Navigating the Microplastic Maze: Implications, Treatment, and Prevention

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Content

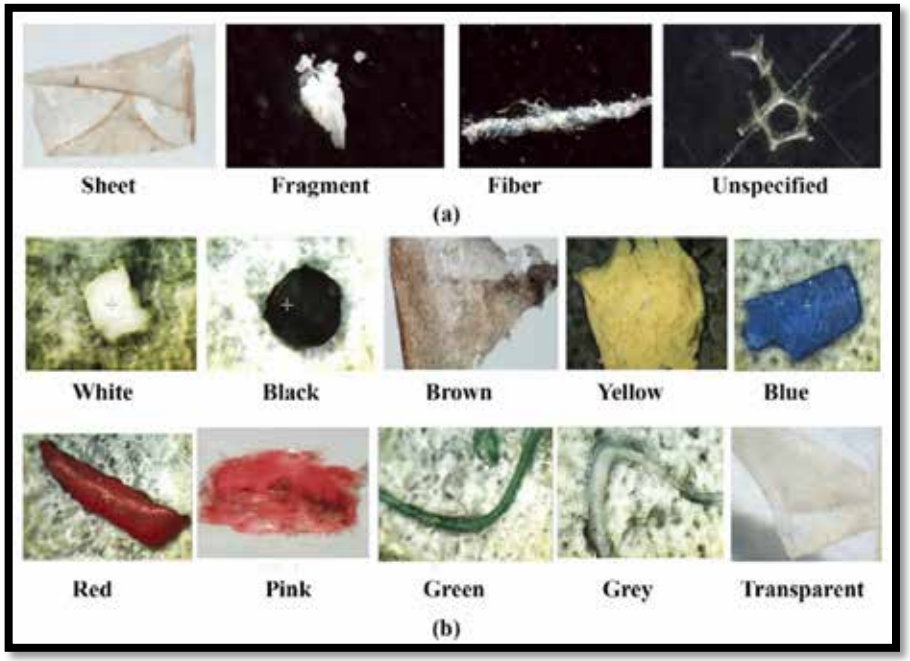
- Introduction to Microplastics (MPs)
- Sources of MPs to the Environment
- Source Control
- Treatment
- Challenges

Definitions

- MPs: - Plastic pieces less than 5mm
- Nanoplastics (NPs)- less than 1 µm
- Two types of MPs:

  Primary – Purposefully manufactured

  Secondary - Derived from the fragmentation of large plastic items



Behavior of MPs in the environment depend on size, shape; color, density, polymer types, additives.

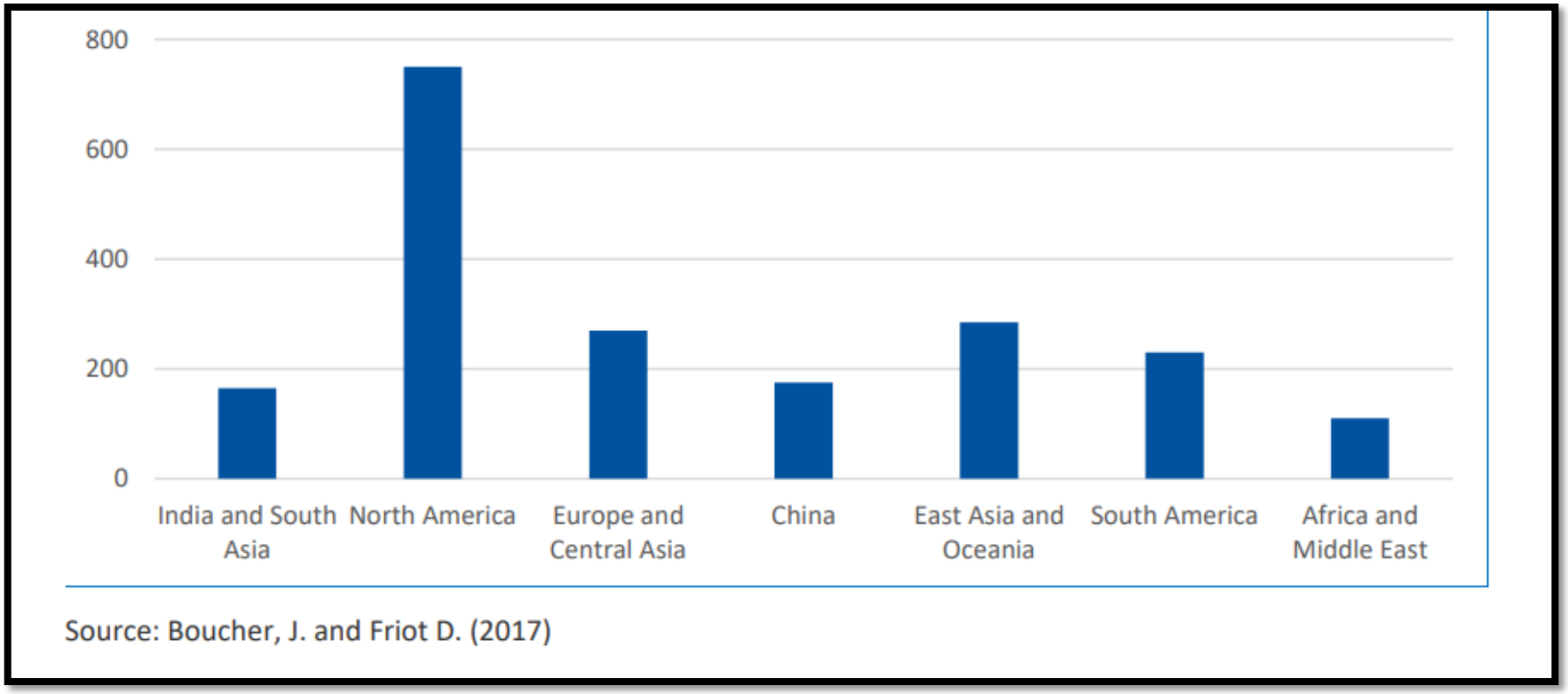
https://doi.org/10.1016/j.eti.2022.102815

Question #1

Identify a location with **NO** microplastics.

A. Near Everest's summit
B. In the Mariana Trench
C. At the North and South poles
D. In clouds
E. None of the above

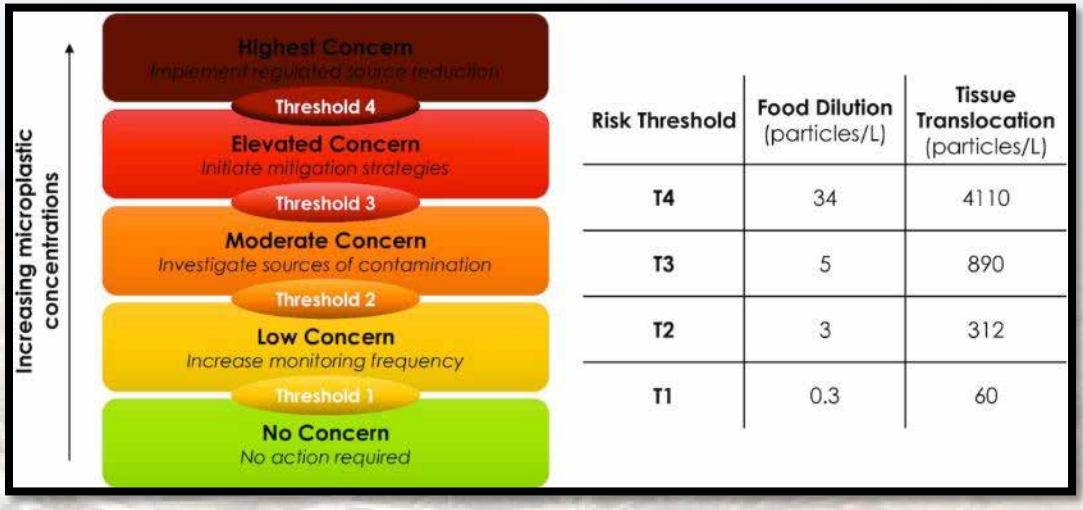
MP Pollution - A Global Issue



MPs released into the oceans by region (grams per capita per year)

Human Consumption: Via Drinking Water

- MP concentrations are comparable to ocean gyres
- Measurable risks from MPs to aquatic communities
- Source water protection is a need



