what are they?

- **Broadly defined nano- and microplastic particles are plastic particles <5mm**

Image source: Visual Capitalist

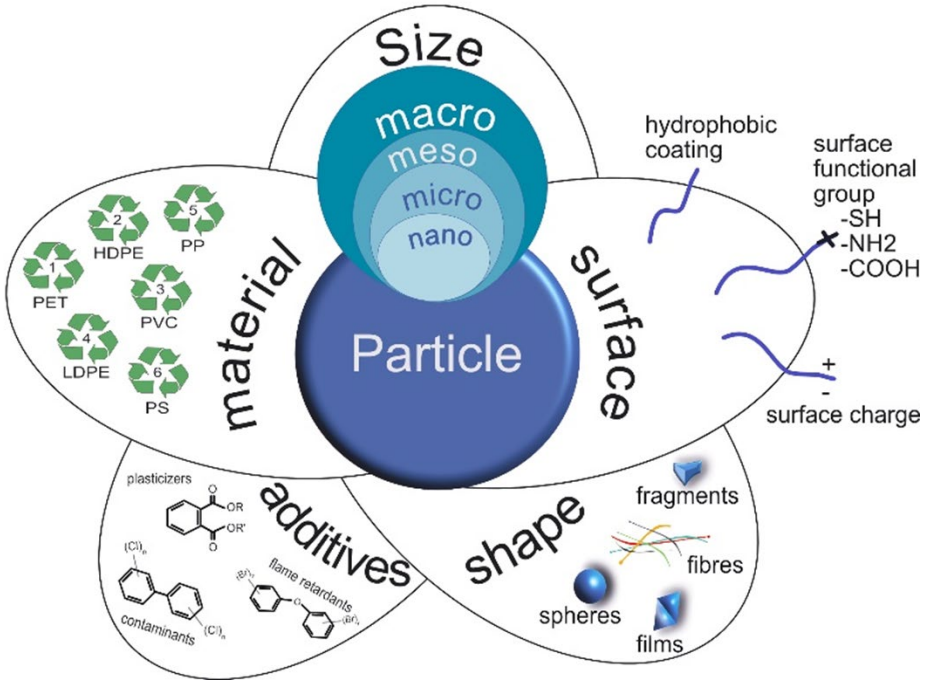

Image source: WHO, Geneva, 2022

Emission sources and (environmental) routes of exposure

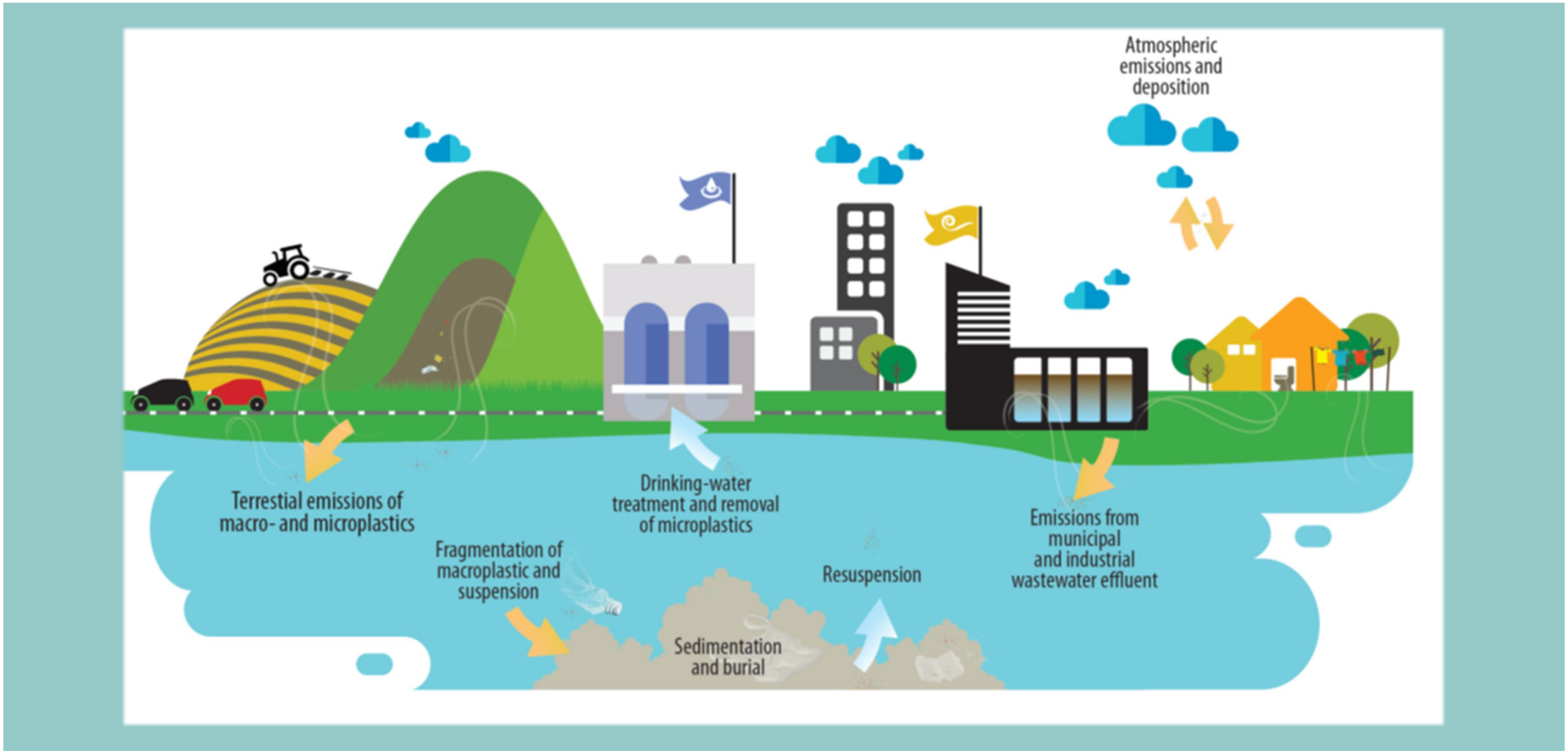

Image source: WHO, 2019

Human exposure to micro- and nanoplastic particles

- What we know
  - Ubiquitous
    - Water
    - Air (indoor/outdoor)
  - Oral
    - **Particles$_{>10\mu m}$**
    - Food, beverages and drinking water
    - Max. daily intake (fish-based diet + glass bottled water)
      - 221 MP/kg bw (Zuri et al., 2023)
  - Inhalation
    - Max. inhaled dose (outdoor and indoor environments)
      - 195 MP/kg bw (Zuri et al., 2023)
  - TDI (worst case)
    - Max 417 MP/kg bw (Zuri et al., 2023)
      - 32,588.55 MP per day (average)

