Occupational and Environmental Exposures and Work Practices for Nanomaterials and Electronic Products

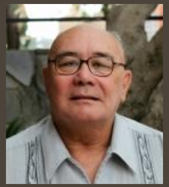
Southern California Superfund Research Program (SCSRP)
Occupational Health and Safety Education Programs on Emerging Technologies
Candace Tsai, MS, ScD, CIH

University of California Los Angeles (UCLA)

UCLA Fielding School of Public Health

Occupational and Environmental Exposures and Work Practices for Nanomaterials and Electronic Products


PI - Dr. Candace Tsai, ScD, CIH


Dr. Shane Que Hee, PhD


Dr. Yifang Zhu, PhD


Dr. Tian Xia, M.D., PhD

Grant No.: 1R25ES033043-01

Goal:
Develop a modern and multidisciplinary training program for <u>students and the community of industrial hygienists</u>, and to prepare next-generation professionals for effective management of stressors caused by <u>emerging technologies such as nanotechnology and electronic products.</u>

Collaborating institutions:


University of California Irvine (UCI)
Dr. Oladele Ogunseitan, PhD,


California State University, Fullerton (CSUF),
Dr. Danny Kim, PhD,


Dr. Airek Mathews, M.Ed., PhD
Consultant

UCLA Fielding School of Public Health

Technologies and Contaminants of Interest

UCLA IH & SC ERC

PARTNERS

Research training

- ✓ Nanomaterials & Nanotechnology
- ✓ Control & Exposure
- ✓ E-product & E-waste
- ✓ Biological Effects
- ✓ Virtual & Augmented Reality

Course training

- ✓ UCLA IH Curricula
- ✓ Continuing Education
- ✓ Virtual & Augmented Reality
- ✓ Interdisciplinary Course
- ✓ Specialized Hazardous & Emerging Substance Courses

Engagement and Diversity

- ✓ Multidisciplinary Training
- ✓ Engage Diverse Population & Leadership Skills

COLLABORATIONS

UC Irvine & California State U

- ✓ Nanomaterial exposure assessment
- ✓ Electronic product and waste assessment.
- ✓ Health effect and toxicity.
- ✓ Virtual reality technology (VRT)

OUTCOMES

- ✓ 46 students and industry professionals are trained across courses and curricula
- ✓ One new courses developed:
  Nanomaterial Related Emerging Technologies: Exposure and Health Effects

	Doctoral trainees	Master trainees	Undergraduate students	IH professional	New Course	URM
2021-2022	1	4	5	N/A	N/A	50%
2022-2023	2	5	4	2	12	75%
2023-2024	1-2	4	5	TBD	6	
2024-2025	3	TBD	TBD	TBD	N/A	

Survey prior to participating in the program/workshop

	Not knowledgeable at all		Slightly knowledgeable		Somewhat knowledgeable		Very knowledgeable		Extremely knowledgeable	
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %
Nanotechnology's role in today's workplace	4	50%	2	25%	1	13%	1	13%	0	0%
Basic aerosol science principles and the potential health effects relevant to nanoparticles	2	25%	3	38%	2	25%	1	13%	0	0%
Basic workplace evaluation for nanotechnology hazards	4	50%	2	25%	1	13%	1	13%	0	0%
The hierarchy of controls, including engineering controls and PPE, to nanoparticle exposure scenarios	3	38%	0	0%	4	50%	1	13%	0	0%
Health effects of occupational exposure caused by nanomaterial and nanotechnology-enabled products	4	50%	1	13%	2	25%	1	13%	0	0%
In-vitro bioassays response caused by metal oxide nanomaterials used in electronic products	6	75%	1	13%	1	13%	0	0%	0	0%
Regulatory enforcement of occupational and environmental exposure	1	13%	1	13%	4	50%	2	25%	0	0%
The theoretical frameworks underpinning the attribution of materials used in electronics manufacturing to the burden of diseases, policy environment, and solutions including green chemistry and LCA	4	50%	2	25%	2	25%	0	0%	0	0%
Exposure risks to e-waste	2	25%	1	13%	5	63%	0	0%	0	0%

Survey **after** participating in the program/workshop

	Not knowledgeable at all		Slightly knowledgeable		Somewhat knowledgeable		Very knowledgeable		Extremely knowledgeable	
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %
Nanotechnology's role in today's workplace	0	0%	0	0%	2	25%	4	50%	2	25%
Basic aerosol science principles and the potential health effects relevant to nanoparticles	0	0%	0	0%	2	25%	4	50%	2	25%
Basic workplace evaluation for nanotechnology hazards	0	0%	0	0%	3	38%	3	38%	2	25%
The hierarchy of controls, including engineering controls and PPE, to nanoparticle exposure scenarios	0	0%	2	25%	1	13%	3	38%	2	25%
Health effects of occupational exposure caused by nanomaterial and nanotechnology-enabled products	0	0%	0	0%	2	25%	3	38%	3	38%
In-vitro bioassays response caused by metal oxide nanomaterials used in electronic products	0	0%	2	25%	2	25%	2	25%	2	25%
Regulatory enforcement of occupational and environmental exposure	0	0%	0	0%	3	38%	3	38%	2	25%
The theoretical frameworks underpinning the attribution of materials used in electronics manufacturing to the burden of diseases, policy environment, and solutions including green chemistry and LCA	0	0%	1	13%	4	50%	1	13%	2	25%
Exposure risks to e-waste	0	0%	0	0%	2	25%	4	50%	2	25%

OUTCOMES

4 Publications and 9 Conference Presentations in 3 years

- ✓ Journal of Cleaner Production IF: 11.07
- ✓ BMC Public Health IF: 4.54
- ✓ ACS Chemical Health and Safety IF: 3.1
- ✓ Journal of The Minerals, Metals & Materials Society IF 2.47

- ✓ American Industrial Hygiene Conference and Exposition (AIHCE)
- ✓ Sustainable Nanotechnology Organization (SNO) annual conference
- ✓ Inhaled Particle and NanoOEH Conference (International Conference)
- ✓ Annual Green Chemistry & Engineering Conference
- ✓ SETAC North America 43rd Annual Meeting

OUTCOMES- Publications

1. Swinnerton, S., Kurtz, K., Neba Nforsoh, S., Craver, V., and Tsai, C., The manufacturing process and consequent occupational health and environmental risks associated with the use of plastic waste in construction bricks in small-scale recycling plants, J Cleaner Production, 2024, revised under review
2. Landskroner, E.A., Tsai, C.S.J.* Occupational exposures and cancer risk in commercial laundry and dry cleaning industries: a scoping review. BMC Public Health. 2023 Dec 21; 23(1):2561. doi: 10.1186/s12889-023-17306-y. PMID: 38129859; PMCID: PMC10740271
3. Munoz, A., Schmidt, J., Suffet, M., Tsai, C.S.J.*, Characterization of emissions from carbon dioxide laser cutting acrylic plastics, ACS Chemical Health and Safety, June 22, 2023
4. Ibrahim, M.G., He, H., Schoenung, J.M., Ogunseitan, O.A. 2023. Challenges and Opportunities of Increasing Materials Circularity: A Focus on Critical Metal Recovery from Electronic Waste. JOM.