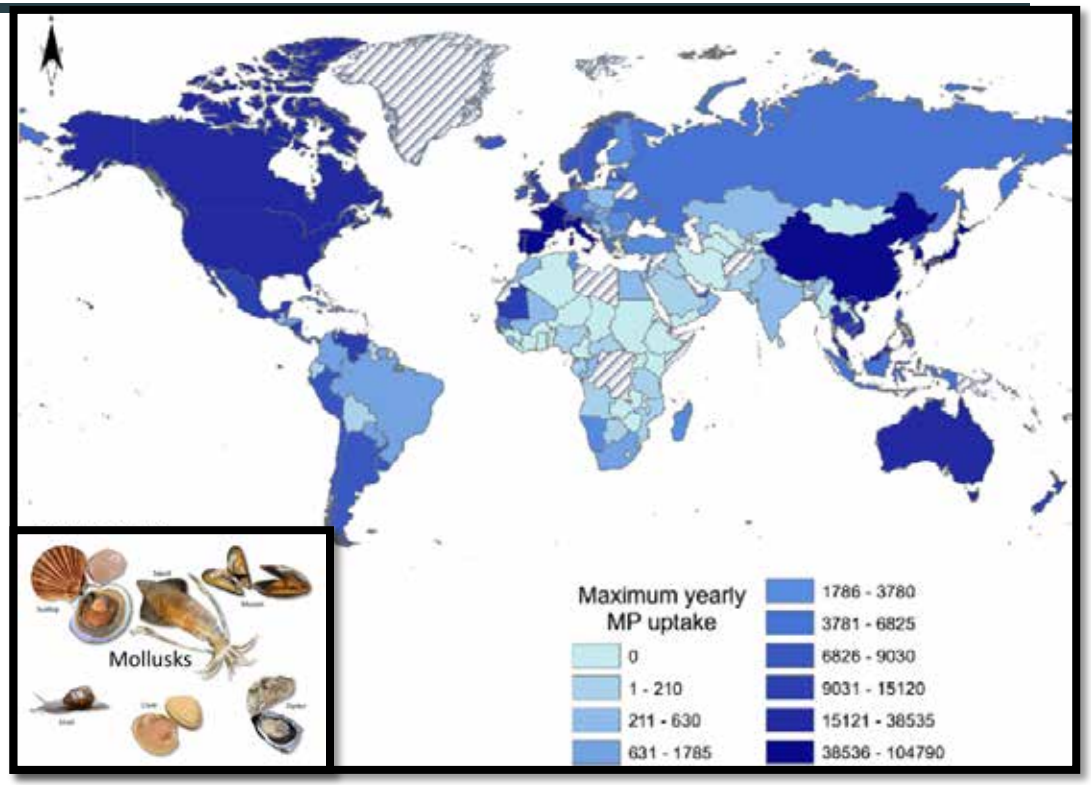
Risk Threshold	Food Dilution (particles/L)	Tissue Translocation (particles/L)
T4	34	4110
T3	5	890
T2	3	312
T1	0.3	60

Source: http://michaelcourier.com/great-lakes-plastic-pollution/; Micropl.&Nanopl. 2, 17 (2022). https://doi.org/10.1186/s43591-022-00033-3

Photo source: NOAA

Human Consumption: Via Food

- MPs are in meat, fish, shellfish, salt, sugar, milk, honey, beer, rice, fruits and vegetables, etc.
- It's feasible to reduce consumption

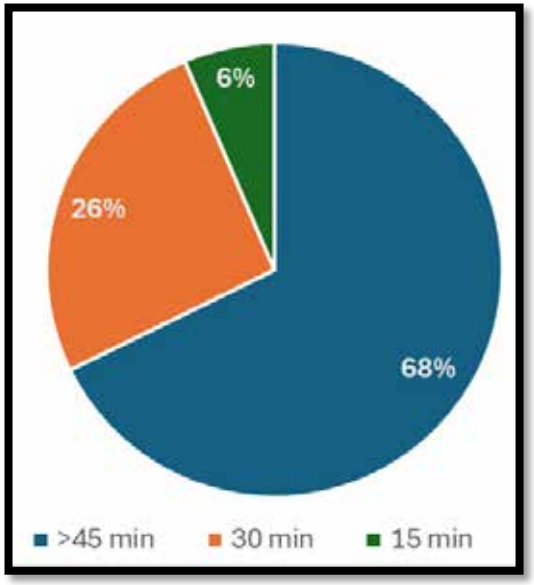


Predicted global yearly maximum MP particles uptake through mollusk consumption

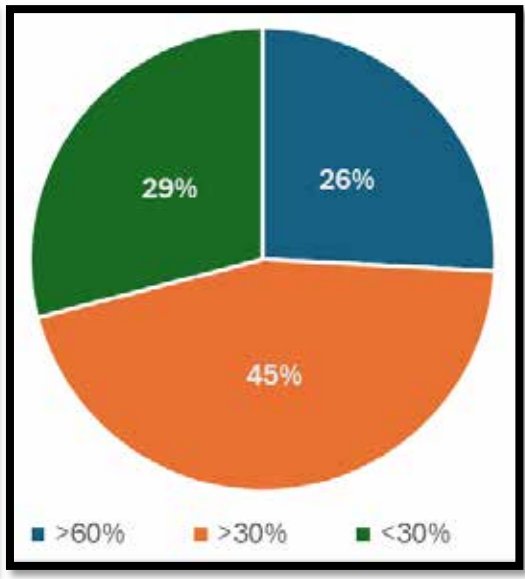
Sources: Danopoulos et al. (2020); Environmental Health Perspectives 128(12); DOI:10.1289/EHP7171

MP Consumption - Via Inhalation

- Many indoors and outdoors sources
- Example: About 0.5 million microfiber emissions from a household vented tumble dryer to ambient air during 15 minutes of use (Tao et al. 2022)
- Oceanic transfer back to atmosphere



Tumble Dryer Cycle Length



Clothing (% Synthetic Polymer)

Source: Mala C. Hettiarachchi (2024)

MP/NP in the Human Body

By Michael Haederle | February 20, 2024

Microplastics in Every Human Placenta, New UNM Health Sciences Research Discovers

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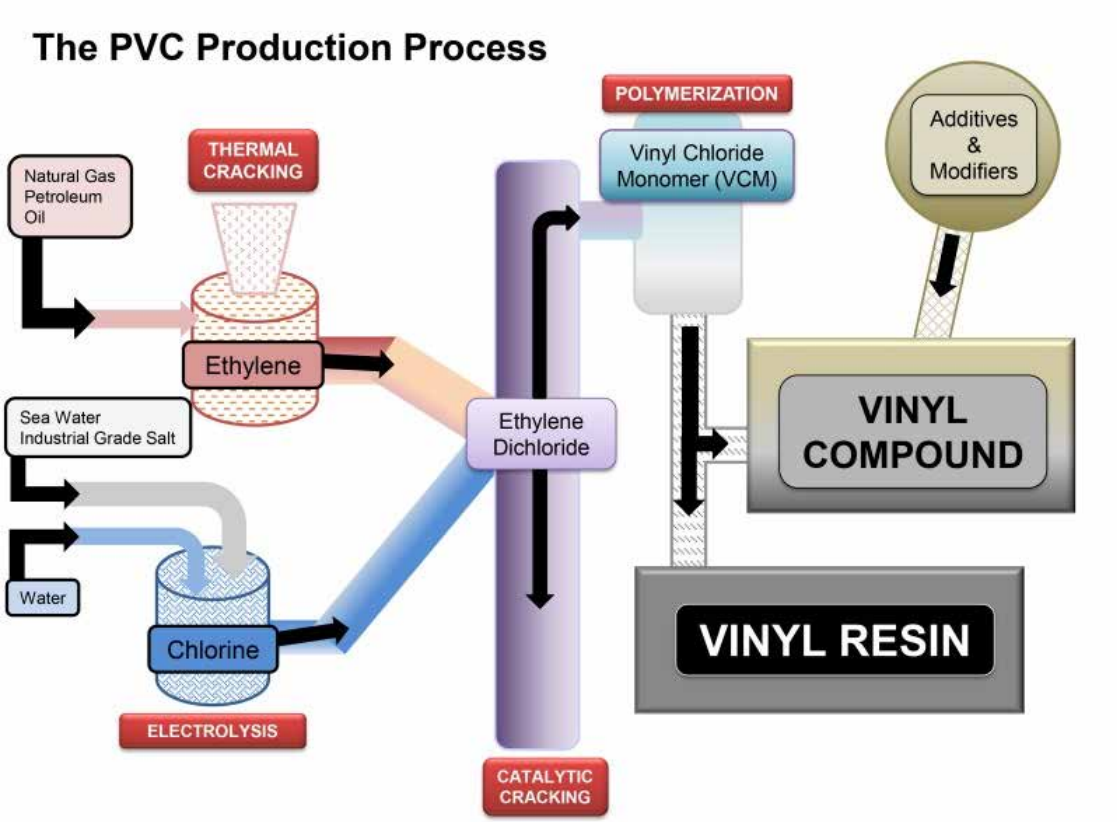
NEWS | 06 March 2024

Landmark study links microplastics to serious health problems

People who had tiny plastic particles lodged in a key blood vessel were more likely to experience heart attack, stroke or death during a three-year study.

Plastic Polymers and Additives

- >10,000 substances used in plastics
- > 2,400 Substances of concern

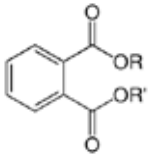


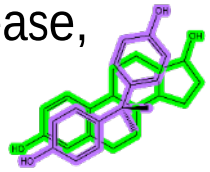
Sources: Environmental Science & Technology; DOI: 10.1021/acs.est.1c00976; https://www.teknorapex.com/the-pvc-production-process

Toxicity - Additives

Bisphenol A (BPA)

- A common additive - provides robustness and stability to plastics. Associated with breast cancer, obesity, cardiovascular disease, reproductive disorders.