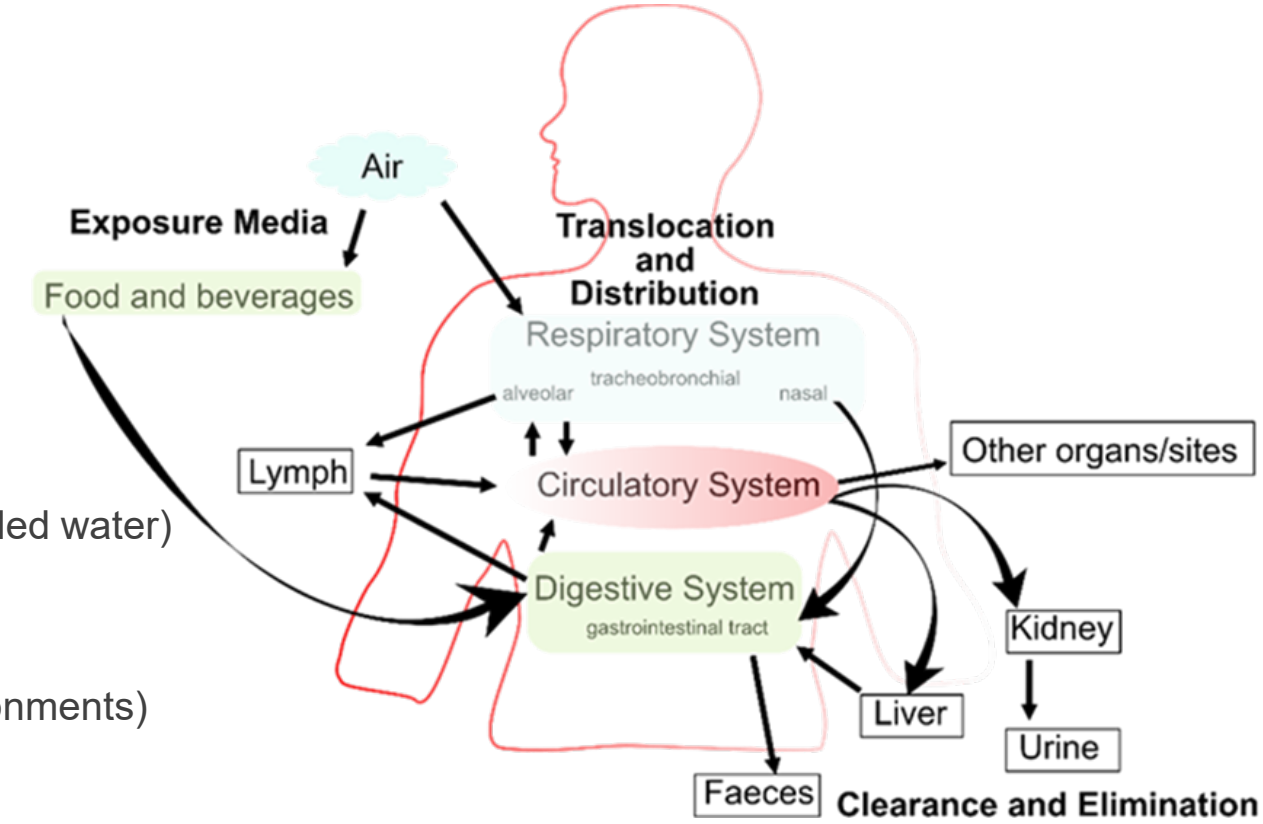

Image source: WHO, Geneva, 2022

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- What we know we don't know
  - Inhalation and oral
    - **Particles$_{<10\mu m}$**

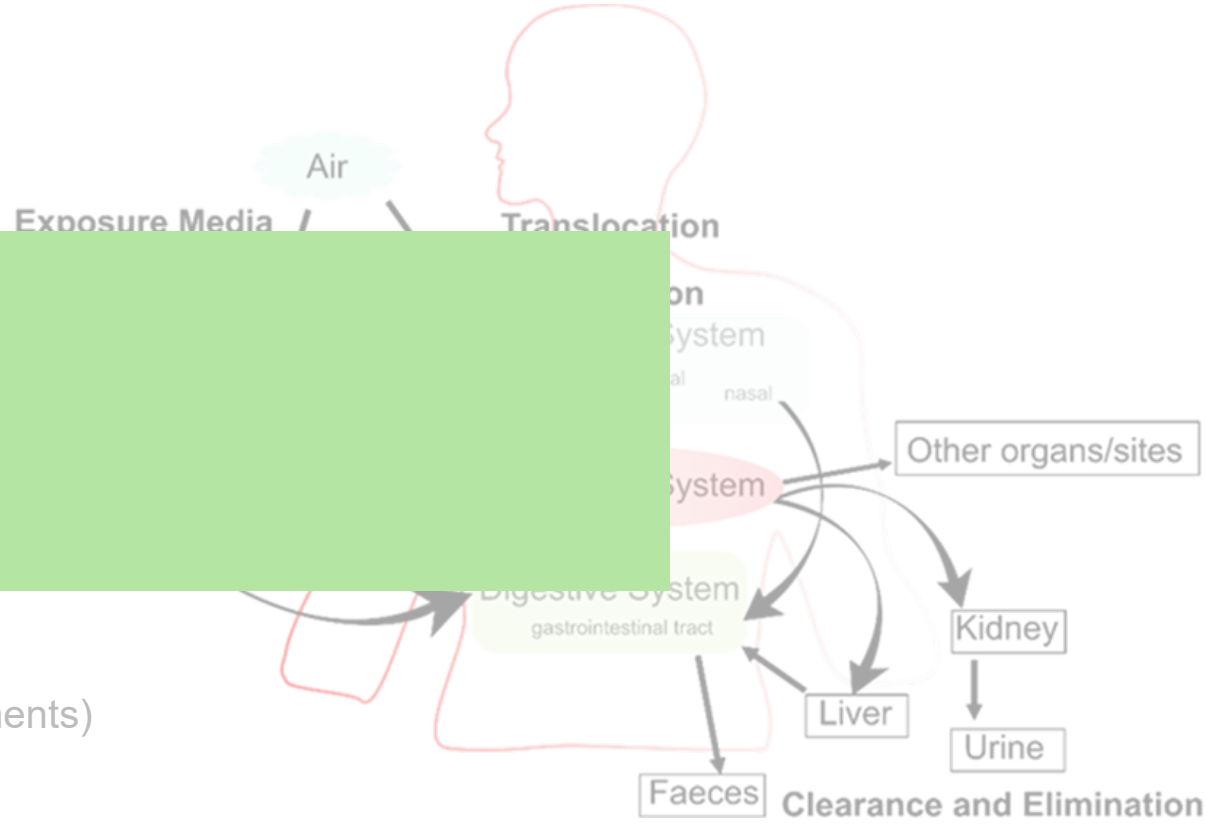
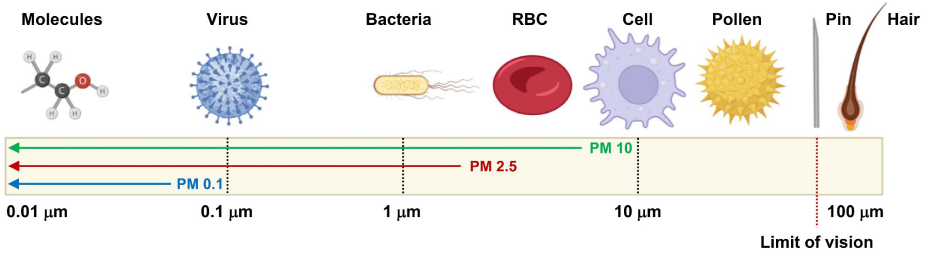