OUTCOMES- Conference Presentations

1. Swinnerton, S., Tsai, CSJ., Emissions associated with the mechanical recycling of plastic waste via shredding, American Industrial Hygiene Conference and Exposition (AIHCE), Columbus, Ohio, May 20-22, 2024.
2. Krause, C., Tsai, CSJ, Emission Comparison Between SLS 3D Printer Operations, 12th Sustainable Nanotechnology Organization (SNO) annual conference, Los Angeles, CA, Nov. 10-12, 2023.
3. Landskroner, E., Cacho, J., Tsai, CSJ, TiO2 Nanoparticles in Automotive Paints and Ceramic Coatings: A Literature Review, 12th Sustainable Nanotechnology Organization (SNO) annual conference, Los Angeles, CA, Nov. 10-12, 2023.
4. Swinnerton, S., Kurtz, K., Nforsoh, S.N., Vinka, C., Tsai, CSJ, The Use of Plastic Waste in Construction Bricks: Emissions Associated with Plastic Shredding, 12th Sustainable Nanotechnology Organization (SNO) annual conference, Los Angeles, CA, Nov. 10-12, 2023.
5. Krause, C., Tsai, CSJ*, 3D printer nylon-12 emissions analysis, American Industrial Hygiene Conference and Exposition (AIHCE), Phoenix, AZ, May 22-24, 2023
6. Tsai, CSJ.*, Munoz, A., Schmidt, J., Suffet, M., Fugitive Emissions from Carbon Dioxide Laser Cutting Activities, Inhaled Particle and NanoOEH Conference, Manchester, England, May 15-18. 2023
7. Munoz, A., Tsai, C.S.J.*, Characterization of fugitive emissions produced from compact laser cutting, podium, American Industrial Hygiene Conference and Exposition (AIHCE), Nashville, Tennessee, May 23-25, 2022.
8. Ibrahim, M. G., Schwartz, E., He, H., Lincoln, J., Nguyen, B., Strauss, K., Ogunseitan, O., & Schoenung, J. (2022, June 6-8). Green Electronics Standards: Gaps, Challenges, and Opportunities for Enhancing the Circular Economy of Printed Wiring Boards. 26th Annual Green Chemistry & Engineering Conference, Reston, VA
9. Ibrahim, M. G., Schoenung, J., & Ogunseitan, O. (2022, November 13-17). A Systems-Toxicology Perspective of Critical Metals Recovery From Waste Printed Circuit Boards: Opportunities, Risks, and Barriers for a Circular Supply Chain. SETAC North America 43rd Annual Meeting, Pittsburgh, PA

RESEARCH HIGHLIGHTS – Electronic Wastes

Navigating Sustainable Resource Recovery from E-Waste through Cryogenic Milling

Maryam Gamal Ibrahim, PhD student, UCI

BOARD MATERIALS → **WPCB** ← **ELECTRONIC COMPONENTS**

Waste Printed Circuit Boards

→ **Epoxy Resin (Polymer)**
(Epichlorohydrin and Bisphenol-A)

→ **Halogenated Organic Compounds**
Tetrabromobisphenol (TBBPA)
Polybrominated bi/di phenyls (PBB/PBDEs)
Polyfluro-alkylated Substances (PFAS)

→ **Reinforcement**
Electronic-grade fiberglass (SiO_2)

→ **Copper Foil**

→ **Solder Alloy**
Sn > Ag > Cu > Bi

→ **Integrated Circuits**
→ **Transistors**
→ **Capacitors**
→ **Resistors**
→ **Switches**
→ **Inductors**

Precious Metals:
Au, Ag, Pt, Pd, Ru

Special Metals:
Co, Ta, Ga, Li, Ni

Rare Earth Elements:
Nd, Dy, Pr, Y

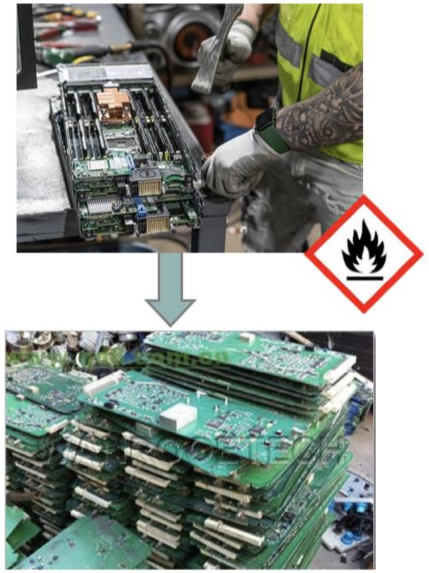
Heavy Metals:
Pb*, Cd, Hg, Cr(VI)), As

WPCB Materials:
~ 40% metals
~ 30% plastics
~ 30% ceramics

Layered and fused materials in WPCBs pose challenges in separation and are incompatible with current recycling methods.

Current Challenges in Critical Metals Recovery from E-waste

(1) **Manual sorting:**
WPCBs removed from devices.



(2) **Mechanical processing:**
Shredding, grinding, or milling reduces WPCBs into particles.

(3) **Physical separation:**
Gravity/magnetic/electrostatic methods separate metals & nonmetals.

(4) **Metal extraction:**
Pyrometallurgy (high-temperature smelting) and hydrometallurgy (chemical leaching)

High amounts of fugitive dust → 30% reduction in the volume of WPCB materials

- **Green House Gasses:** CO_2, CH_3 SO_2, CO, H_2
- **POPs:** Mixed dioxins and furans
- **VOCs:** Phenol, benzene, toluene, xylene

- **Metal Oxides:** Cu, Zn, As, Pb, Al
  → Majority of critical metals are lost as particulates or oxidized in slag/sludge.

Toxic waste generation ↑
Energy consumption ↑
Operating costs ↑
Resource Recovery ↓

✕ **NOT SUSTAINABLE**

The Cryogenic Milling Process for E-waste Recycling

Preliminary data support **Cryogenic Milling** as an environmentally benign alternative to the existing e-waste recycling methods.

(1) **Milling Conditions:** Feed materials are submerged in liquid nitrogen (LN_2) at -150°C to promote cold embrittlement, crystallization, and early fracture.

(2) **Milling Intensity:** Two rotating shafts and circulating ball media agitate feed materials, exerting mechanical forces to achieve rapid grain refinement.

Cryogenic Parameters:

- LN_2 BP: -195.8°C (1:696)
- LN_2 flow rate (L/min)
- Cooling Rate (°C/min)

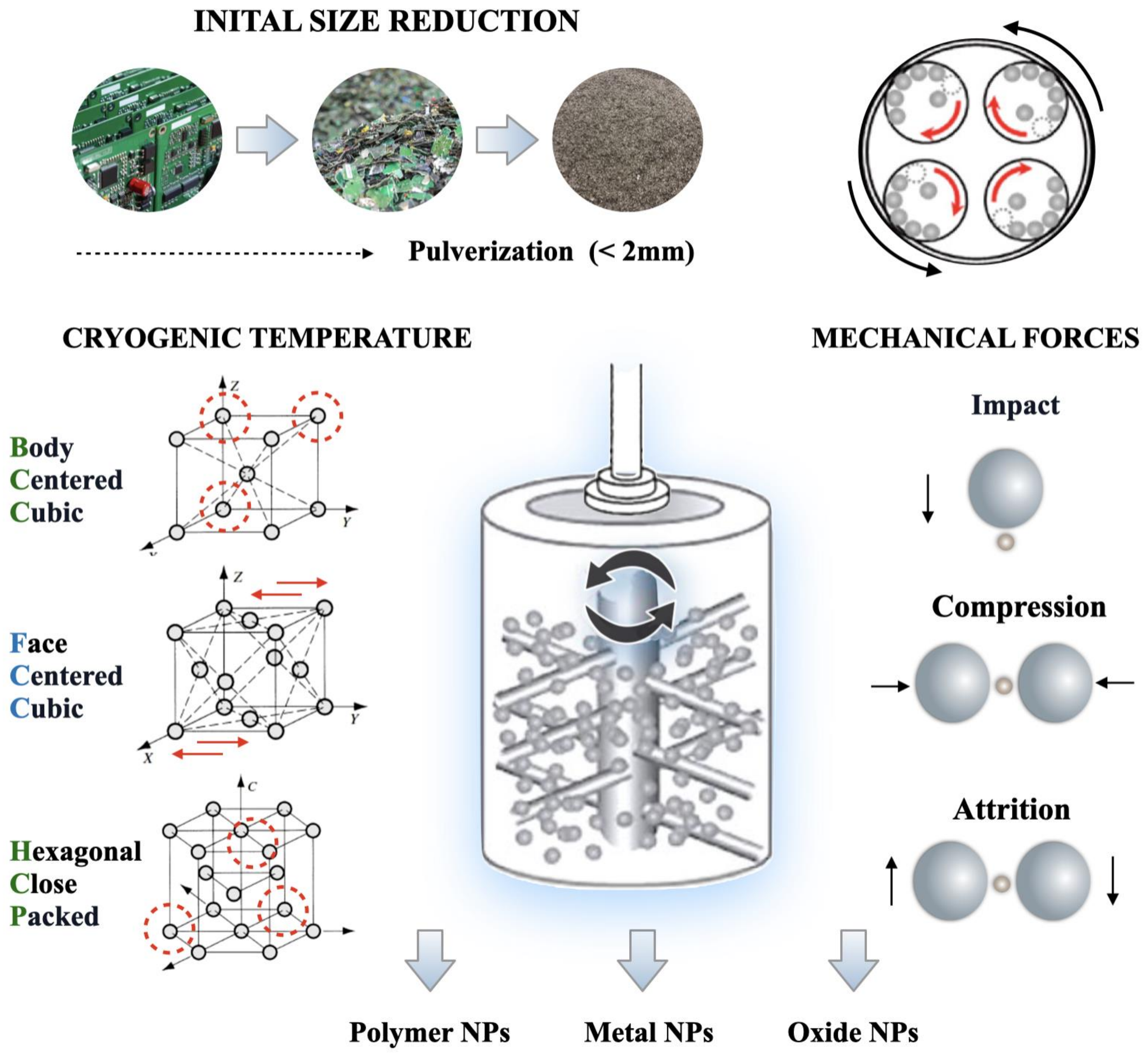
Milling Parameters:

- Ball:powder (BPR)
- Milling time (hrs)
- Milling speed (r/min)

Output: Uniform dispersion of single-phase metal, polymer, and oxide nanoparticles with an even size distribution.