Phthalates

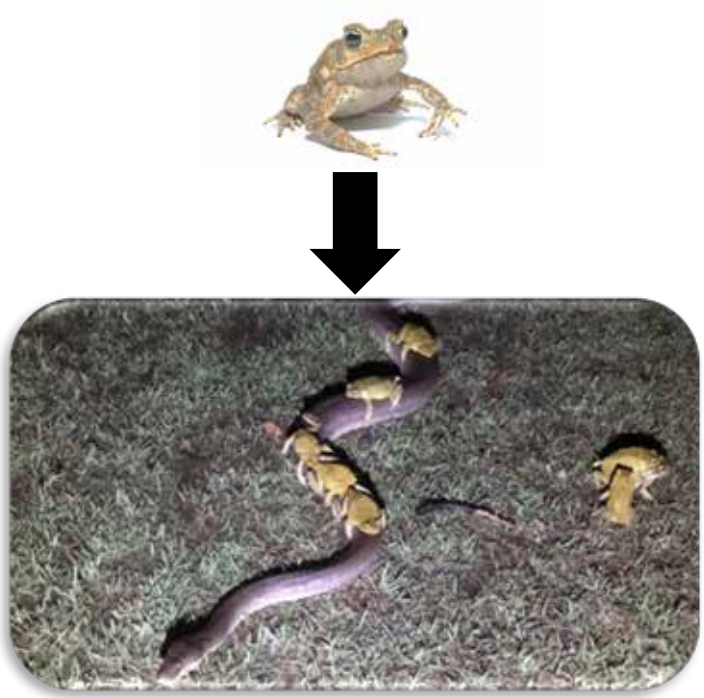
- Used as plasticizers - provide flexibility, pliability and elasticity to plastics. Many phthalates are endocrine disruptors and/or being carcinogenic. E.g., Exposure to Di(2ethylhexyl)phthalate (DEHP) may increase the risk of cancer, and may also harm the male reproductive system

PFAS

- Research by Notre Dame University (2023):
  - Detected PFAS (from 2.7 to 7.2 ng/g) in food
  - PFAS leached from fluorinated plastic containers
  - Leaching potential increased by 830% at elevated temperatures

Toxicity – As a Vector for Chemicals

- MPs can adsorb heavy metals and organic pollutants from environment
- Per a recent study conducted at The University of California – Irvine:
  - PET MPs (from water bottles) adsorbed PFAS.
  - Adsorption was spontaneous at 25^{o}C
- MPs serve as vectors for contaminants (act as a conveyor of contaminants to organisms and between environment media)



Venomous toads hitch ride on a poisonous snake

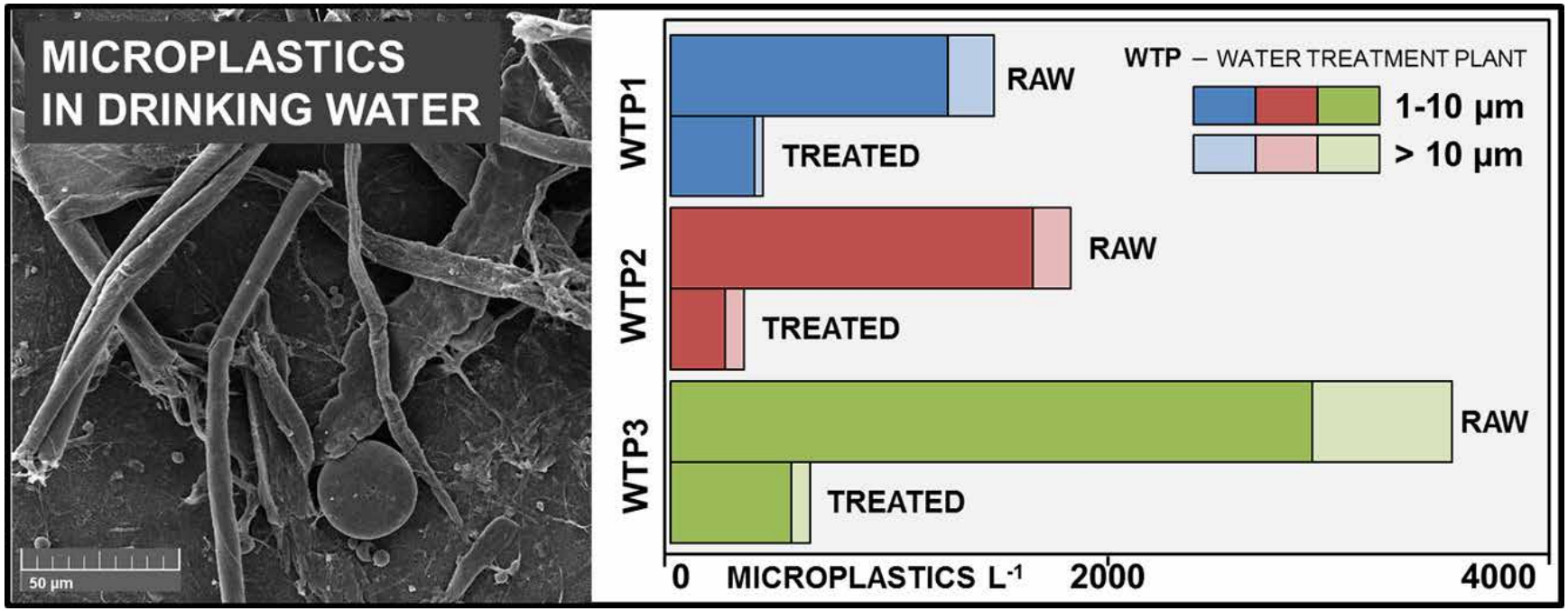
Photo Source: Google; Getty; iStock

Particle Toxicity

- Need more clinical observational studies
- Polystyrene NPs breached the blood-brain barrier (BBB)
- Accumulated NPs in brain tissues as early as 2 hours after exposure
- Inflammation created behavioral changes.
- Increased risk of neurological disorders or neurodegenerative diseases such as Alzheimer's or Parkinson’s

Source: Nanomaterials 2023, 13(8), 1404; https://doi.org/10.3390/nano13081404; https://doi.org/10.1016/j.jhazmat.2022.128431

Particle Toxicity

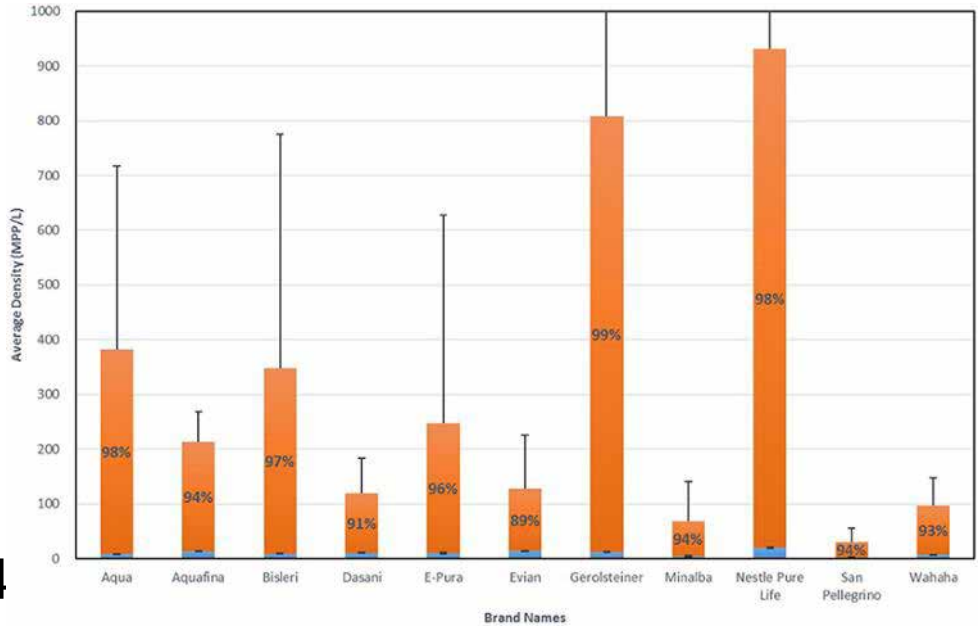


Pivokonsky et al. Science of The Total Environment; Volume 643, 1 December 2018, Pages 1644-1651