Image source: WHO, Geneva, 2022

Size (and other properties) influence particle fate and internal exposure



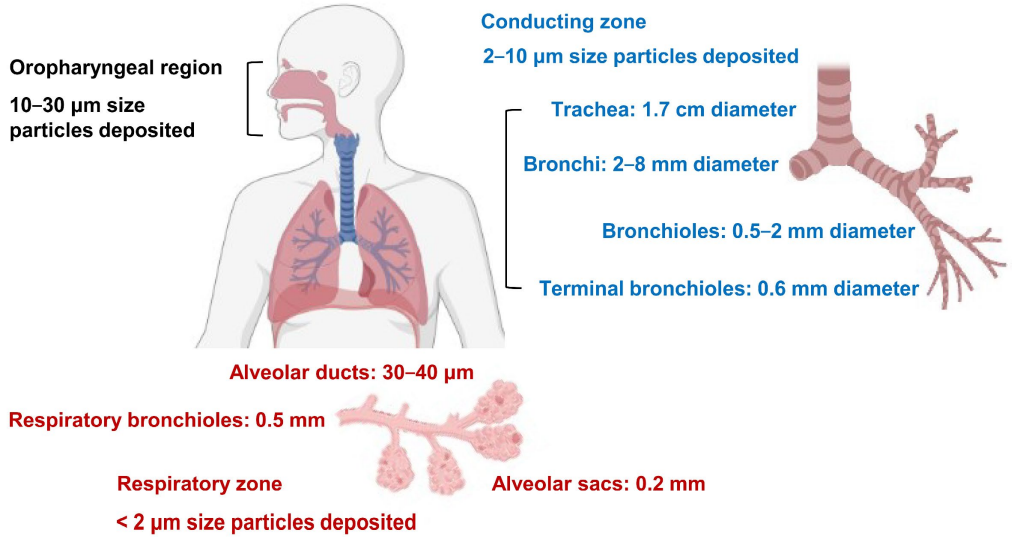


Image source: Lim and Kim, 2024

- Mucus
  - ~100-200 nm pore size
  - Negative charge (Wang et al., 2024)

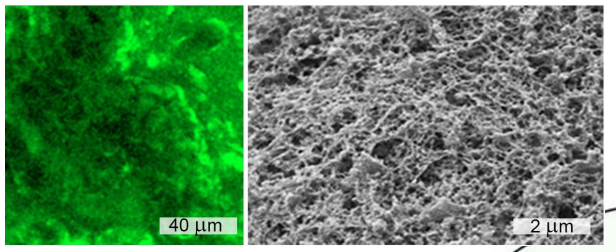
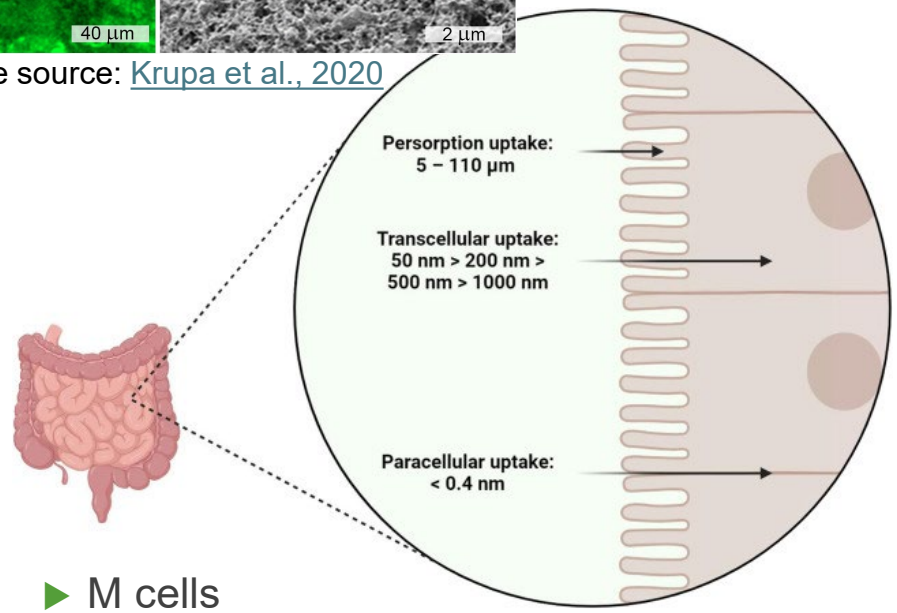


Image source: Krupa et al., 2020



- M cells
  - Particles 20 nm – 10 μm (1 μm) (Ermak and Giannasca, 1998)

Image source: Mok, 2024

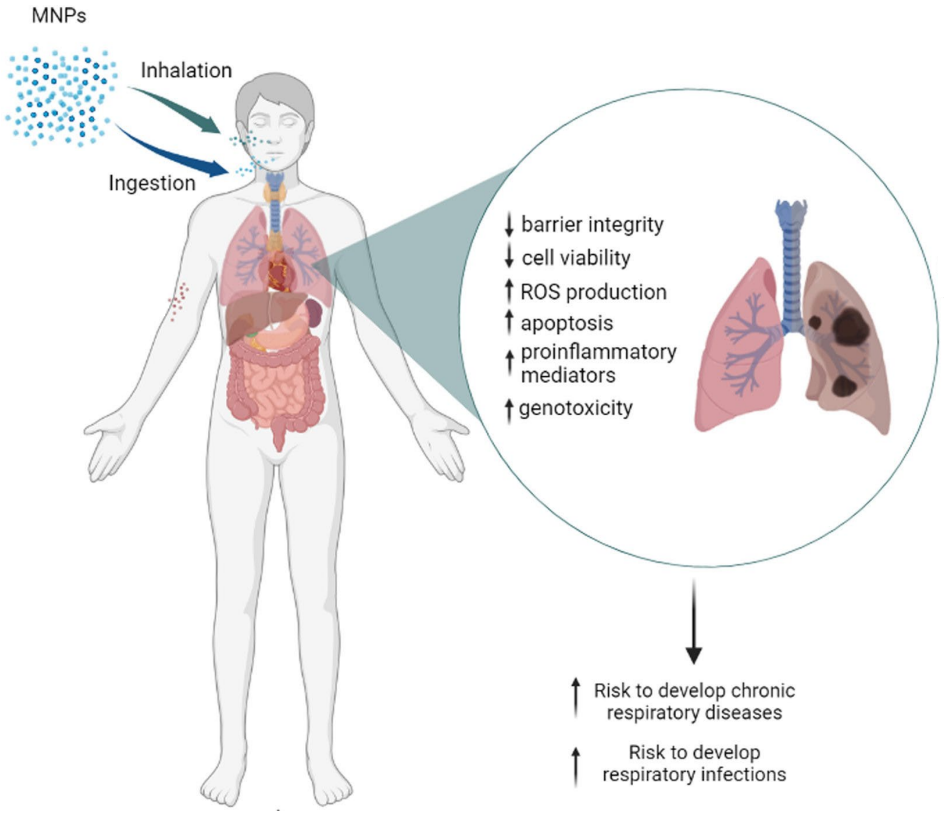
Potential hazards of micro- and nanoplastic particles