Easy separation of nanoparticles via sedimentation in DI water

→ Hydroclone separators can be utilized on an industrial scale



Anticipated Outcomes and Broader Implications

Scaling up Cryogenic Milling can overcome technological, economic, and environmental barriers in e-waste recycling

(1) Reduced Environmental Hazards

→ Eliminates hazardous emissions associated with the thermal and chemical degradation of e-waste materials

→ The consolidation of particles within a tightly closed system reduces the risk of contamination from fugitive dust.

(2) Enhanced Industrial Feasibility:

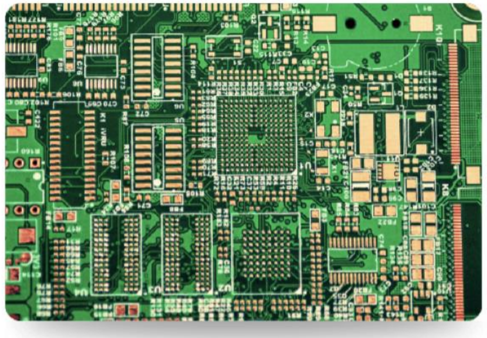
→ Stand-alone process and does not require multiple processing phases and steps

→ Manual removal of hazardous components not necessary

→ Shorter milling times reduces energy consumption

(3) Maximum Recovery Efficiency

→ The production of cryomilled nanoparticles enhances the structural and functional properties of e-waste materials and **recovers nearly all recyclable elements.**

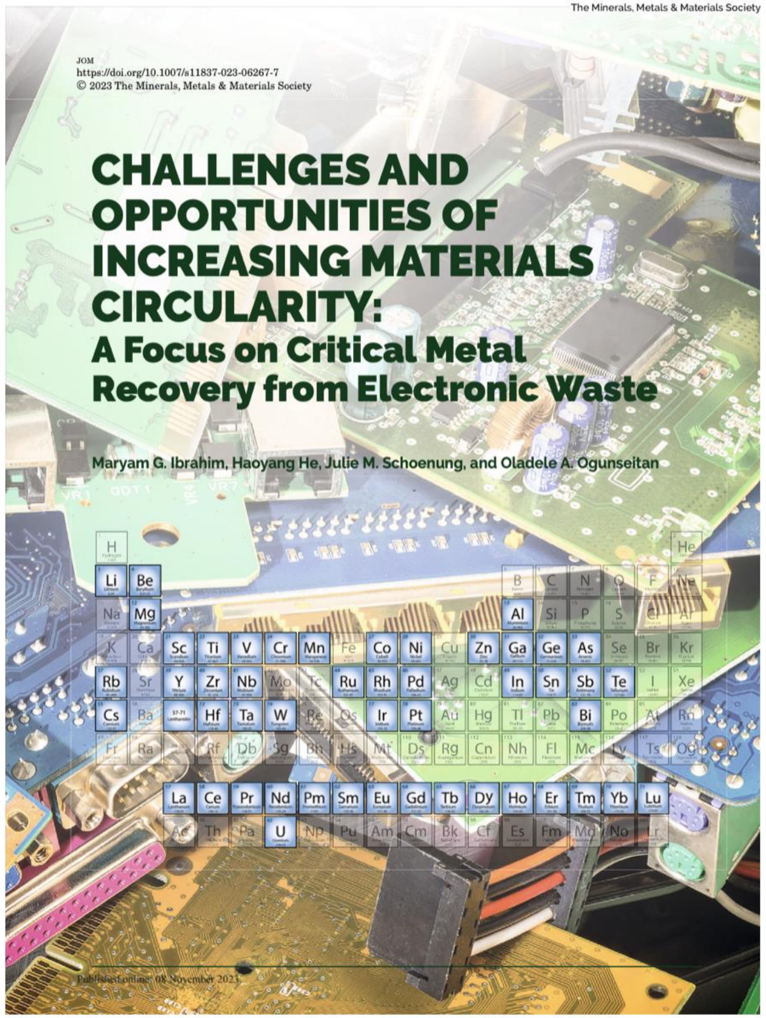


WPCBs contain **100 times more gold** and **10-40 times more critical metals** per ton than mined ore (net value $62.5 billion/yr)

The U.S. Department of Energy prioritizes research and development in urban mining technologies, particularly e-waste recycling, to secure the future of domestic critical metals supply chains.

JOM: The Magazine

TMS
The Minerals, Metals & Materials Society



Published November 8th, 2023

Acknowledgments

UCI Population Health and Disease Prevention

UCI Samueli School of Engineering | Department of Materials Science and Engineering

UCLA Fielding School of Public Health

Dr. Oladadele Oguneitan
Distinguished Professor and Presidential Chair

Dr. Julie Schoenung
Distinguished Professor and Presidential Chair

Dr. Haoyang He
Postdoctorate Scholar

Dr. Candace Tsai
Associate Professor and Certified Industrial Hygienist (CIH)

WISDOM World Institute for Sustainable Development of Materials

NIH National Institute of Environmental Health Sciences *Superfund Research Program*

Yourtronics REPAIR

calnano Materializing Nano

Union Process

INRF Integrated Nanosystems Research Facility

RESEARCH HIGHLIGHTS – Emerging Green Solvents

Assessing Emerging Green Solvents in the Dry Cleaning Industry

Emma Landskroner, PhD student, UCLA

Background Identification of Gap: BMC Public Health Publication

- 12 total articles
- 33% assessing health effects via clinical symptoms or biomarker exposure
- 66% examining PCE
- None of which on "green" alternatives

Absence of modern research on "green" solvents

Landskroner and Tsai *BMC Public Health* (2023) 23:2561
https://doi.org/10.1186/s12889-023-17306-y

BMC Public Health

RESEARCH Open Access

Occupational exposures and cancer risk in commercial laundry and dry cleaning industries: a scoping review

Emma Ann Landskroner[1] and Candace Su-Jung Tsai[1*]

Abstract

Background The laundry and dry cleaning industries are critical for maintaining cleanliness and hygiene in our daily lives. However, they have also been identified as sources of hazardous chemical exposure for workers, leading to potentially severe health implications. Despite mounting evidence that solvents like perchloroethylene and trichloroethylene are carcinogenic, they remain commonly used in the industry. Additionally, while alternative solvents are increasingly being utilized in response to indications of adverse health and environmental effects, there remains a significant gap in our understanding of the potential risks associated with exposure to these new agents.

Methods This study aims to identify gaps in the literature concerning worker exposure to contemporary toxic chemicals in the laundry and dry cleaning industry and their associated carcinogenic risks. A scoping review of peer-reviewed publications from 2012 to 2022 was conducted to achieve this objective, focusing on studies that detailed chemical exposures, sampling methods, and workers within the laundry and dry cleaning sector.

Results In this scoping review, 12 relevant papers were assessed. A majority (66%) examined perchloroethylene exposure, with one notable finding revealing that biomarkers from dry cleaners had significant micronuclei frequency and DNA damage, even when exposed to PCE at levels below occupational exposure limits. Similarly, another study supported these results, finding an increase in early DNA damage among exposed workers. Separate studies on TCE and benzene presented varied exposure levels and health risks, raising concern due to their IARC Group 1 carcinogen classification. Information on alternative solvents was limited, highlighting gaps in health outcome data, exposure guidelines, and carcinogenic classifications.