Particle Toxicity

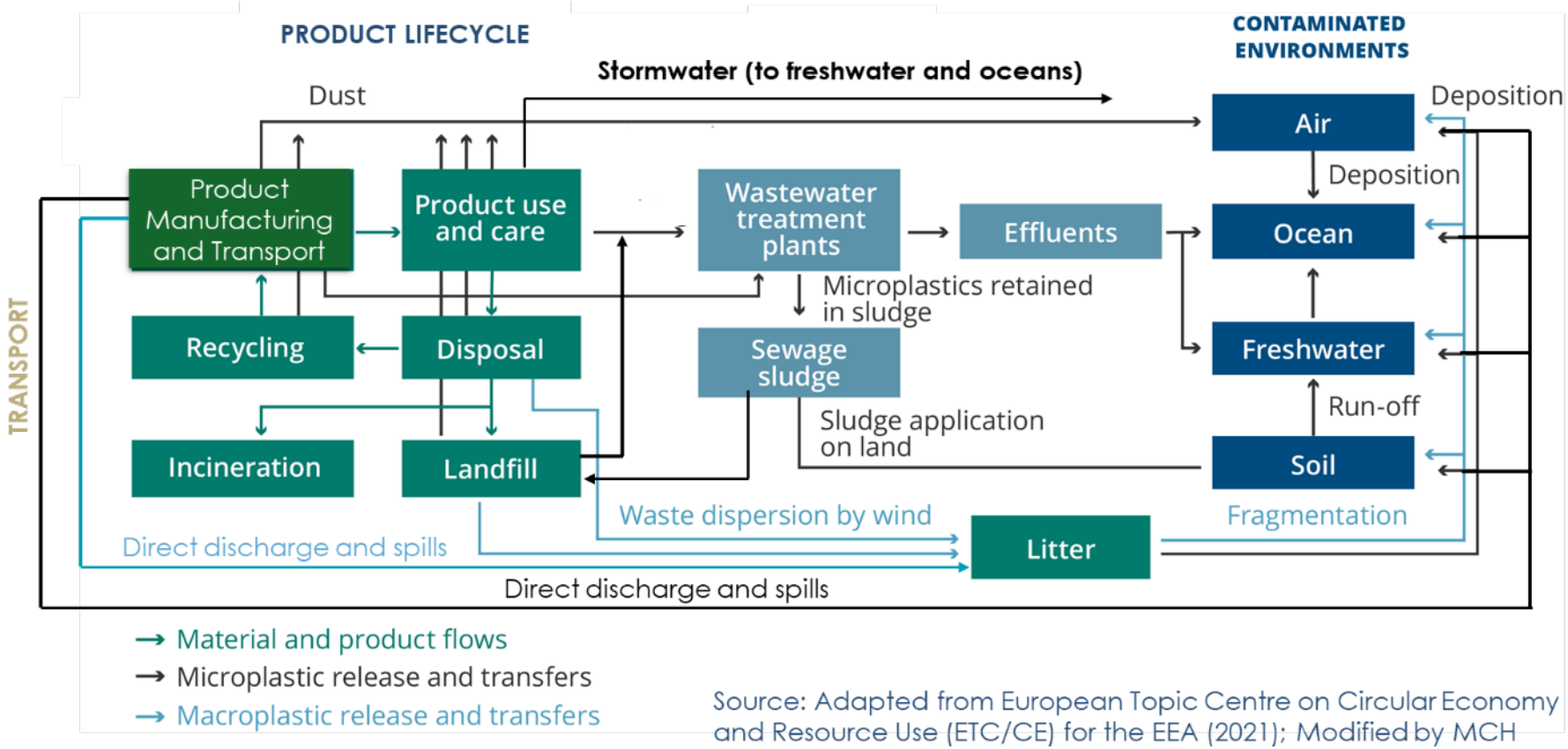
- "The tiny particles previously invisible under conventional imaging actually dominate in number and account for ~90% of the entire population of plastic particles detected. The remaining 10% identified as microplastics have a concentration of around 3 × 104 particles per liter."

January 8, 2024, 121 (3) e2300582121, https://doi.org/10.1073/pnas.2300582121



https://doi.org/10.3389/fchem.2018.00407

MP Cycle



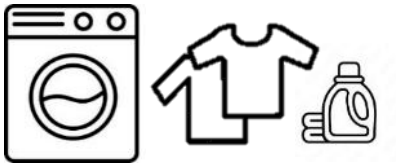
Source: Adapted from European Topic Centre on Circular Economy and Resource Use (ETC/CE) for the EEA (2021); Modified by MCH

MP Sources to Aquatic Environment

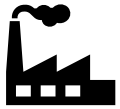
Mismanaged plastics

Paint

Tires



Synthetic clothing



Plastic Manufacturing and transport

Major Sources of MPs to Water

Cosmetics and personal care products

WWTPs

Sewage Sludge

Agriculture

Artificial turf

MP Sources to Agricultural Soil

Plastic mulch

Compost

Atmospheric deposition

Major Sources of MPs to Soil

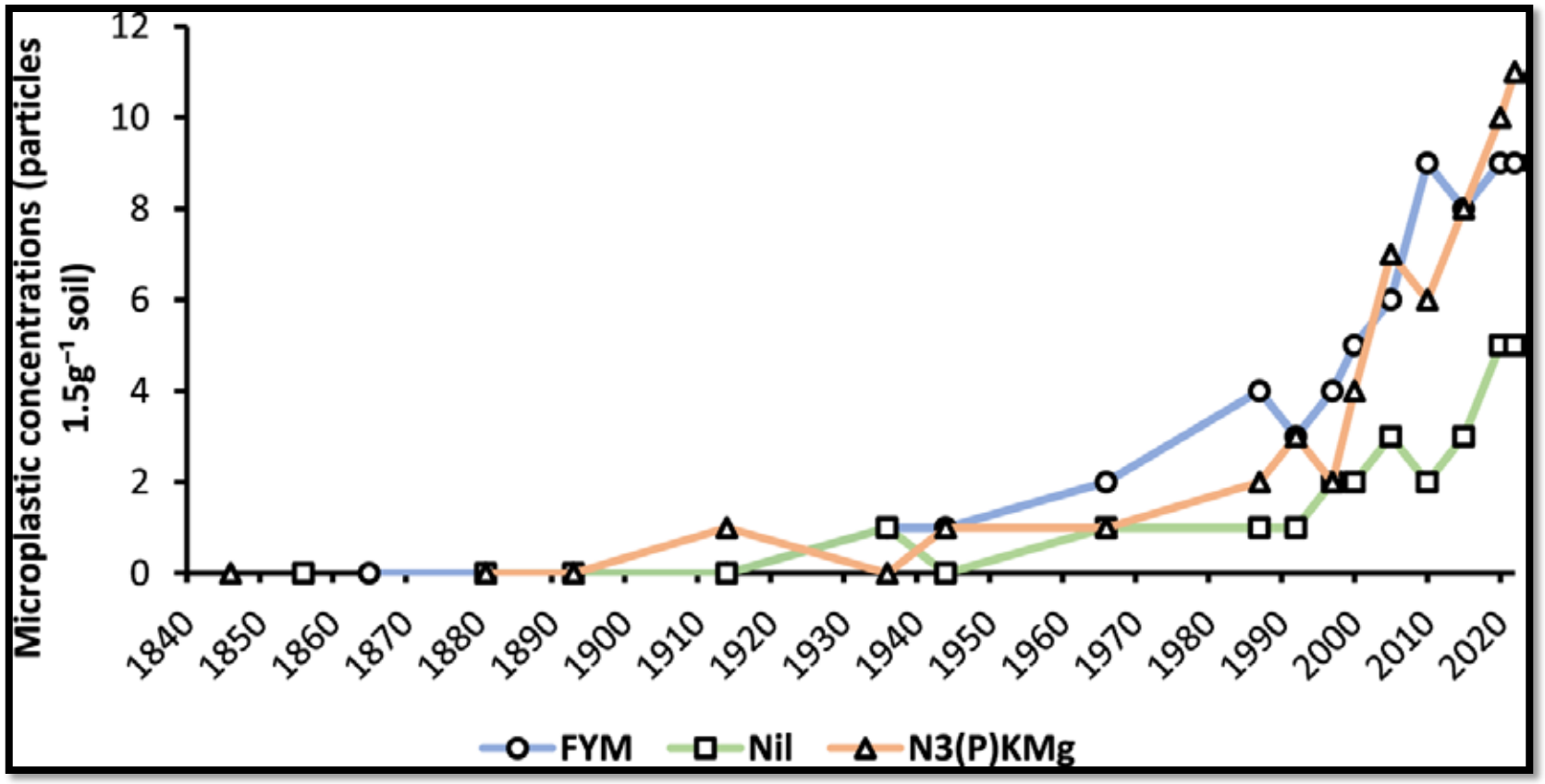
Controlled Release Fertilizers/Pesticides and Anti-Caking