- Direct and indirect
- Localized effects

Potential hazards at the cellular level

- Oxidative stress
  - Too many free radicals (Reactive Oxygen Species, ROS) and not enough antioxidants to neutralise
  - Free radicals on surface of weathered microplastics (Hu and Palic, 2020)
  - Intracellular ROS as part of innate immune system defence (Hu and Palic, 2020)
- Inflammation
  - Response to injury or infection: remove cause of damage, clear debris and repair tissue
  - Microplastics are foreign bodies
  - Oxidative stress may lead to inflammation
- Metabolic disruption
  - Normal processes are altered, leading to impaired function or cell death
  - MNP can disrupt mitochondrial function
  - Oxidative stress can disrupt energy metabolism

Localized hazards in the airways



Source: Romero-Andrada et al., 2023

DIRECT EFFECTS

When in contact with cells, MNPs can:

- Lead to ROS formation
- Reduce cell viability and metabolic activity
- Increase membrane permeability
- Activate inflammatory pathways

Pathology includes:

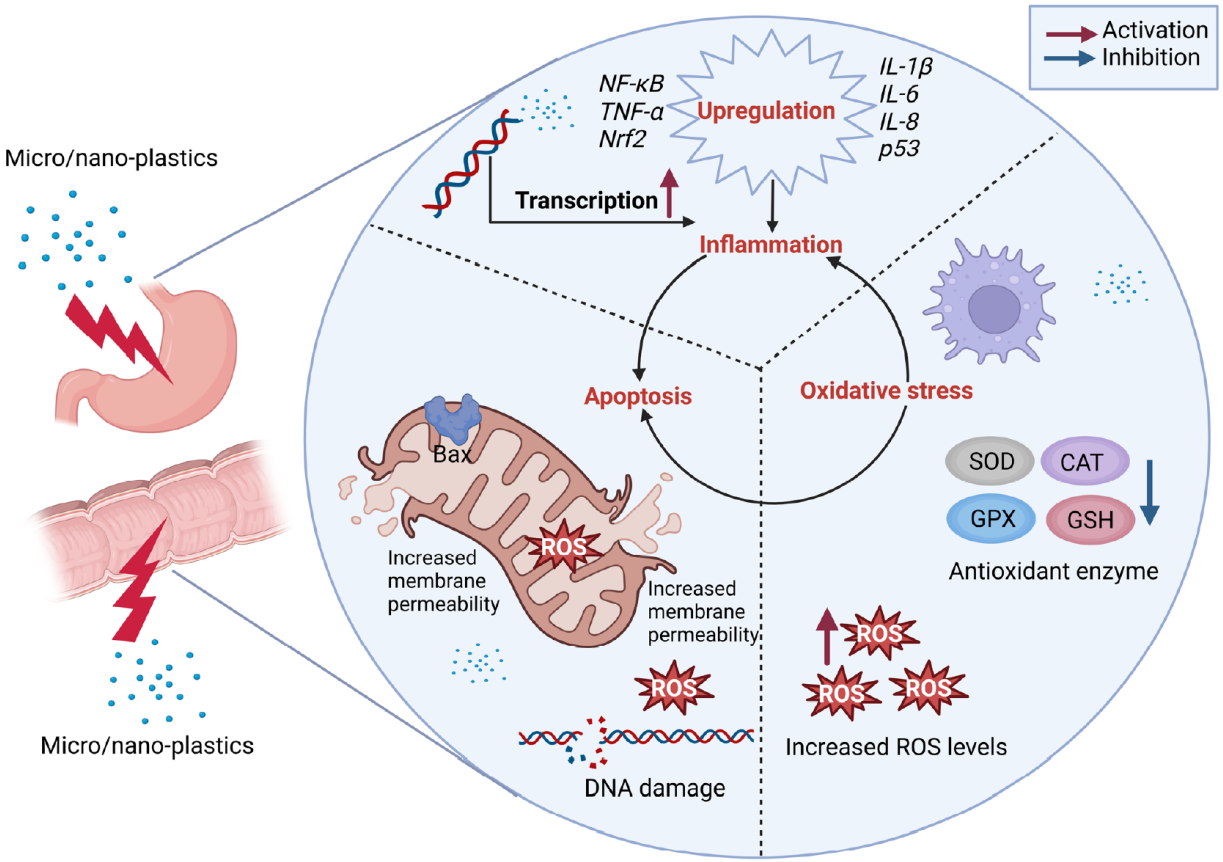
- Fibrosis

Influential factors include:

- Particle shape > irregular more toxic than spherical
- Size > smaller = more toxic
- Surface charge > positive = more toxic
- Plastic material
- Model cell line or organism

Source: Zhao et al., 2024

Localized hazards in the gastrointestinal tract



DIRECT EFFECTS

When in contact with cells, MNPs can:

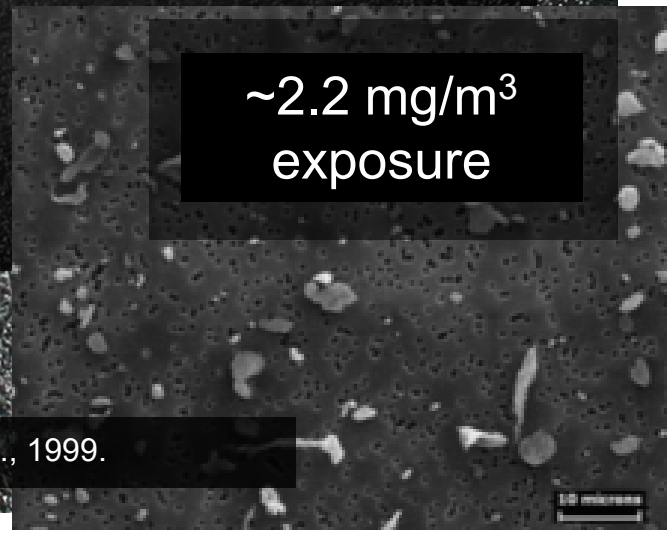
- Stimulate cells to produce reactive oxygen species (ROS) resulting in oxidative stress.
- Stimulate cells to produce inflammatory cytokines or induce an inflammatory response through oxidative stress.

- Common endpoints reported across studies (both *in vitro* and *in vivo*) include:
  - Apoptosis (programmed cell death)
  - Upregulation of cytokines and ROS
  - Downregulation of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX) and glutathione (GSH)

Source: Wang et al., 2024

The case of nylon – clinical observations

- Interstitial lung disease – nylon (most commonly 66), acrylic, PP, PE, PET, synthetic textiles
- Flock Worker's Lung (nylon flock industry)
  - Lymphocytic bronchiolitis and peribronchiolitis with lymphoid hyperplasia represented by lymphoid aggregates
- IR all interstitial lung disease = 48 (95% CI 23-88)
- IR IPF = 258 (95% CI 104-530)
- PE (Spain), PP (Turkey), Rayon (USA)



- Kern et al. 1998, 2000, 2003; Barroso et al., 2002; Atis et al., 2005; Antao et al., 2007; Burkhart et al., 1999.

Risk Assessment

“All substances are poisons; there is none which is not a poison.

The right dose differentiates a poison.”

What are the human health risks?

RISK = EXPOSURE x HAZARD

KEY QUESTIONS

Are the data reliable and relevant – Is there a dose-response relationship?

EXPOSURE

- What are the main sources of nano- and microplastic particles in air, food and beverages?
- Are the analytical methods currently used sufficient to characterize and quantify exposure?

HAZARD

- What is the primary endpoint of toxicological concern?
- Are there intrinsic properties of microplastic that are more ‘toxic’ than others?