Conclusion Research on health outcomes, spec
limited, with 66% of studies not monitoring heal
indicated potential DNA damage from perchloro
need to reevaluate safety limits. As alternative so
prevalent, investigations into the effects of their
review is registered with the Open Science Fram

BMC Part of Springer Nature

BMC Public Health

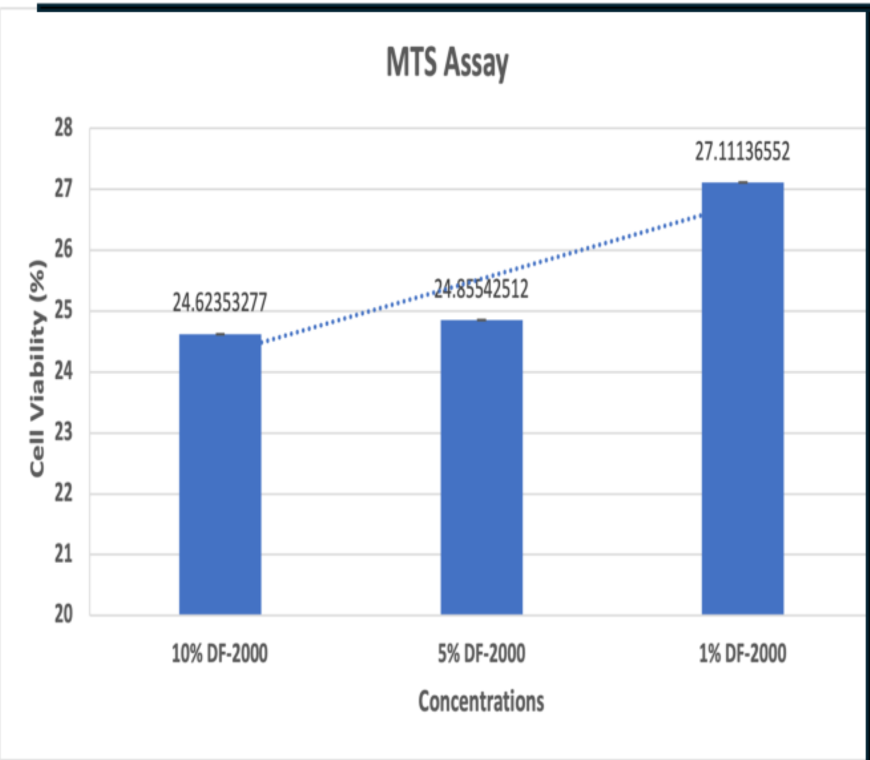
BMC Public Health. (2023) https://bmcpublichealth.biomedcentral.com/submission-guidelines/preparing-your-manuscript/.

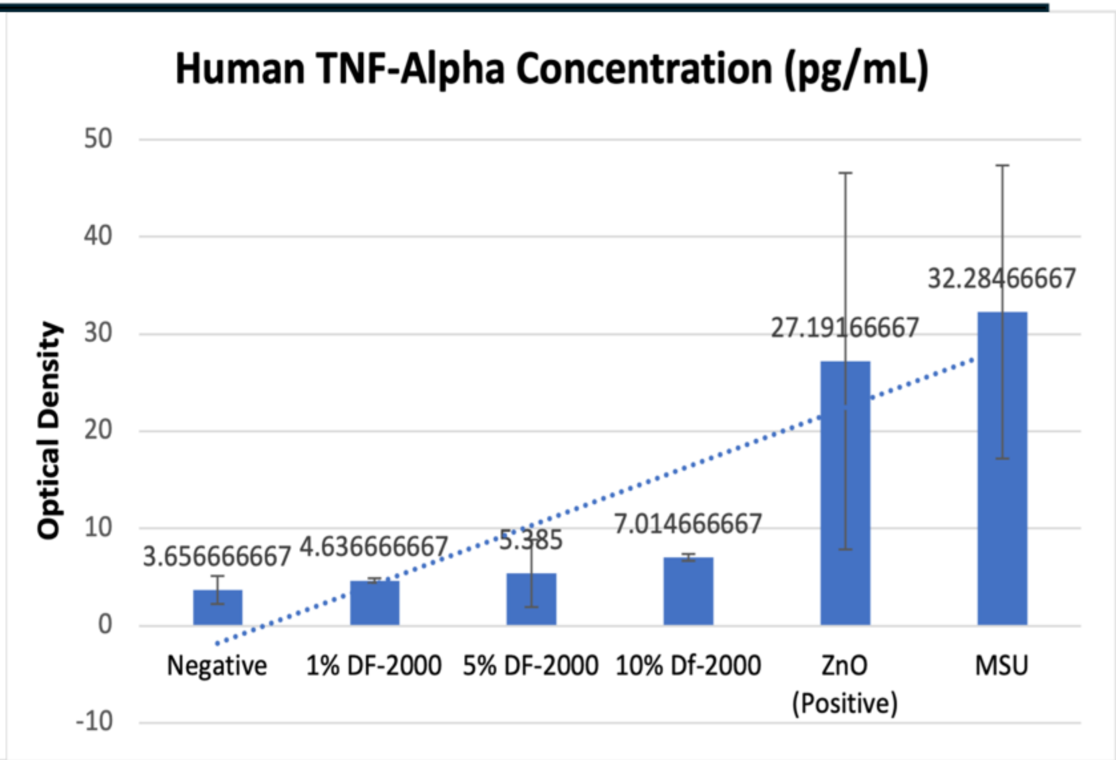
BEAS-2B Cell Study on Popular Emerging Green Solvent

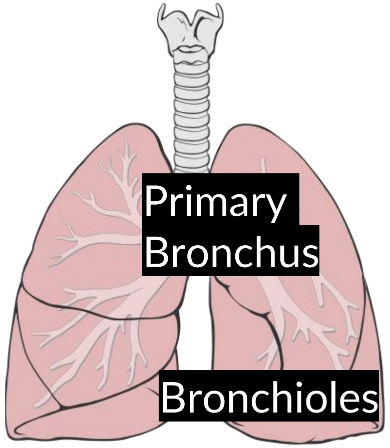
Preliminary Results

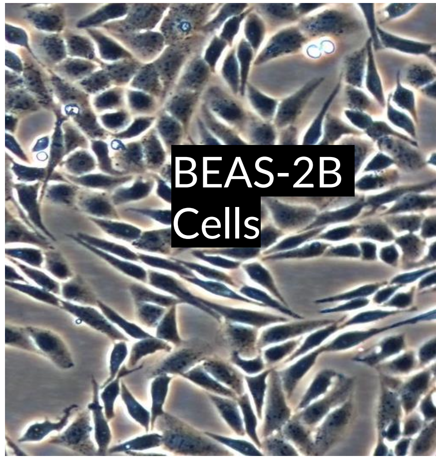
- MTS: :Suggested effects at low concentrations
- TNF-Alpha: Dose-dependent increase, with both controls validated

Indication of greater toxicity than what has been marketed and potential carcinogenicity





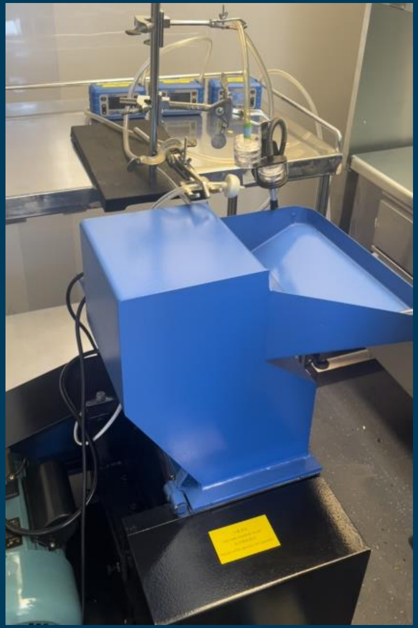




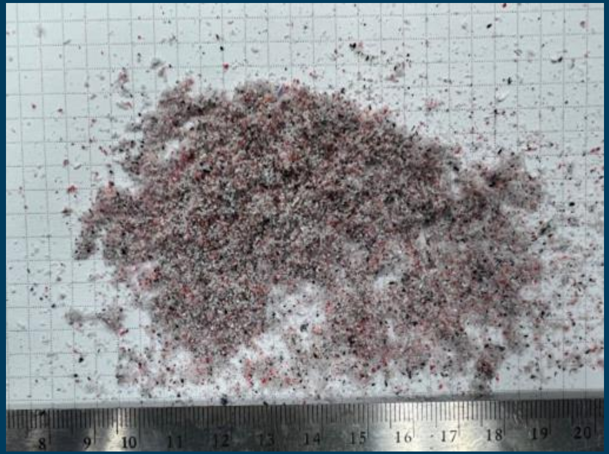
RESEARCH HIGHLIGHTS – Nanoplastics Exposure Assessment