Irrigation water

Sewage Sludge

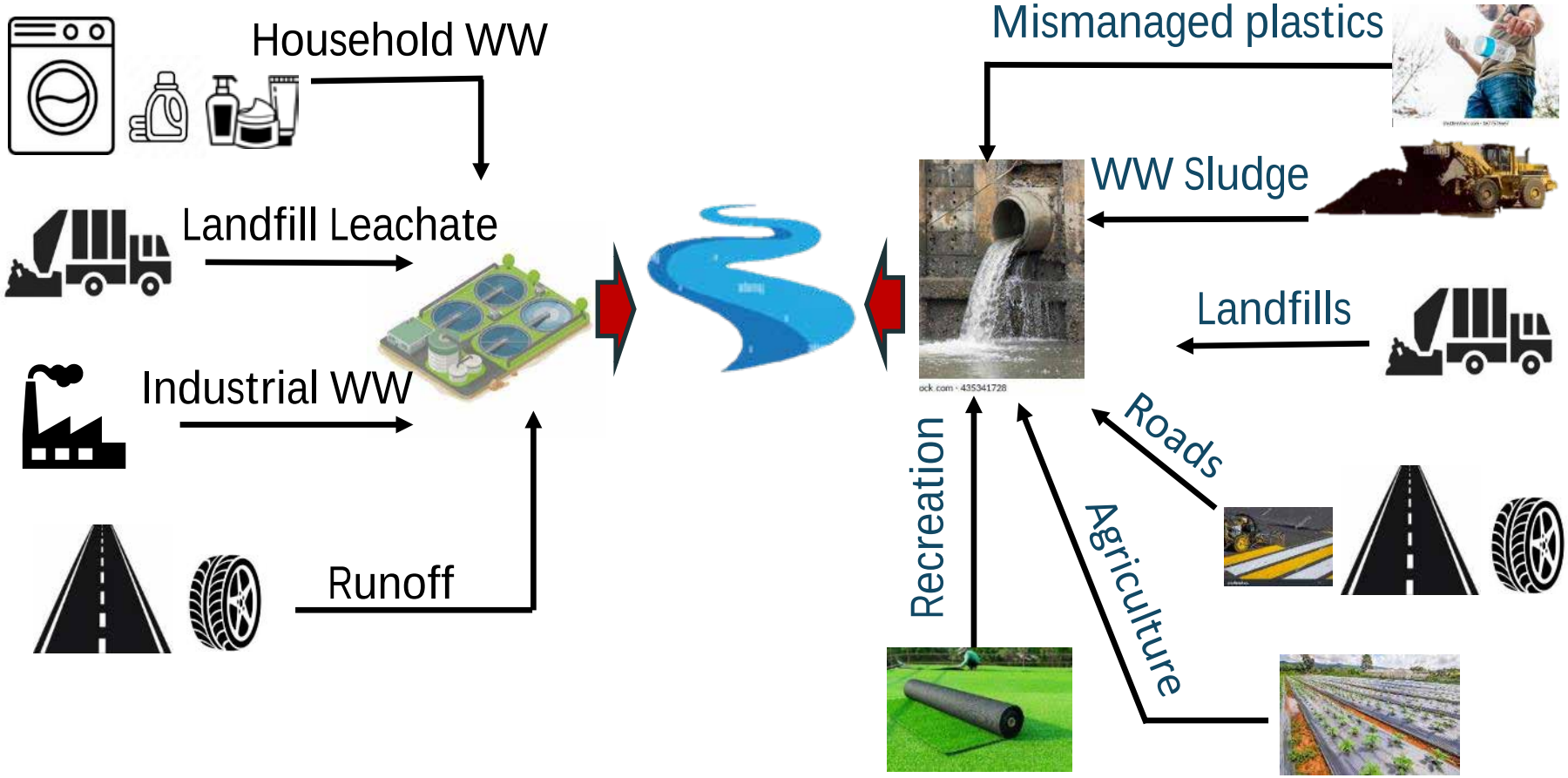
Greenhouse farming

MPs in Agricultural Soil



Microplastic concentrations in agricultural soil (UK); https://doi.org/10.6084/m9.figshare.24759615

Major Outlets: WWTPs and Stormwater



Question #2

Which statement is incorrect?

1) MPs can create negative human health impacts
2) Microplastics have significant environmental impacts
3) Microplastics contribute to climate change
4) None of the above

Microplastics vs Climate

"The GHG emissions of U.S. plastics industry is equivalent to the average emissions from 116 average-sized (500- megawatt) coal-fired power plants in 2020."

"The plastics industry's contribution to climate change will exceed that of coal by the year 2030."

https://www.beyondplastics.org/plastics-and-climate

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NEW STUDY FINDS THAT MICROPLASTICS REDUCE THE EFFICIENCY OF REMOVING CARBON DIOXIDE FROM THE ATMOSPHERE

New Study Finds That Microplastics Reduce the Efficiency of Removing Carbon Dioxide from the Atmosphere

May 21, 2024

ELSEVIER

Journal of Hazardous Materials
Volume 468, 15 April 2024, 133841

Carbon sequestration reduced by the interference of nanoplastics on copper bioavailability

Yanting Du [a 1], Qianyan Huang [a 1], Shunxing Li [a b c], Minggang Cai [d], Fengjiao Liu [a b c], Xuguang Huang [a b c], Fengying Zheng [a b c], Luxiu Lin [a b c]

Source Control – Mismanaged Plastics

- Linear economy (buy-use-discard) to circular model
- Moving from symptom management to upstream plastics prevention
- Reduce-Reuse-Recycle

Poor plastic recycling rate:
- 10% globally
- 6% in the USA (USEPA 2021)

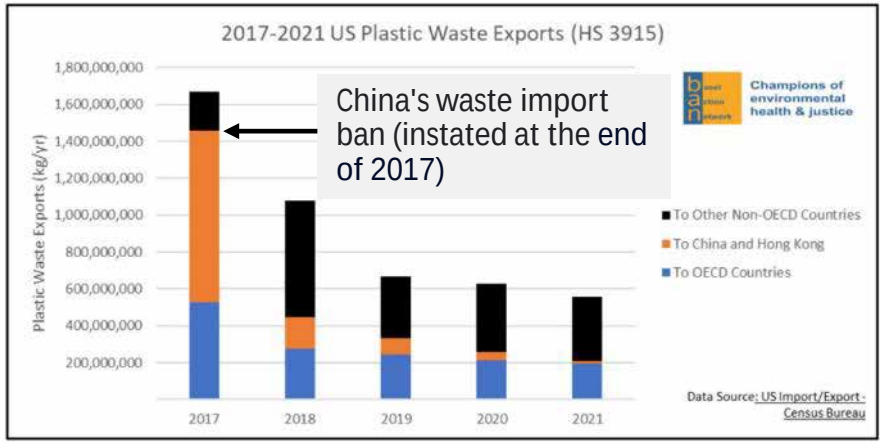
Nearly 22 million pounds of plastics enter the Great Lakes every year.
Source: the Rochester Institute of Technology

Trash collected during the Newaygo County Conservation District cleanup. "Volunteer Stream Cleanup program nets 31K pounds of trash in 2023" Source: EGLE

Source Control – Mismanaged Plastics

- Policies to regulate and reduce upstream production
- California's SB 54 -- requires all packaging to be recyclable or compostable by 2032
- 99.8% of plastic packaging was recycled in Germany in 2021 due to 2019 Packaging Law (*VerpackG*)
- Stringent regulations on plastic waste imports/exports

Out of 400 million tons of plastics produced yearly, over 40% is single use packaging



Stormwater: Mismanaged Plastics

Photo source: Google

Source Control: Mismanaged Plastics

City of San Diego -
Storm Drain Insert

Source: Anacostia Watershed Society; Bladensburg, MD

Source: DESMI

Collaborate with local governments and communities

Source Control: Road Runoff

- Regulations on MP emissions from brakes and tires
- Safe management of end-of-life tires
- Paint products with improved durability
- Peelable paints to reduce releases due to sanding
- Alternative application, cleaning, and surface maintenance techniques
- Paint waste management

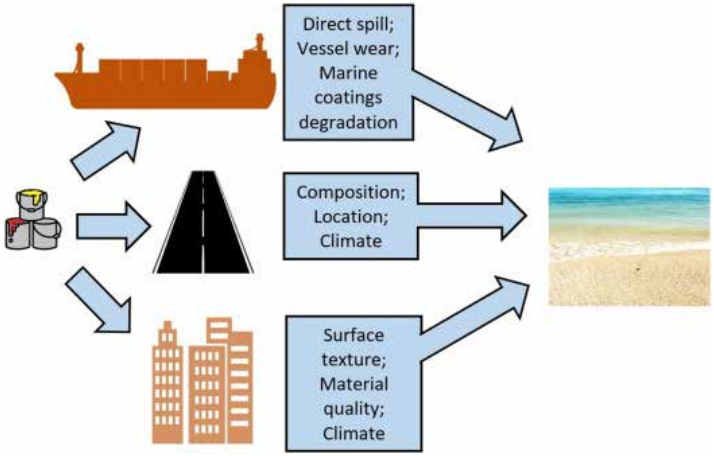


Photo Source: https://doi.org/10.1016/j.marpolbul.2020.111847;

Annual MP emissions:
Tires: 1 million tons
Paint: 1.9 million tons

Source Control: Road Runoff

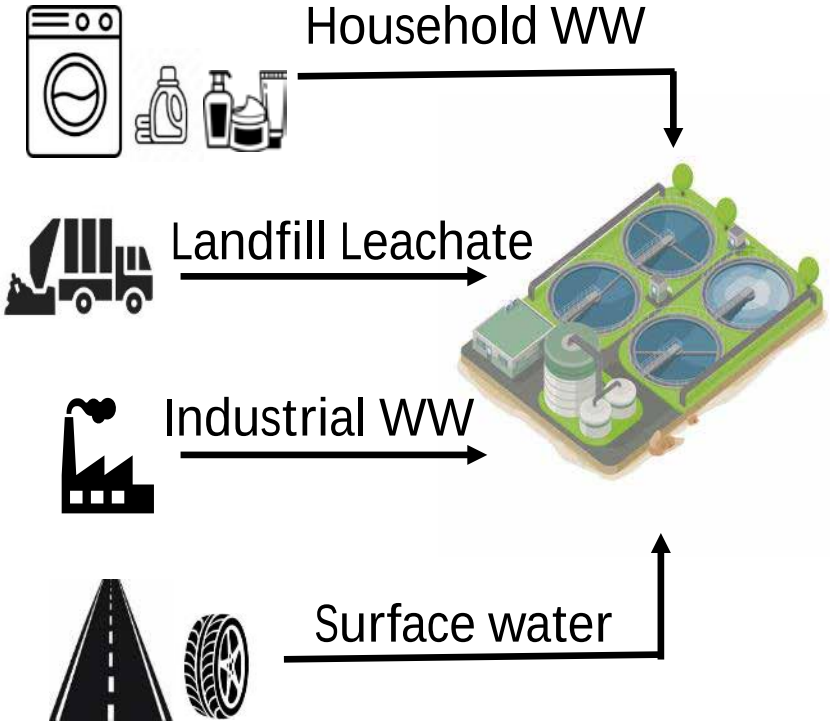
- Revisions to stormwater management practices
- Road runoff treatment in urban areas