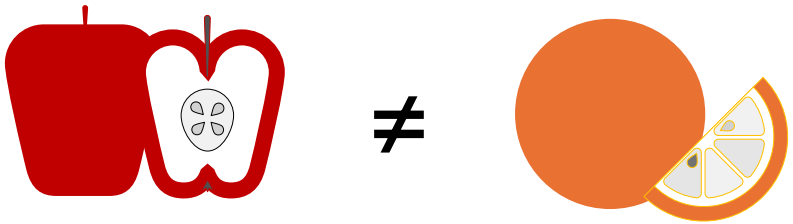
WHAT WE KNOW

- There are negative effects
- non-standard mammalian in vivo and in vitro lab-based studies
- Occupational epidemiology
- There is exposure

ARE THE DATA FIT-FOR-PURPOSE?

Are the data fit-for-purpose?

- Toxicity testing to date is represented by:
  - The use of very high concentrations, which are understood to be inconsistent with typical ambient exposure.
  - Limited number of studies reporting dose-response relationships that include environmentally relevant exposure.
  - Studies using a single type of particle (e.g. shape, size, polymer composition)



Canadian Journal of
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Discussion

On the need to avoid apple-to-orange comparisons in microplastic research

Albert A. Koelmans[a], **Todd Gouin**[b], **Alvine C. Mehinto**[c], **and Scott Coffin**[d]

[a]Aquatic Ecology and Water Quality Management Group, Wageningen University, Wageningen, the Netherlands; [b]TG Environmental Research, Sharnbrook, Bedfordshire, UK; [c]Southern California Coastal Water Research Project Authority, Costa Mesa, CA, USA; [d]California State Water Resources Control Board, Sacramento, CA, USA

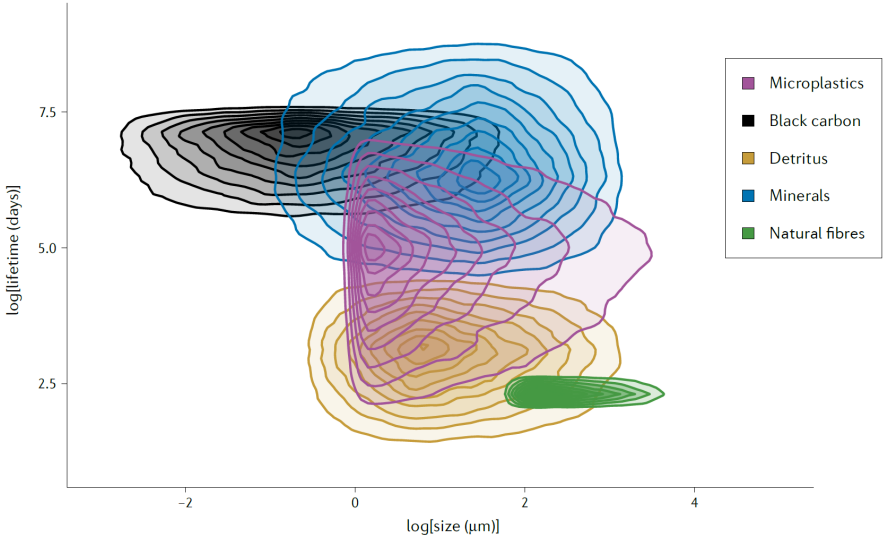
Corresponding author: **Albert A. Koelmans** (email: bart.koelmans@wur.nl)

Koelmans et al. (2024)

Aligning the dose to the microplastic continuum space

- Recognizing similarities between the properties of microplastic and other types of particles opens opportunities to advance our ability for risk assessment.

Koelmans et al. (2022)



- Particle and Fiber toxicology fundamentals – Best practices

Particle Characterization

1. Particle size
2. Particle shape
3. Particle polymer composition
4. Source of particles
5. Particle surface chemistry
6. Chemical purity
7. Microbial contamination

Experimental study design

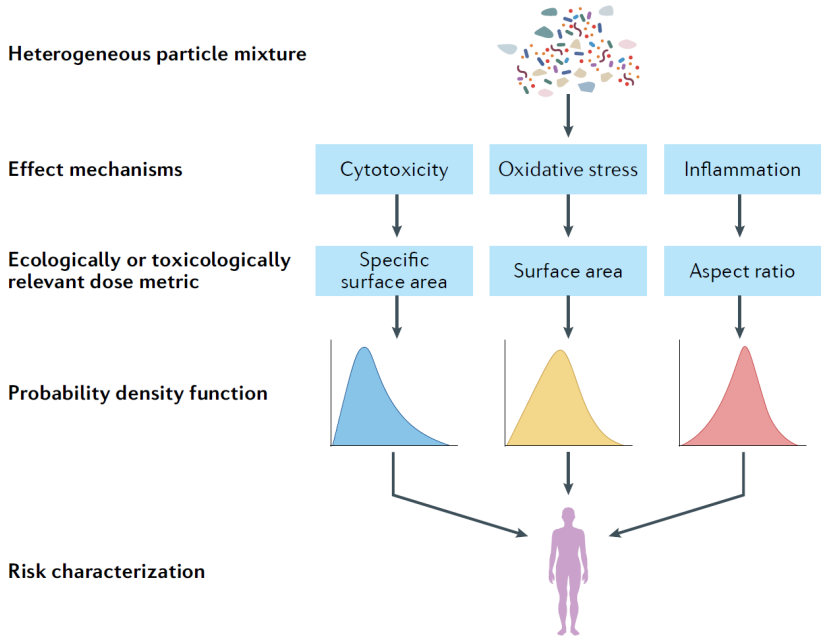
in vivo	in vitro
1. Concentration units	1. Concentration units
2. Particle stability	2. Particle stability
3. Test medium / delivery vehicle	3. Test medium / delivery vehicle
4. Administered dose / concentration	4. Administered dose / concentration
5. Homogeneity of exposure	5. Homogeneity of exposure
6. Administration route	6. in vitro test system description
7. Test species	7. Additional in vitro test elements
8. Feeding / housing conditions	8. Sample size
9. Sample size	9. Frequency and duration of exposure
10. Frequency and duration of exposure	10. Controls
11. Controls	
12. Replicates	
13. Confirmation of internal dose	

Applicability for risk assessment

1. Statistical analysis
2. Endpoints
3. Dose-response relationship
4. Concentration range
5. Effect threshold
6. Test particle relevance

Gouin et al. (2022)

Vogel et al. (2024)



Microplastic and chemicals
Is there an intrinsic risk?