The emissions and physicochemical properties of airborne microplastic and nanoplastic generated during plastic shredding
Sarah Swinnerton, MS student, UCLA

Cell toxicity study of micro and nanoplastics
Srinidhi (Serina) Sridharan, MS student, UCLA   Yi-hsuan (Amelia) Chen, UCLA

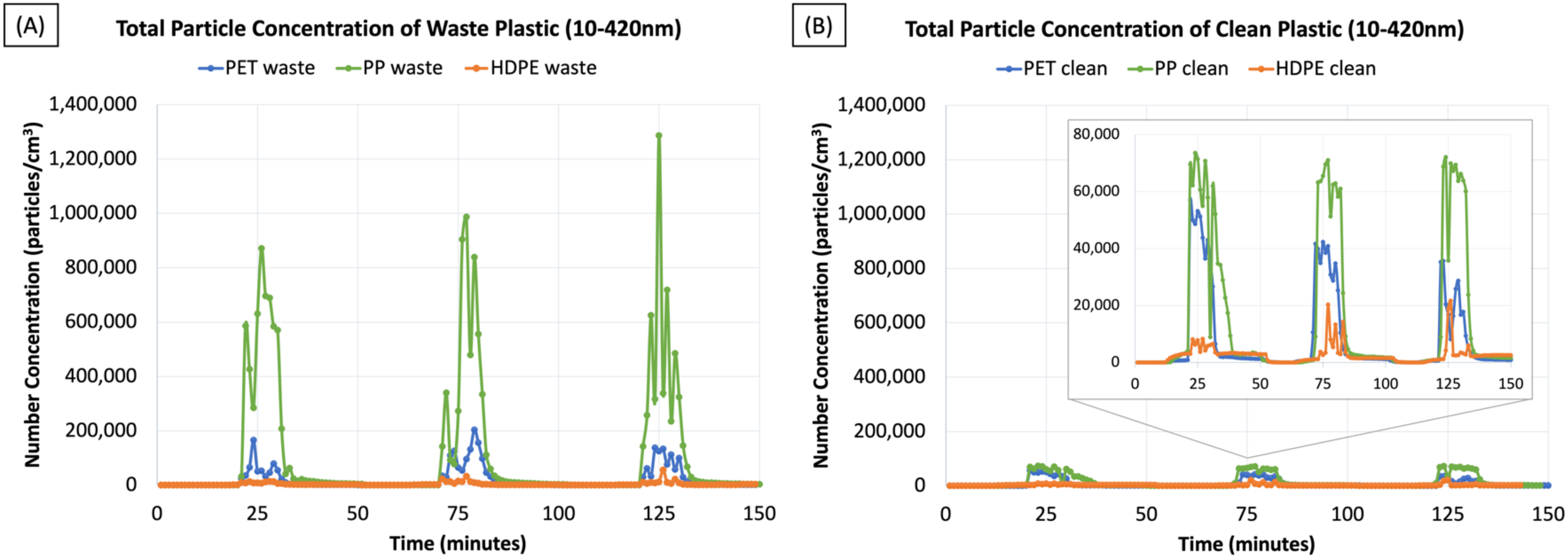


Microplastic particles of PET, PP, and HDPE are obtained by shredding waste plastics with INTBUYING 220V Heavy Duty Plastic Shredder Machine



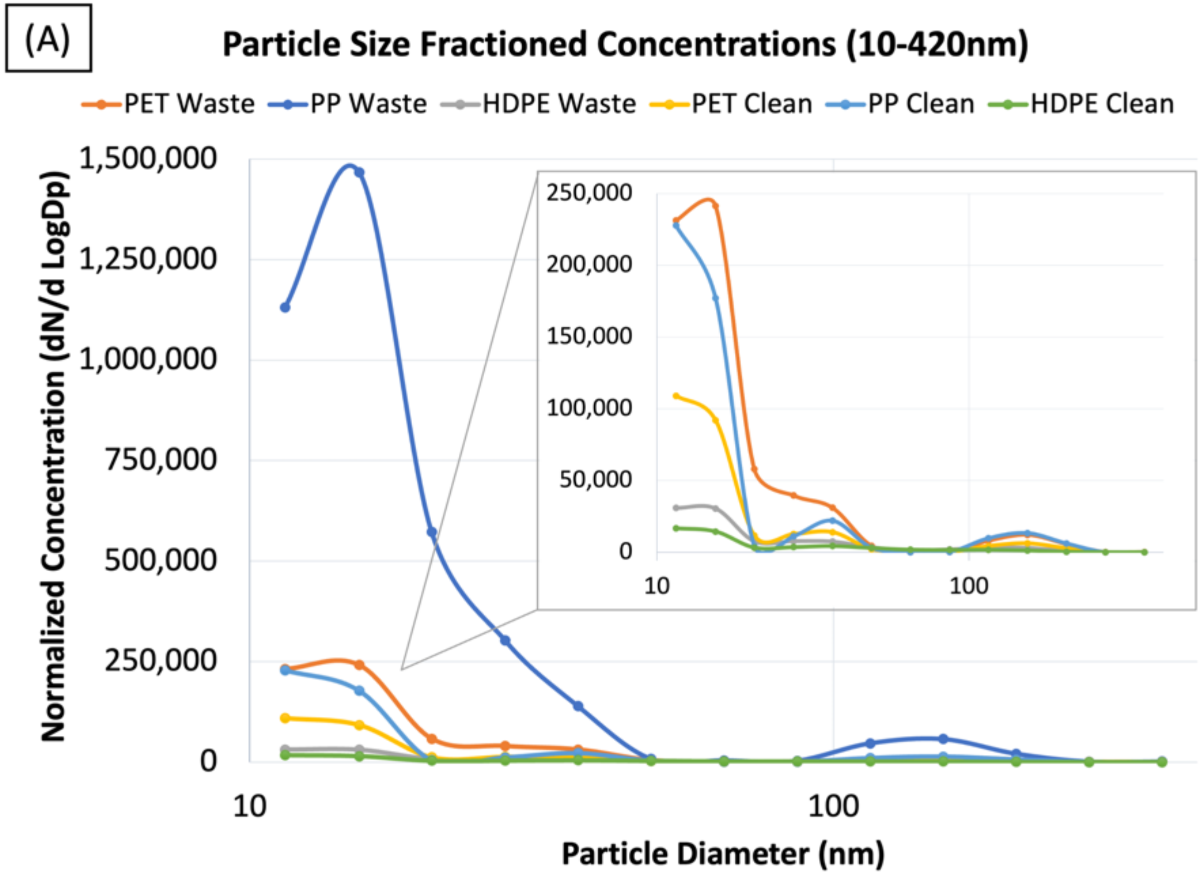
HDPE plastics before (top) and after being milled through a 0.50mm sieve ring (bottom). *(From Fritsch Milling & Sizing, Inc.)*