https://doi.org/10.1016/j.jenvman.2022.115510

Annual MP emissions: Tires: 1 million tons; Paint: 1.9 million tons

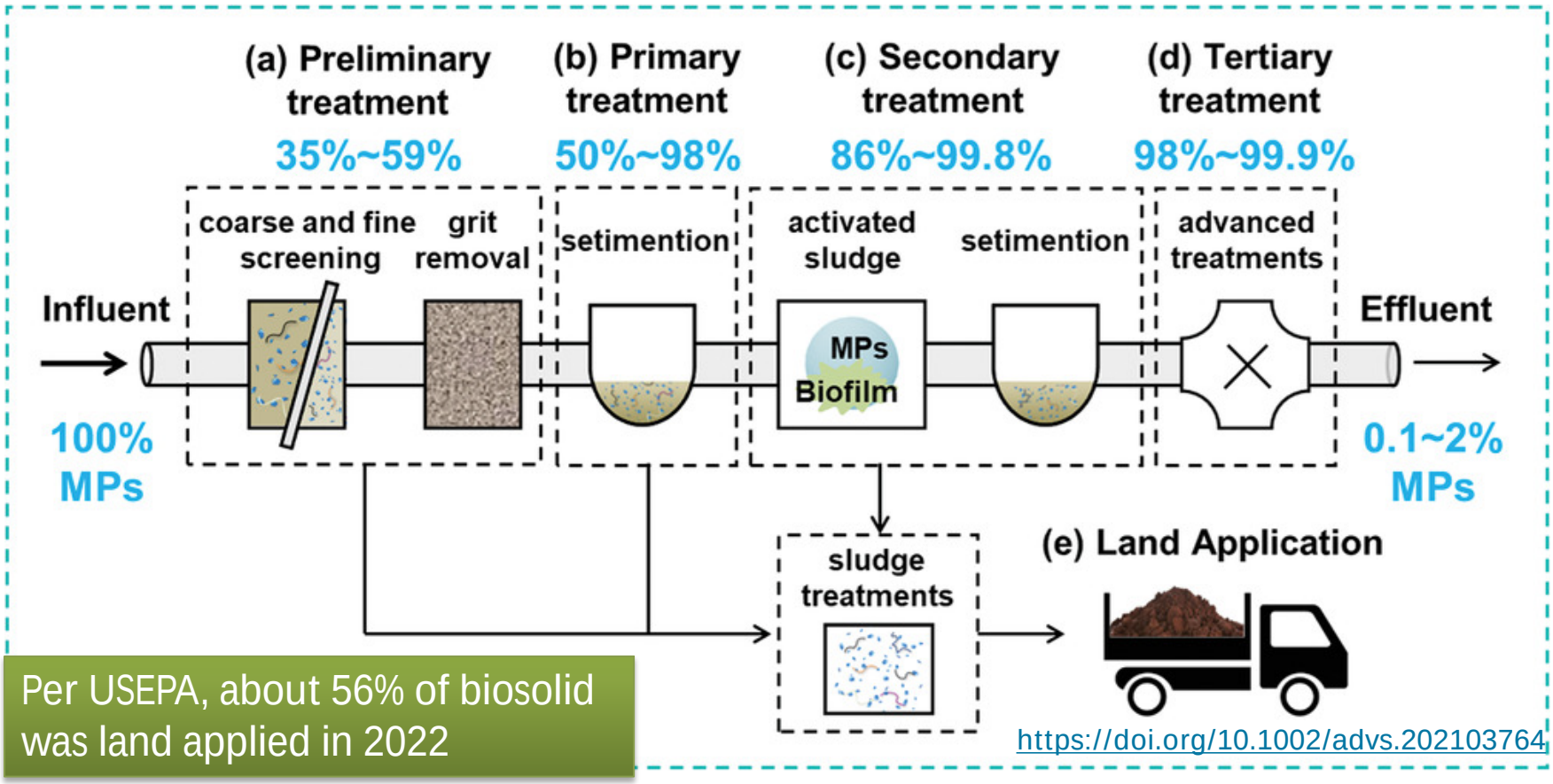
Source Control: WWTPs

- Public outreach to reduce MPs/NPs in household wastewater (WW)
- Removal of MPs from industrial WW
- WW treatment (Advanced oxidation methods; Photocatalytic degradation such as UV photolysis, UV/H_2O_2, O_3, Plasma)



Source: Meegoda and Hettiarachchi (2023); doi: 10.3390/ijerph20085555

Source Control: WWTPs

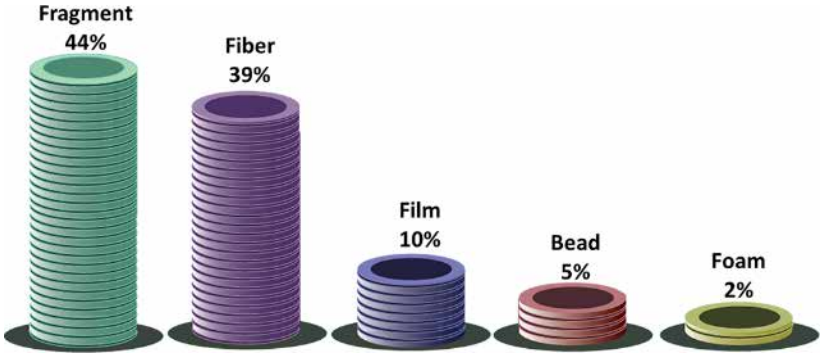


Per USEPA, about 56% of biosolid was land applied in 2022

https://doi.org/10.1002/advs.202103764

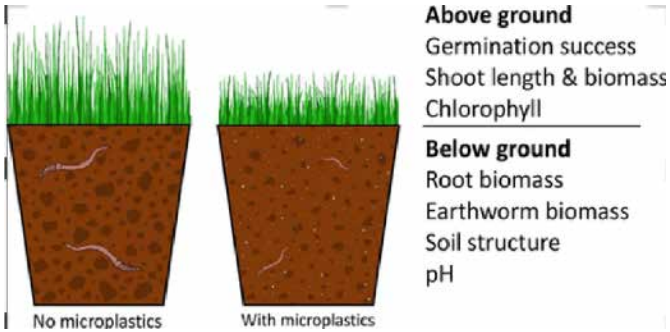
Source Control: Sludge/Biosolids Land Application

- MPs/NPs accumulation inhibit plant growth; seedling development; hinder earthworm development; and alter soil fungal communities (Sun et al. 2020; Source: Li et al. 2022; Lozano et al. 2024)
- Source controls to reduce MPs entering WWTPs
- Thermal treatments
- Bioremediation
- Policies and regulations



Morphology of MPs detected in biosolids

Source: Commun Earth Environ **4**, 42 (2023). https://doi.org/10.1038/s43247-023-00691-y; https://doi.org/10.1021/acs.est.9b03304



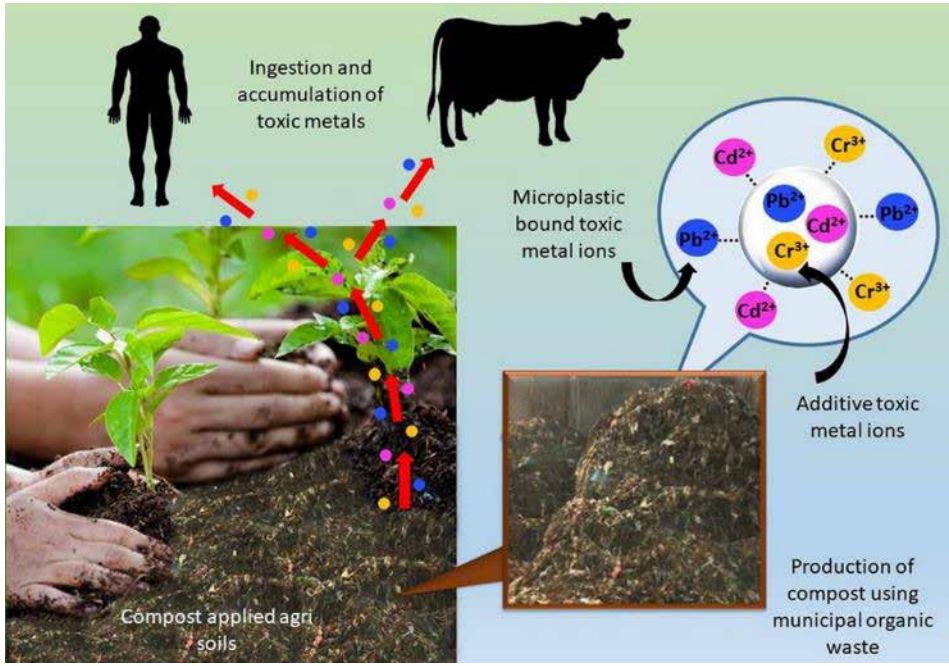
Source Control: Agriculture

- The agriculture sector in the USA uses about 1 billion pounds of plastics (the University of Washington)
- Plastic mulch is reapplied seasonally, and the mulch removal process is laborious, expensive, and incomplete.
- Sustainable plastic usage with an emphasis on reduction, reusing, and recycling
- Organic mulches (compost, straw, grass clippings, woodchips, paper mulch)

Photo Source: Earth.com

Source Control: Agriculture

- Some composting programs allow residents to put plastic-coated paper products including coffee and tea capsules into compost collection bins
- Dry matter of compost can contain up to 6.6 grams of plastics in 1 kilogram (Scopetani, et al. 2022)
- Develop appropriate composting guidelines



Source: https://doi.org/10.1016/j.coesh.2021.100297

Source Control: Agriculture

- MPs are deliberately added to fertilizers and pesticides to allow for a controlled release of nutrients or chemicals (by wrapping a nutrient in a polymer material to form a small capsule)

Photo Source: https://cen.acs.org/

- Rules and regulations on these products may have to be revised to encourage the use of easily biodegradable material

Source Control: Agriculture

- MP concentration in farmlands with surface water irrigation is high
- Control of MPs that enter soil via surface water irrigation is complex and challenging
- MPs found in surface water represent a vast array of solid particles originating from various sources
- Source control is an urgent need