RISK = EXPOSURE x HAZARD

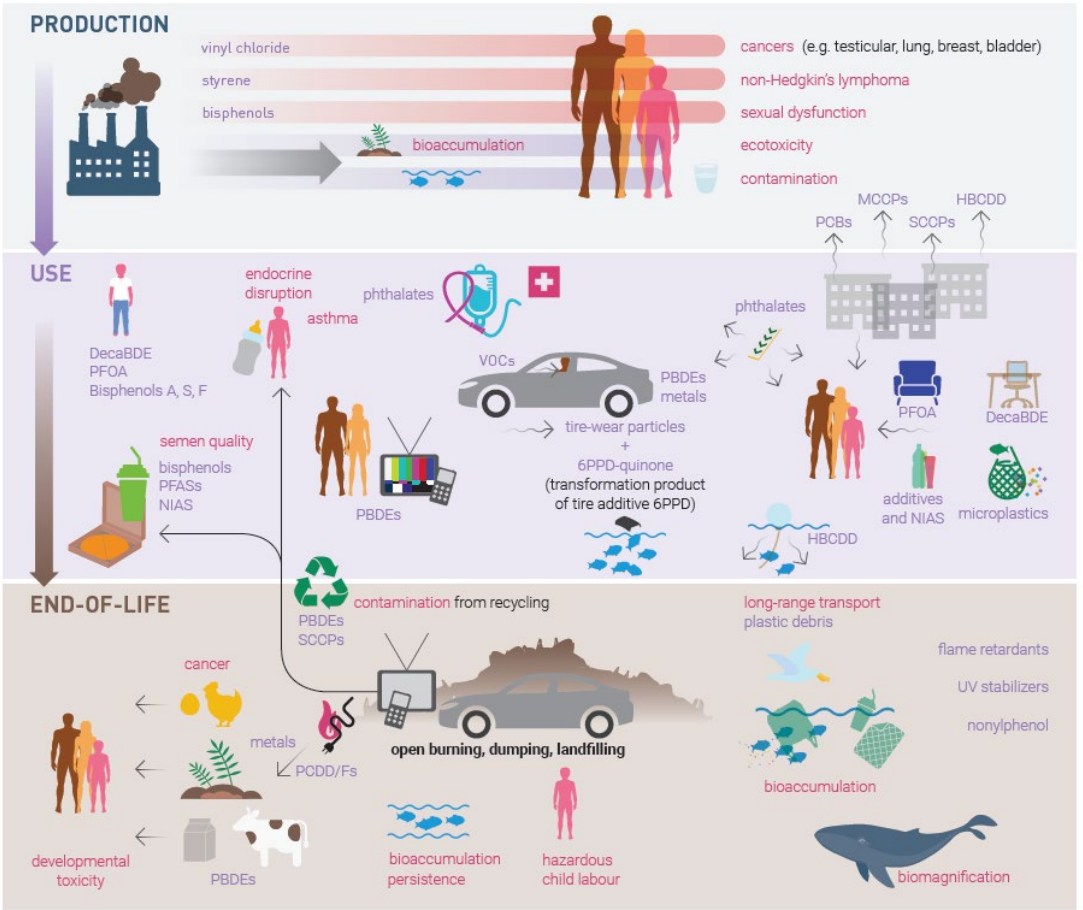
KEY QUESTIONS

Do we data that provide use with a reliable and relevant dose-response relationship?

“All substances are poisons; there is none which is not a poison.

The right dose differentiates a poison.”

Plastic and plastic associated chemicals: Exposure pathways



UNEP 2023

Estimating chemical exposure and potential risk in relation to ingesting microplastic particles

Calculating exposure and risk requires estimates of the mass of microplastic ingested, mass of chemical in the microplastic and a toxicological threshold value

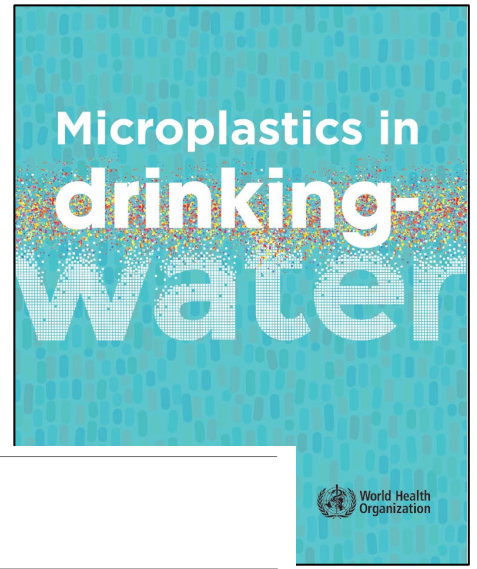


Table 3.3 Upper-bound daily intake estimates of chemicals from microplastics, maximum levels of contaminants associated with microplastics, and corresponding MOE

Chemical[a]	Upper bound concentration in microplastic (µg/g)	Maximum daily intake (ng/kg bw/day)[b]	Point of departure (µg/kg bw/day)	Margin of exposure (MOE)	Adequacy of MOE	Conclusion
Bisphenol A	0.7297	0.001	609	5.9×10^8	MOE of at least 100	No safety concern
Cadmium	3390	5.0	0.8	1.7×10^2	MOE of at least 10[c]	No safety concern
Chlordane	0.0144	0.00002	50	2.5×10^9	MOE of at least 100	No safety concern
Di(2-ethylhexyl)phthalate	0.0699	0.0001	2500	2.5×10^{10}	MOE of at least 100	No safety concern
Dichlorodiphenyltrichloroethane	7.1	0.0001	1000	1.0×10^8	MOE of at least 100	No safety concern
Hexachlorobenzene	0.0587	0.00002	50	6.0×10^8	MOE of at least 100	No safety concern
Polyaromatic hydrocarbons	119	0.06	100	6.0×10^5	MOE of at least 10 000	No safety concern
PBDEs	9.9	0.01	100	7.2×10^6	MOE of at least 100	No safety concern
PCBs	18.7	0.03	5	1.9×10^5	MOE of at least 1000[d]	No safety concern

WHO, Microplastics in drinking-water, World Health Organization, Geneva, Switzerland, 2019.

Estimating exposure to chemicals in microplastic requires quantification of the mass of microplastic ingested

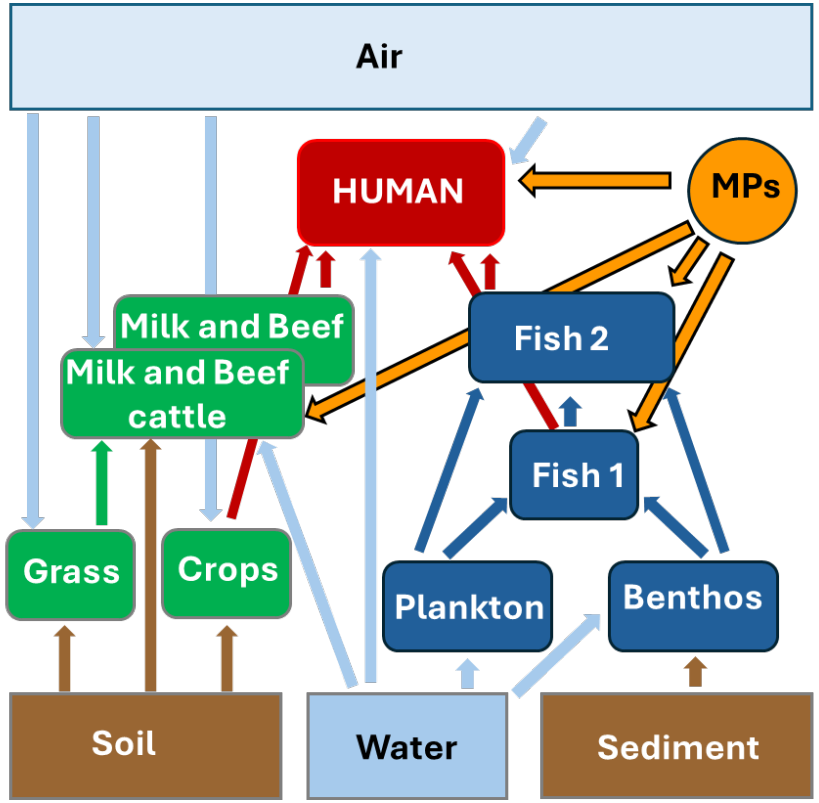
Ingestion = egestion (number of MPs per day)