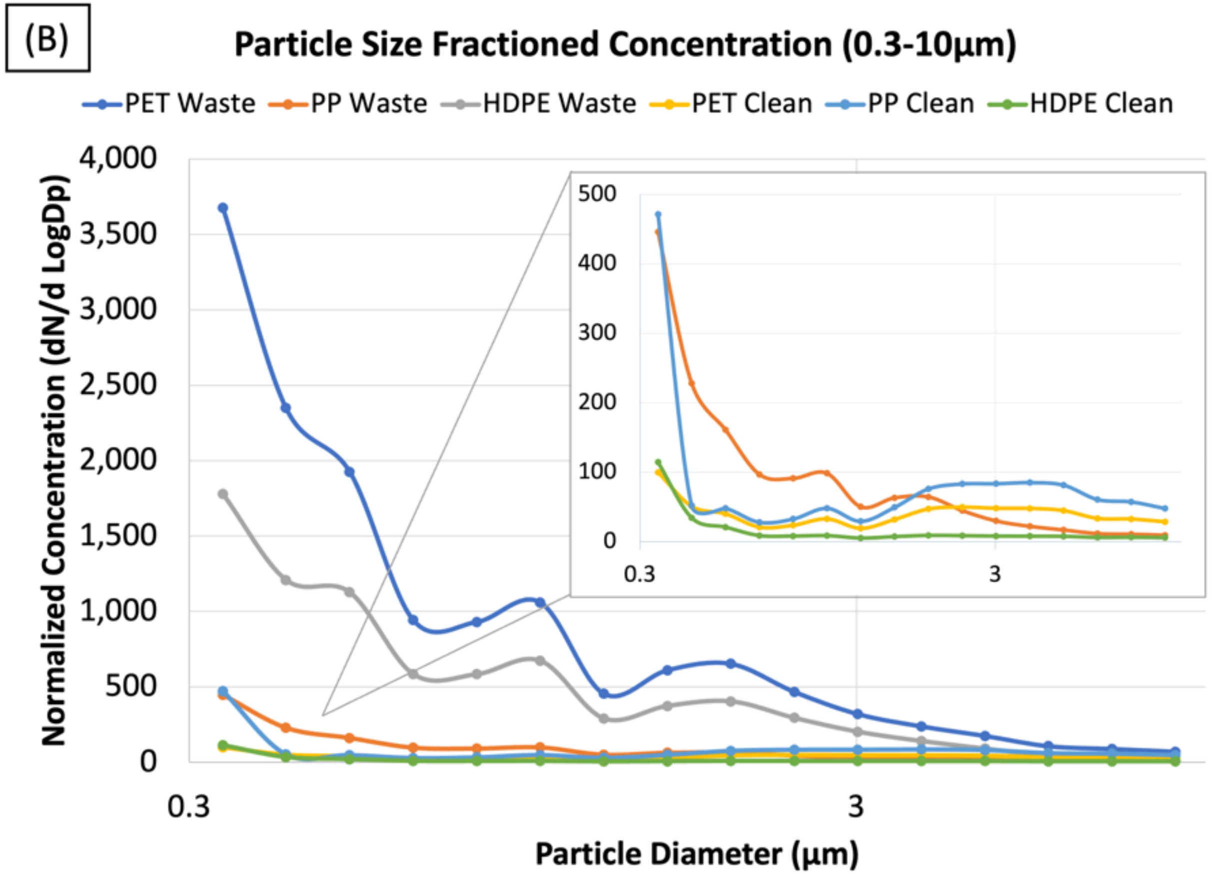
Total SMPS Particle Concentrations



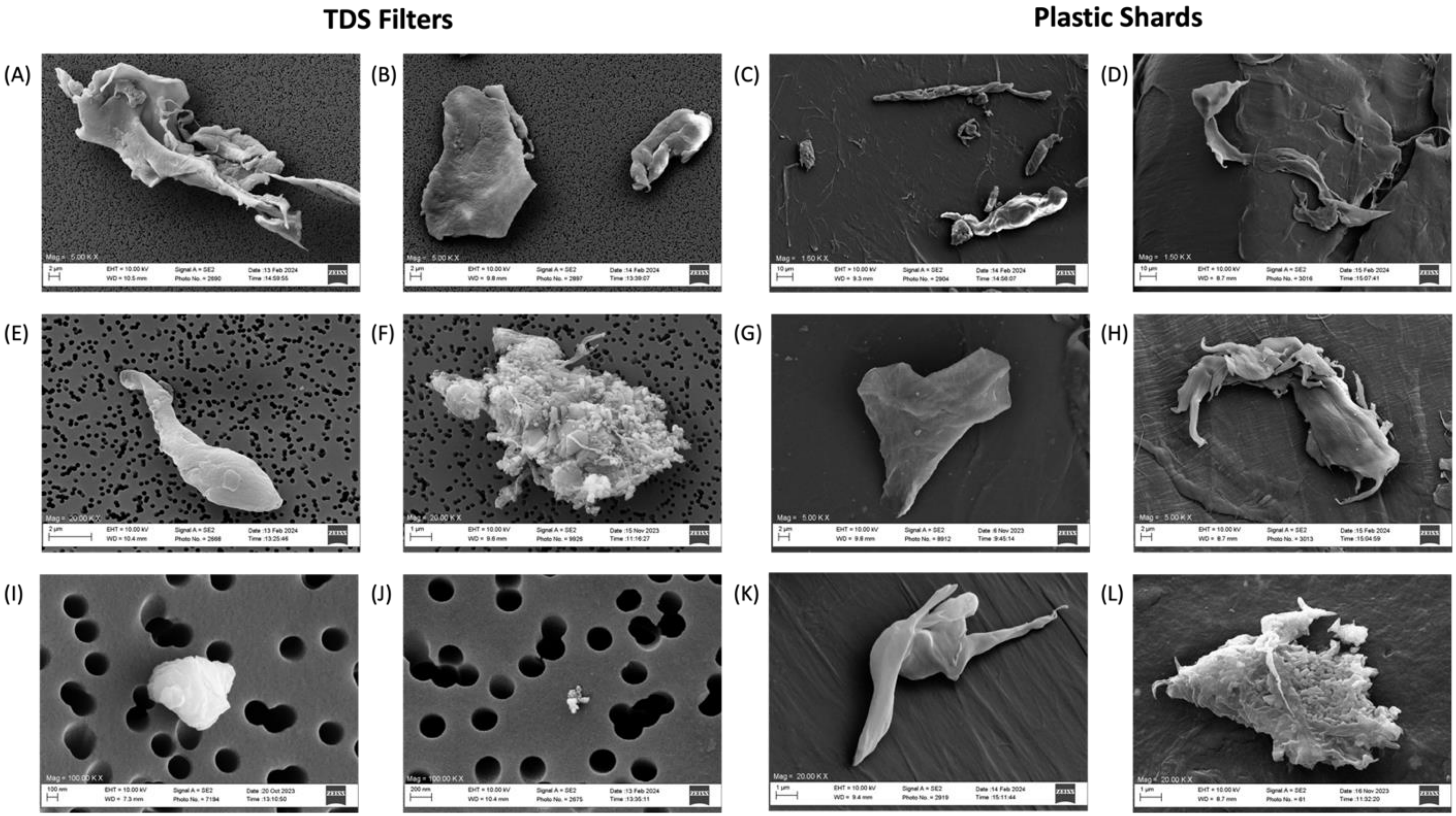
Substantial changes in particle concentration was observed during periods of shredding