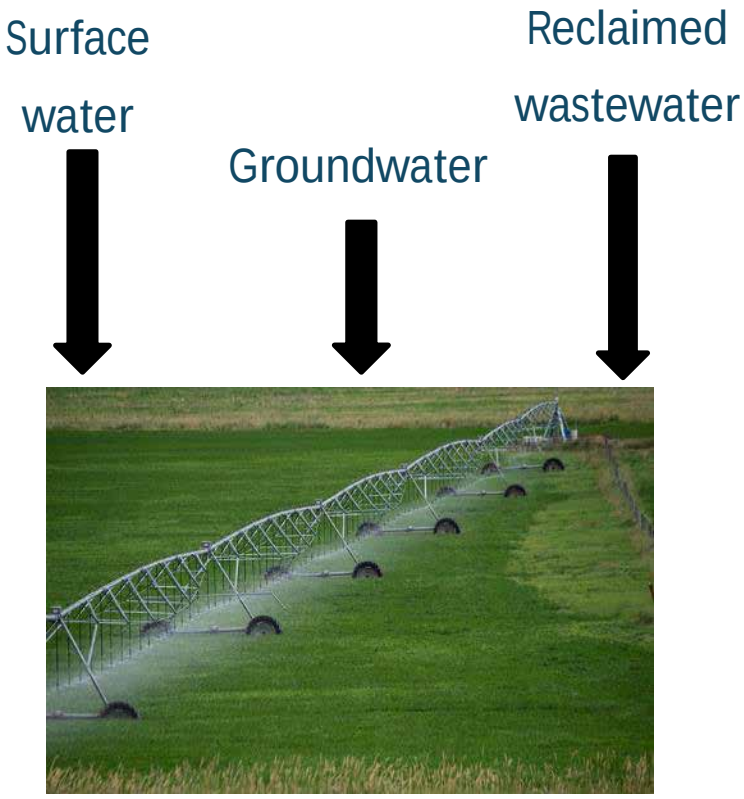
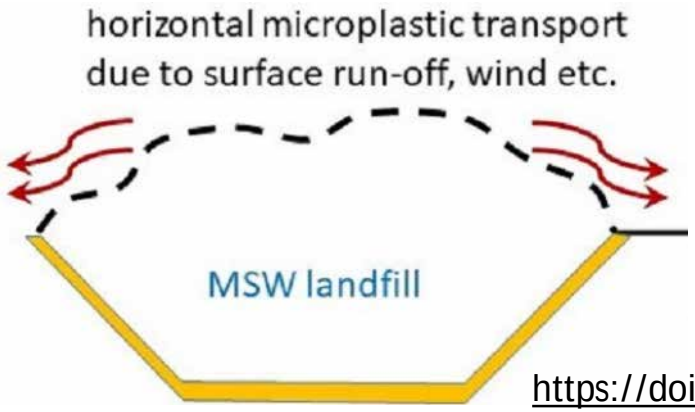


Photo Source: USDA

Source Control: Landfills

- Plastics and MPs/NPs enter the environment during collection, transport, and landfilling operations
- Collaboration with solid waste operators

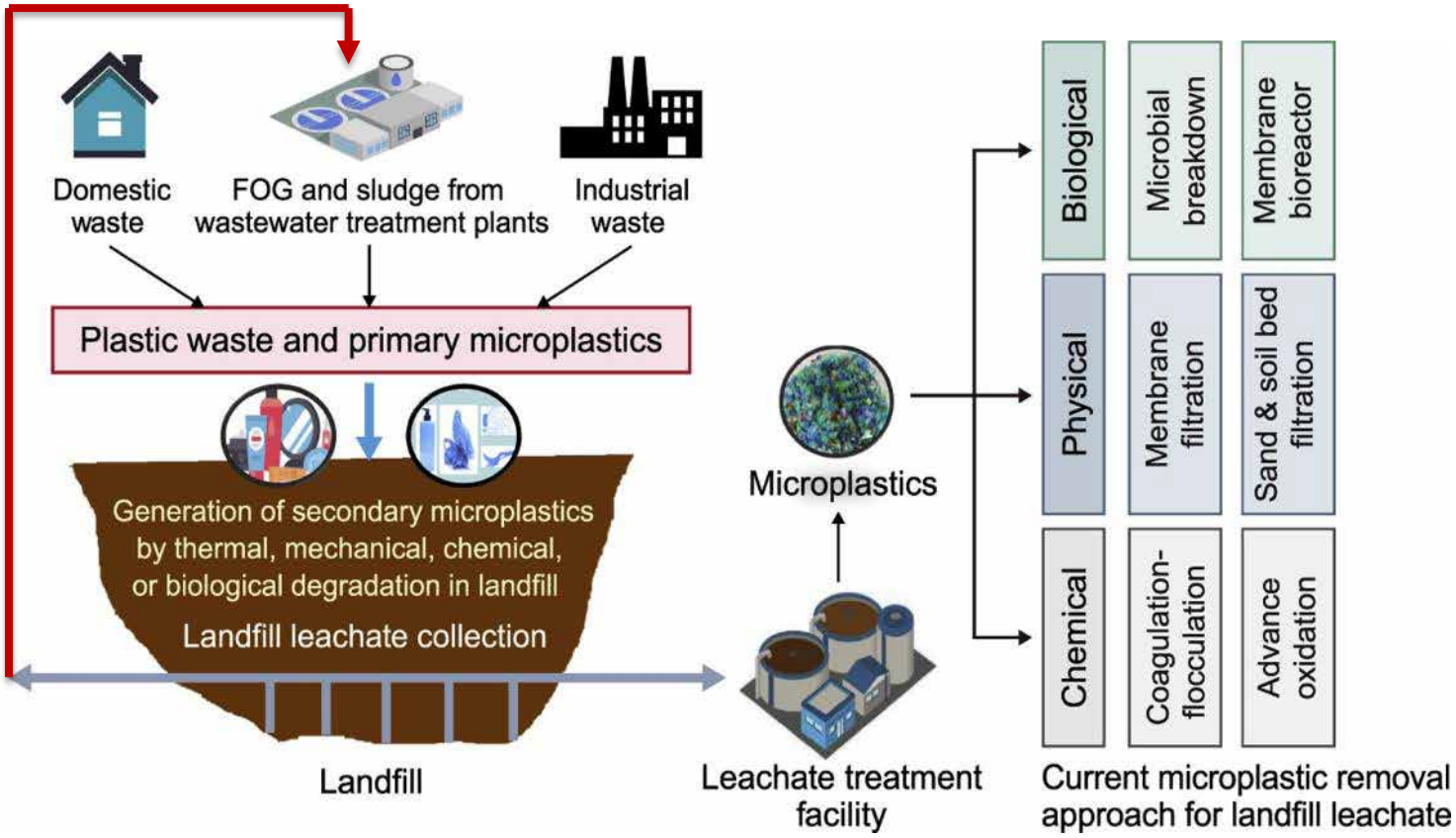
The Outagamie County landfill, Wisconsin; Source: FOX 11 News