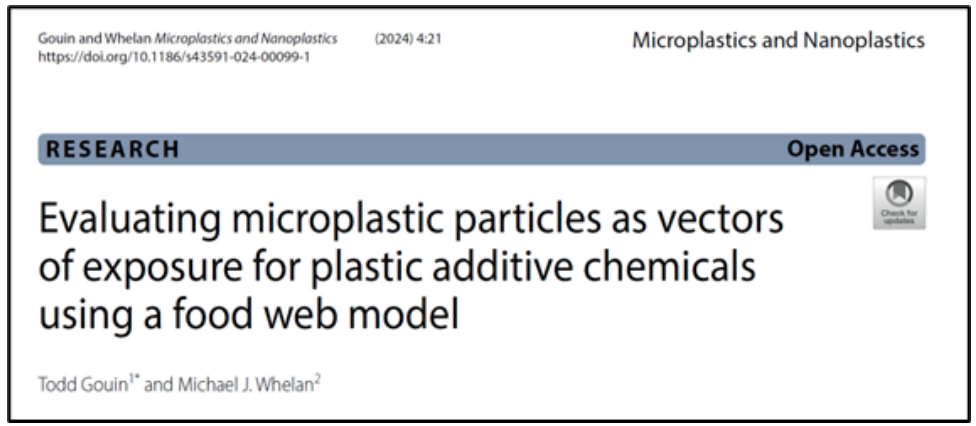
$$I_P = E_P = mc_F.n_F = n_H$$

Steady state number of MPs in the human

Mass of food and beverages consumed by humans (kg d^{-1})

Number of MPs per kg food and beverages




Gouin and Whelan *Microplastics and Nanoplastics* (2024) 4:21
https://doi.org/10.1186/s43591-024-00099-1

Microplastics and Nanoplastics

RESEARCH Open Access

Evaluating microplastic particles as vectors of exposure for plastic additive chemicals using a food web model

Todd Gouin[1*] and Michael J. Whelan[2]