Particle Size Differentiated Graphs



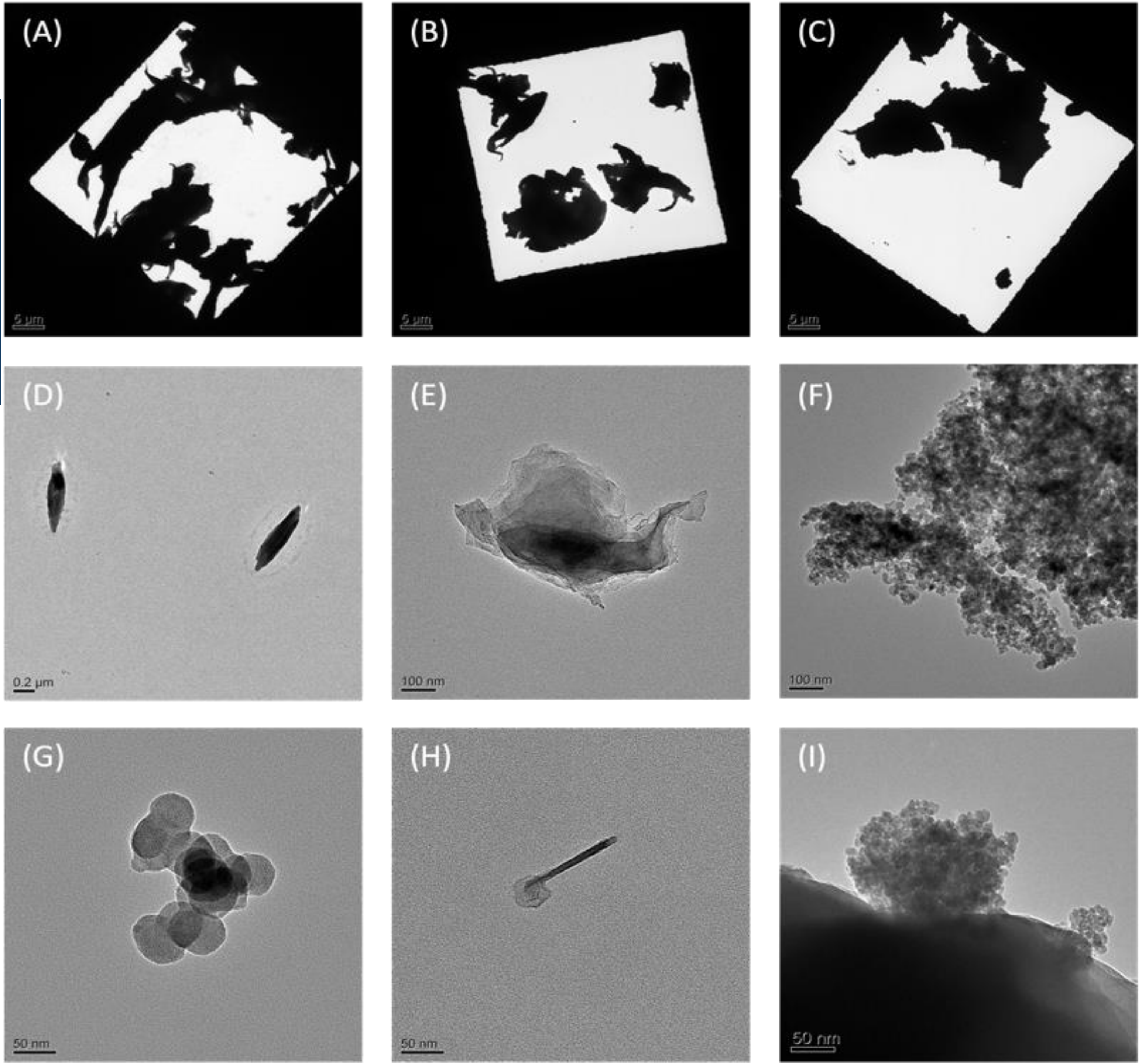


Particle Morphology by SEM

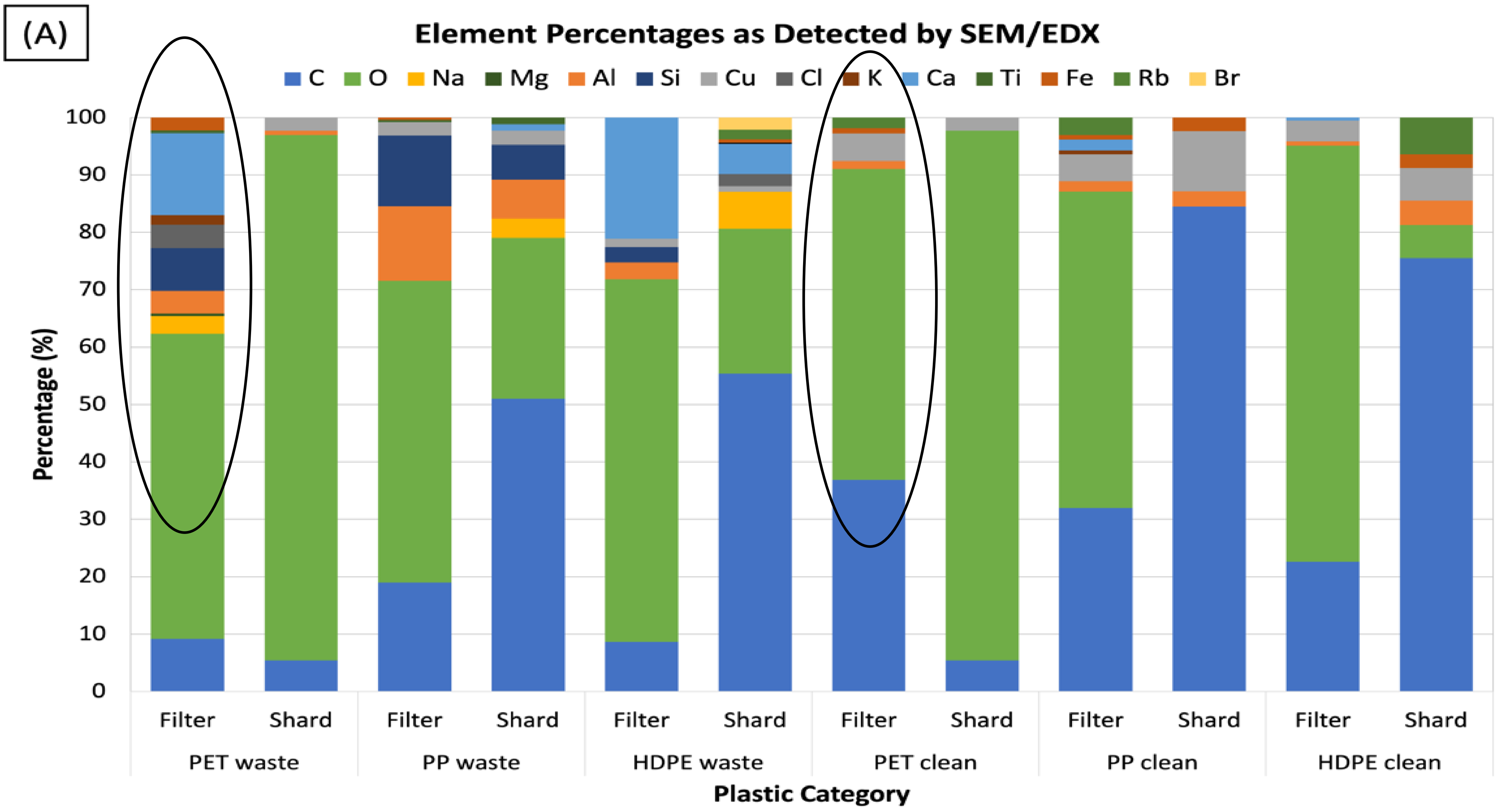


Particle Morphology by TEM

Particles varied drastically and did not adhere to one shape



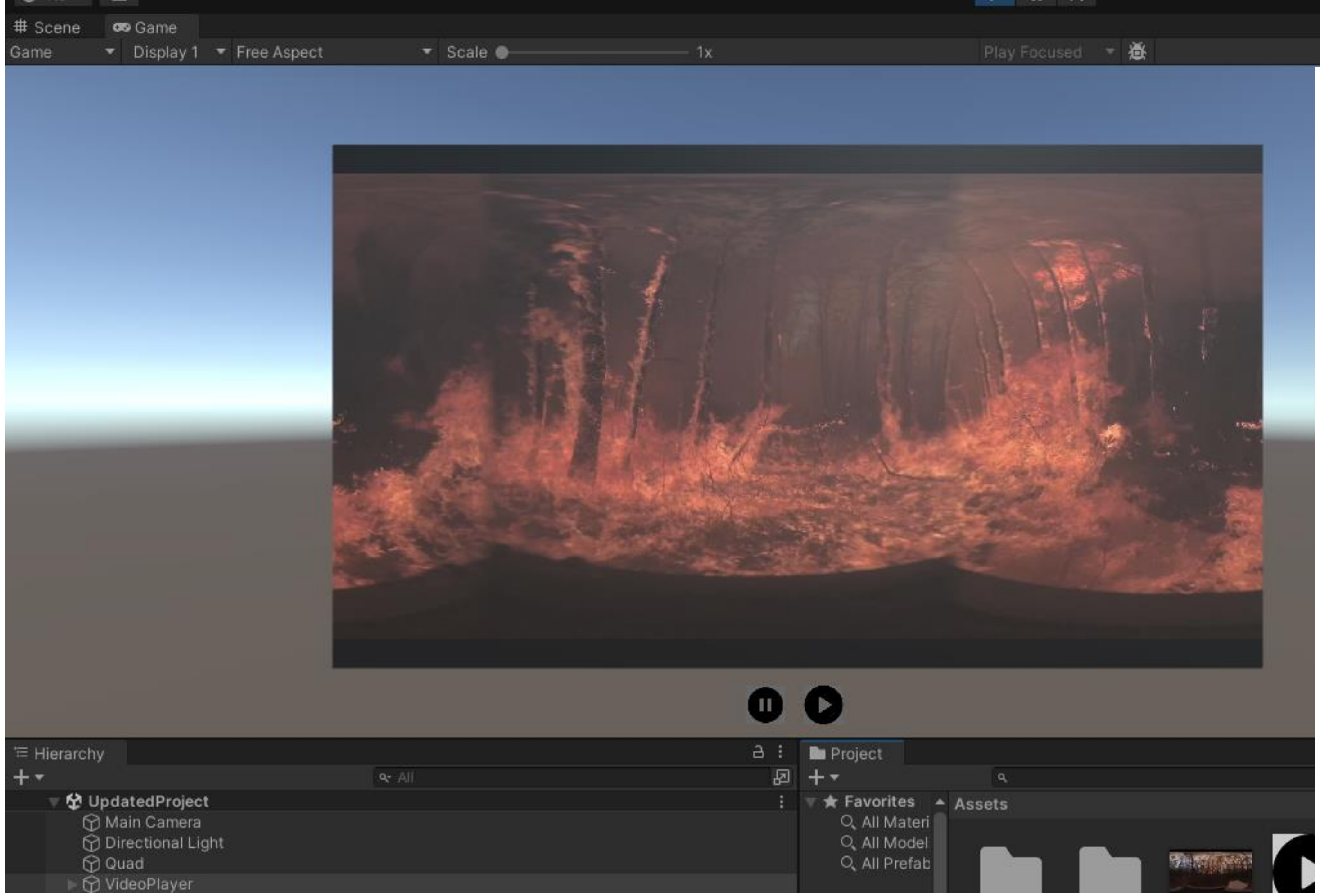
Elemental Composition of Samples