https://doi.org/10.3390/polym13234129

Source: 89.1 WEMU

Source Control: Landfills

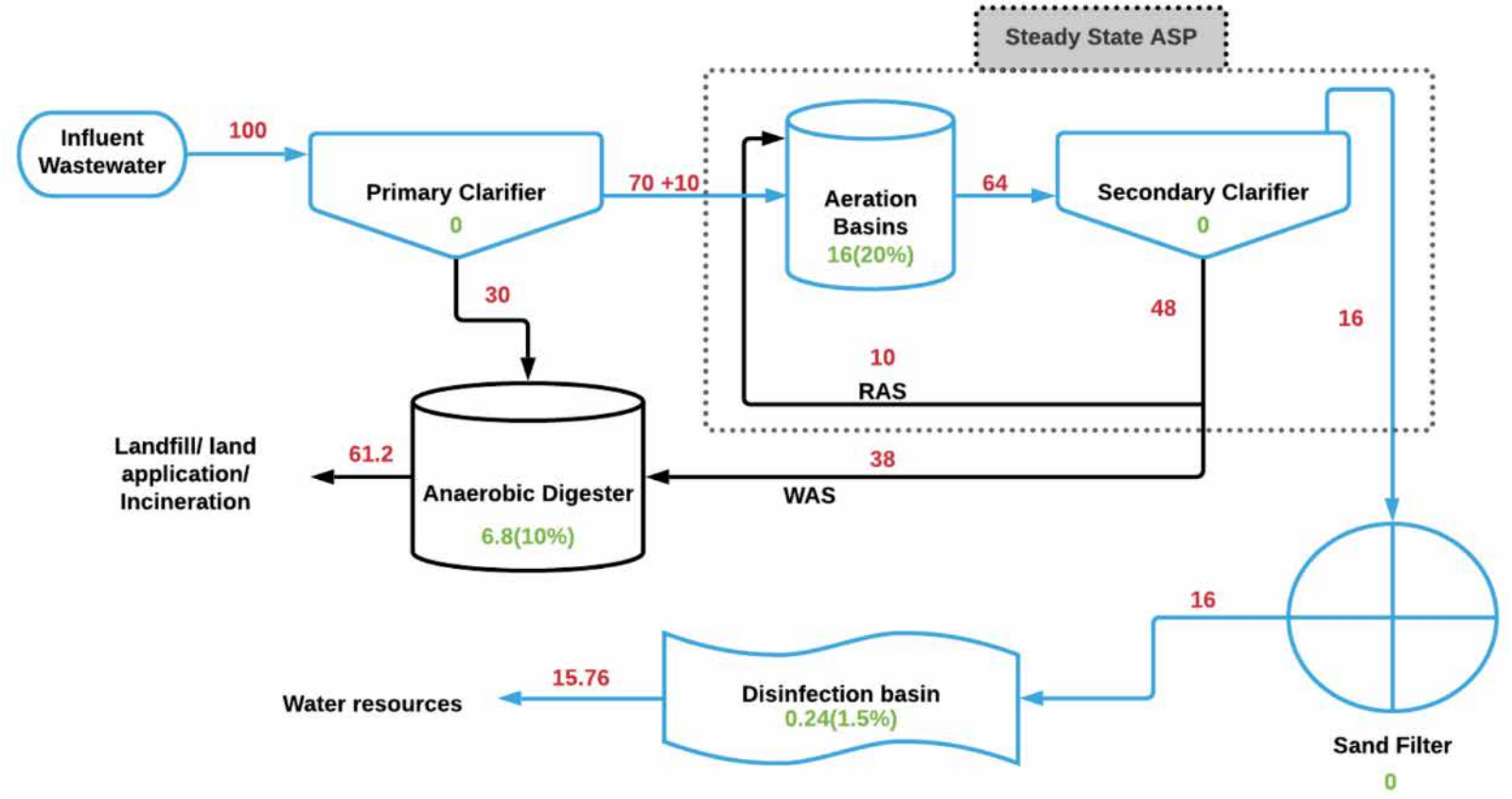


Alternative Materials

- It is necessary to conduct thorough investigations before using alternative materials as substitutes for plastics.

- Some laundry detergent sheets are advertised as “Biodegradable” and “zero-waste”
- They contain polyvinyl alcohol (PVA), a water soluble or dissolvable plastic polymer

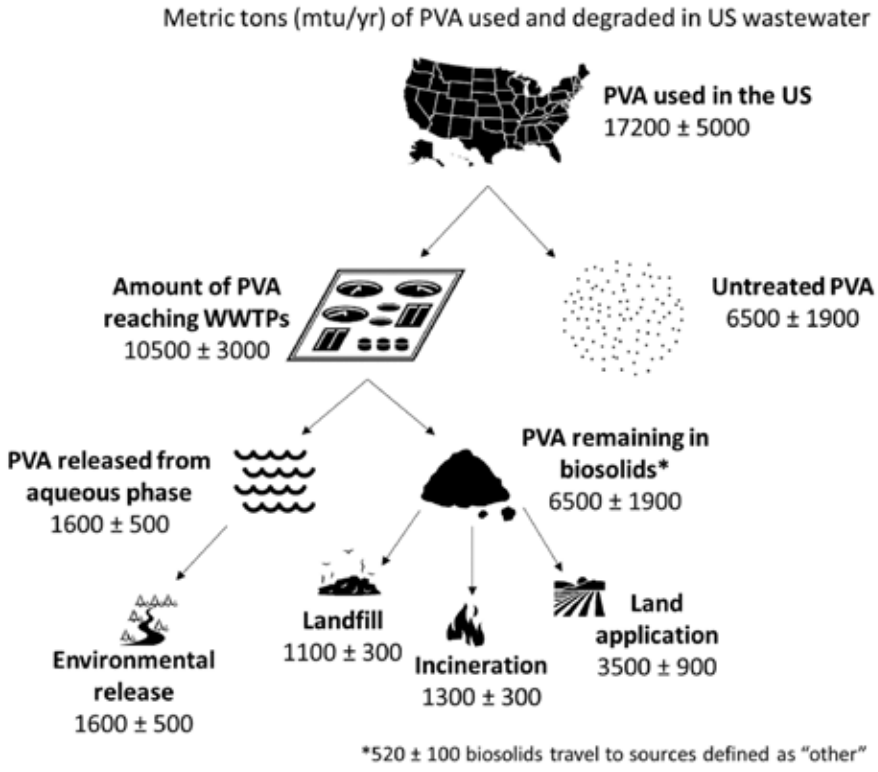
Alternative Materials



Rolsky, C.; Kelkar, V. Degradation of Polyvinyl Alcohol in US Wastewater Treatment Plants and Subsequent Nationwide Emission Estimate. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6027. https://doi.org/10.3390/ijerph18116027

Alternative Materials

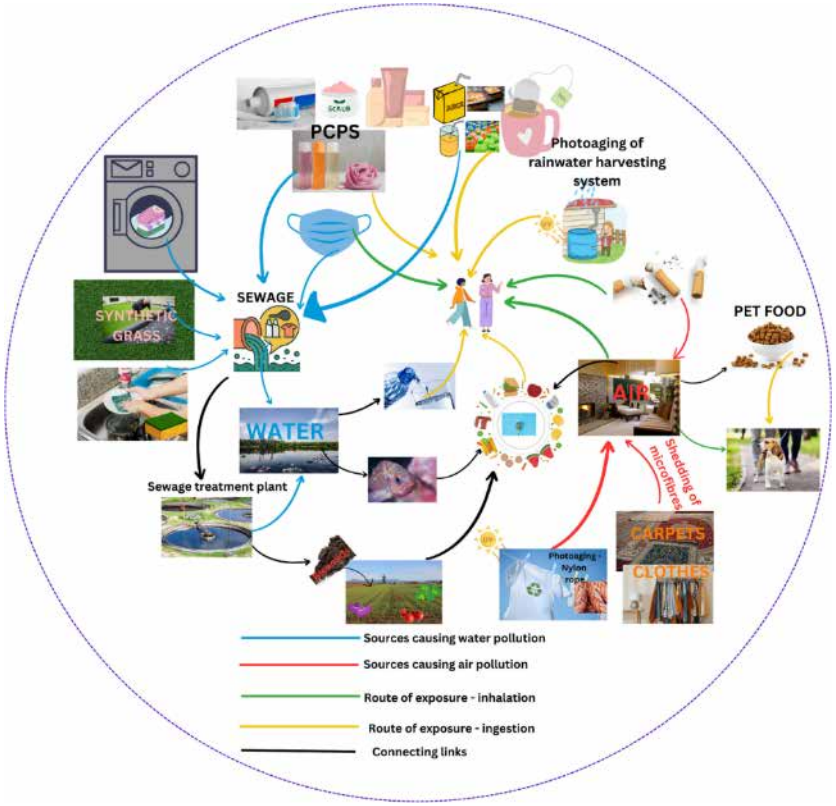
- Chemical-based AOPs (ozonation, Fenton reagent, persulfate),
- Hybrid AOPs (wet air oxidation; wet peroxide oxidation)
- Energy-based AOPs (photocatalytic oxidation; electrochemical oxidation; ultrasonic oxidation; ionizing radiation)
- Adsorption to granular activated carbon



Source: Rolsky et al. (2021); https://doi.org/10.6084/m9.figshare.24759615
Sun et al. Journal of Advanced Oxidation Technologies. 20170018.

Public Outreach

- Residential houses are a major source of MP/NP pollution
- People are largely responsible for littering
- Educate to reduce, reuse, recycle, and proper disposal
- Educate on the safe use of plastics



Source: https://doi.org/10.1007/s11356-023-26918-1

Source Water Protection

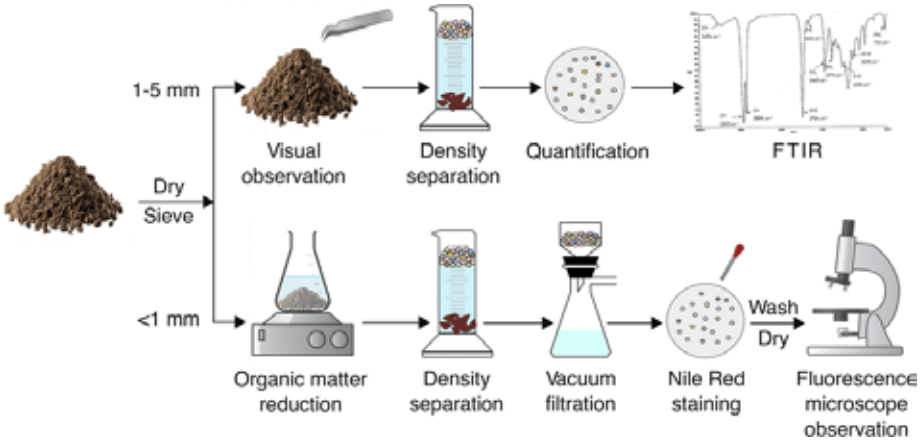
Challenges

- Definitive research on health impacts
- Efficient/straightforward detection methods
- MPs' interactions with other contaminants
- Regulations on macro and microplastics
- Sustainable alternatives
- Public outreach
- Sustainable plastic waste management

Photo source: Google

Challenges

- Visual microscopy (typically for particle counts)
- Infrared (IR) spectroscopy (for visuals, particle counts, and chemical identification.
  - q Fourier Transform IR (FTIR)
  - q Laser Direct Infrared (LDIR) Imaging
  - q Optical Photothermal IR (O-PTIR)
  - q Attenuated total reflectance (ATR) FTIR
- Raman spectroscopy



DOI:10.1007/s11356-021-17378-6

There are standard methods for collecting and preparing MP samples.

Some Tips!

- Choose sustainable and durable clothing
- Pick up litter
- Try to avoid single use plastics
- Support initiatives on plastic waste reduction or prevention
- Reduce, reuse, recycle, and dispose waste appropriately
- Don’t microwave food in plastic containers
- Drink filtered tap water
- Spread the word

Thank you!

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Assessment • Remediation • Compliance • Risk Management

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