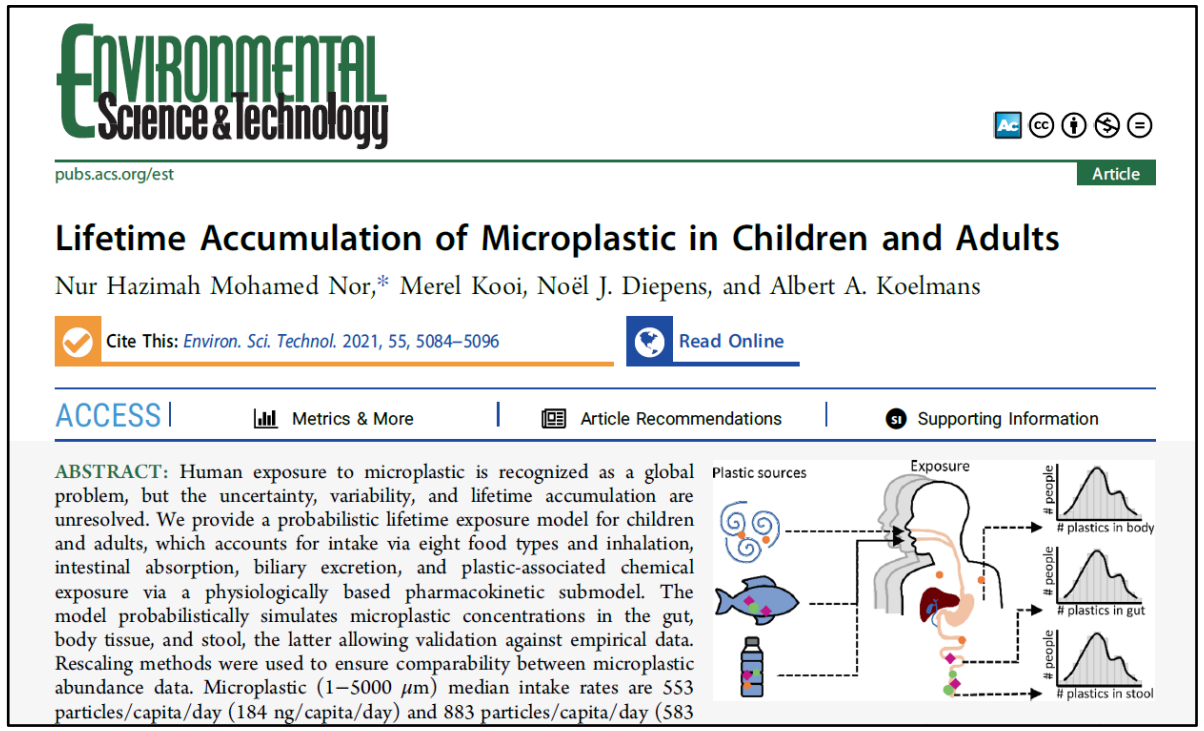
Gouin and Whelan, 2024

EU Horizon 2020

LABPLAS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003954

Estimating human ingestion of microplastic particles



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Article

Lifetime Accumulation of Microplastic in Children and Adults

Nur Hazimah Mohamed Nor,* Merel Kooi, Noël J. Diepens, and Albert A. Koelmans

Cite This: *Environ. Sci. Technol.* 2021, 55, 5084−5096

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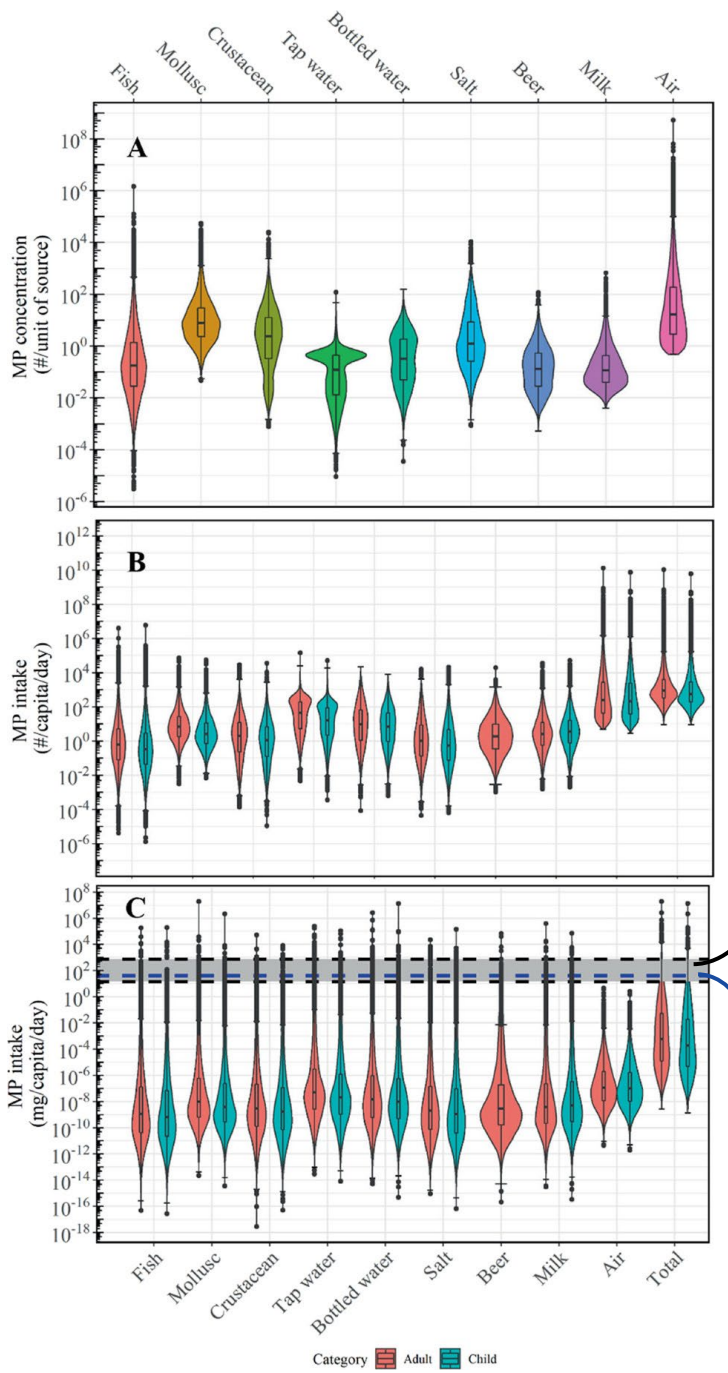
ABSTRACT: Human exposure to microplastic is recognized as a global problem, but the uncertainty, variability, and lifetime accumulation are unresolved. We provide a probabilistic lifetime exposure model for children and adults, which accounts for intake via eight food types and inhalation, intestinal absorption, biliary excretion, and plastic-associated chemical exposure via a physiologically based pharmacokinetic submodel. The model probabilistically simulates microplastic concentrations in the gut, body tissue, and stool, the latter allowing validation against empirical data. Rescaling methods were used to ensure comparability between microplastic abundance data. Microplastic (1−5000 μm) median intake rates are 553 particles/capita/day (184 ng/capita/day) and 883 particles/capita/day (583

Mohamed Nor et al., 2021

Estimates of human exposure to microplastic particles varies by >20 orders of magnitude, ranging from 10^{-16} mg/person/day to 10^{6} mg/person/day.

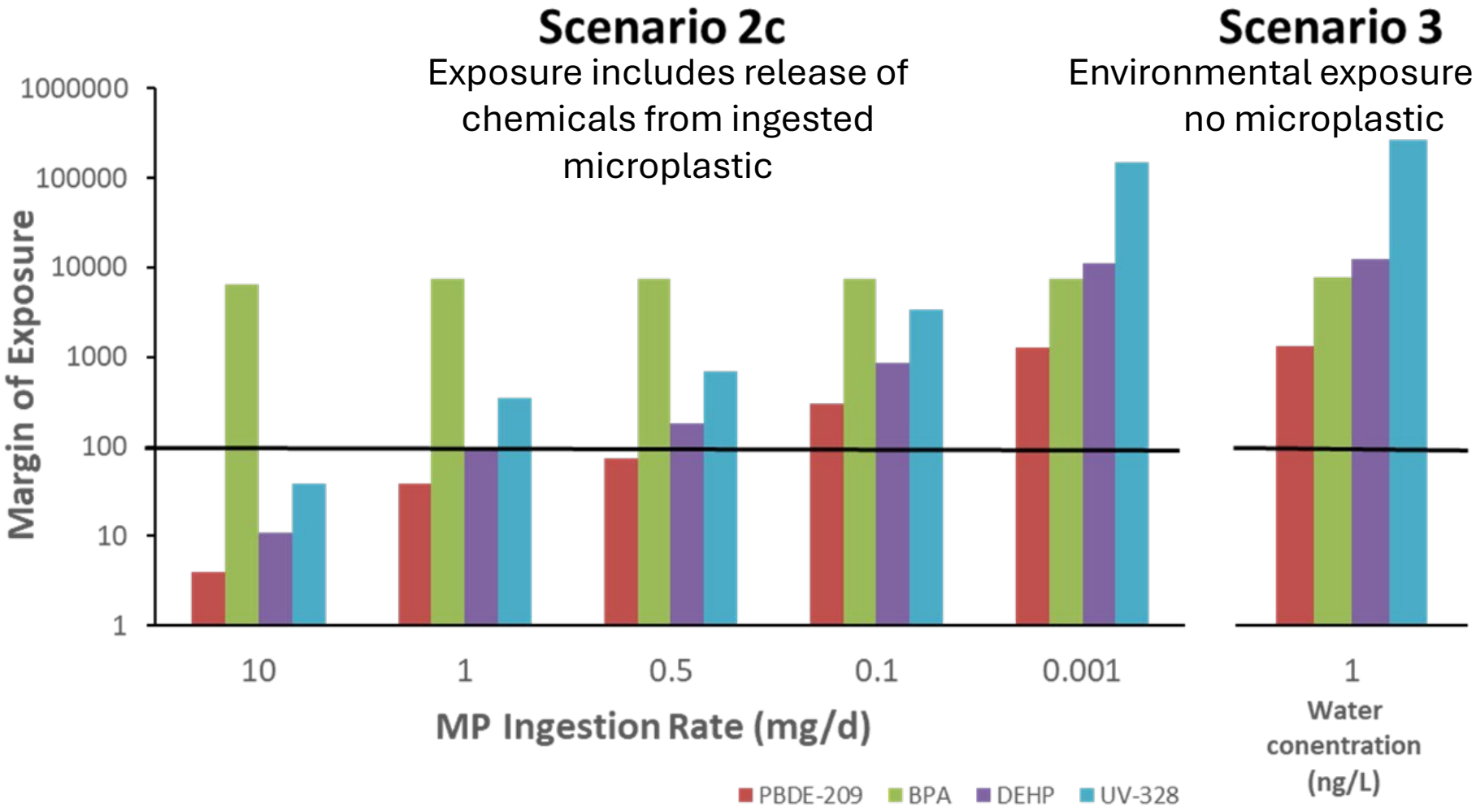
- The median values are 184 ng/person/day for children and 583 ng/person/day for adults



14-714 mg/person/day range of masses estimated by WWF report

40 mg/person/day estimated ingested of inorganic particles

Estimating human health risks related to chemicals leaching from ingested microplastic



Gouin and Whelan, 2024

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003954

Several outstanding research needs

EXPOSURE

- Standard and harmonized methods:
  - Sampling and analysis of NMP in air, water, food and beverages require robust, quality-assured methods, supported by the availability of nano- and microplastic particles representative of environmentally relevant human exposure
- Sources of contamination:
  - The contributions of different factors would guide strategies for mitigating exposure.

- Uptake and fate for both inhalation and oral ingestion exposure:
  - More information is required on the absorption, distribution and elimination of NMP.

- Particle characterization:
  - Quality-assured environmental monitoring studies should be conducted to characterize the distributions of size, shape and composition of NMP in the environment for studies of the effects of exposure on human health and to prepare reference standards for environmentally relevant testing of toxicity.

HAZARD

- Toxicology
  - Quality-assured experiments suitable for risk assessment should be conducted, with adequate characterization of exposure to the types of NMP to which humans are most commonly exposed.