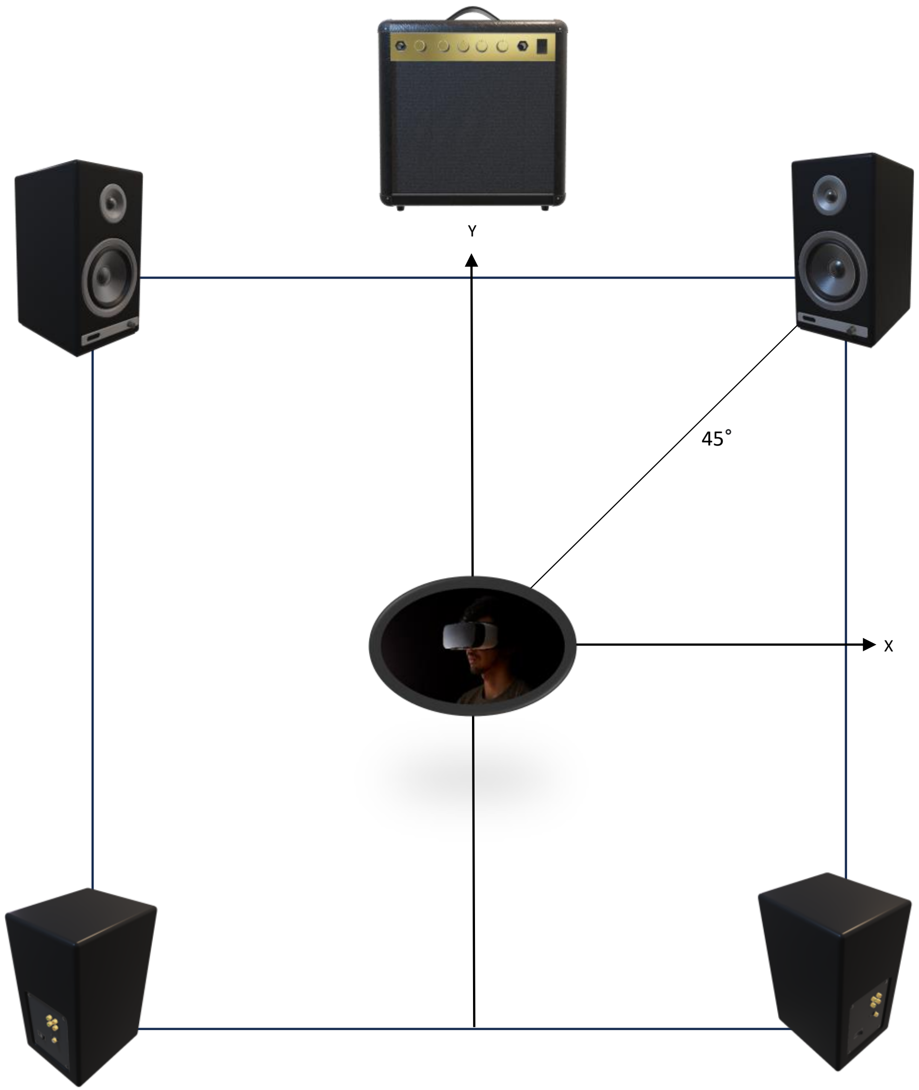


RESEARCH HIGHLIGHTS – Virtual Reality Technology and 3D printing

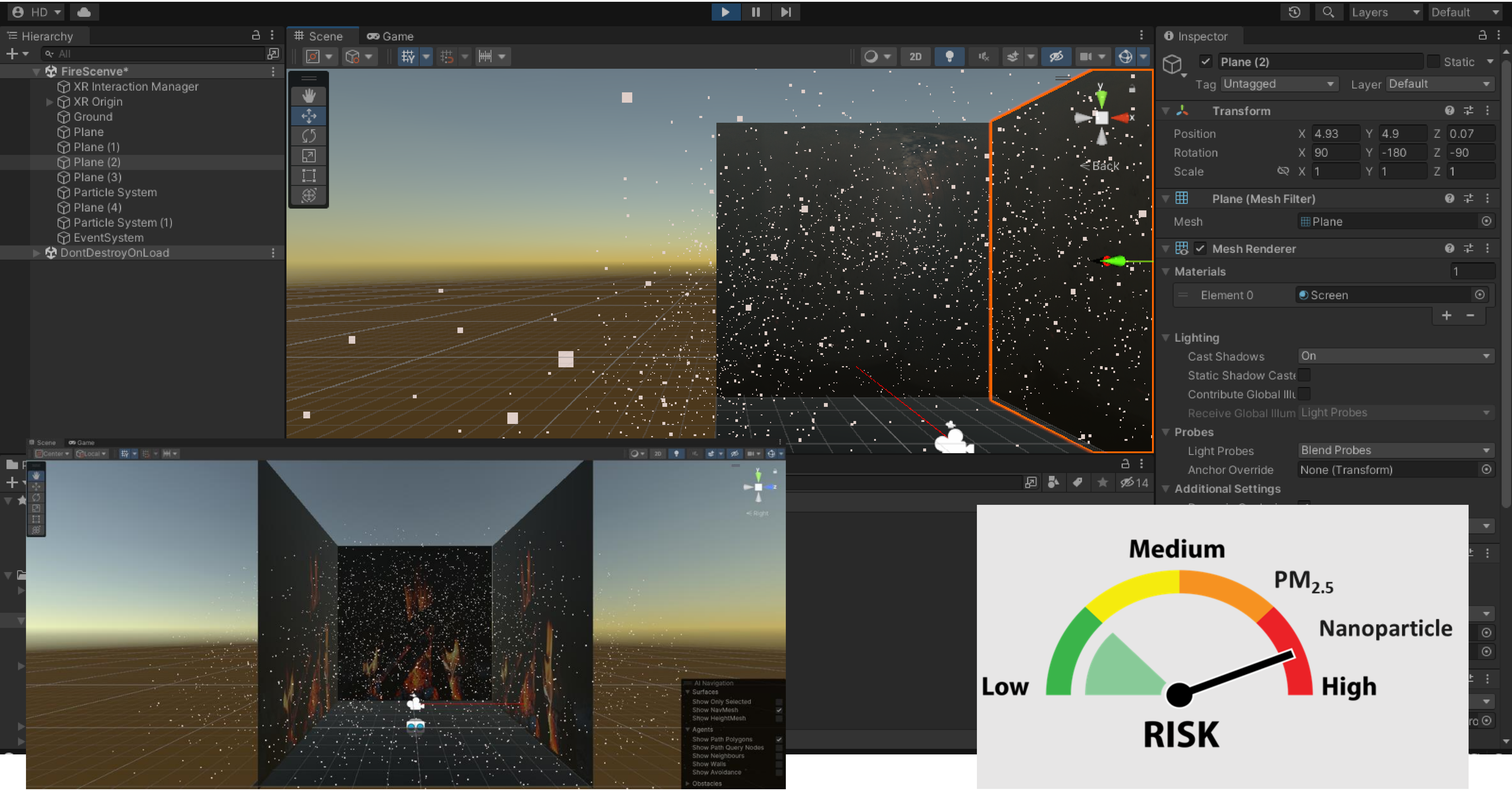
An Emerging VR Training Tool for Wildland Firefighters on Particle Pollution Exposure
Hope Davey, MS student, UCLA

Characterization of Fugitive Emissions of SLS 3D Printing
Connor Krause, MS student, UCLA



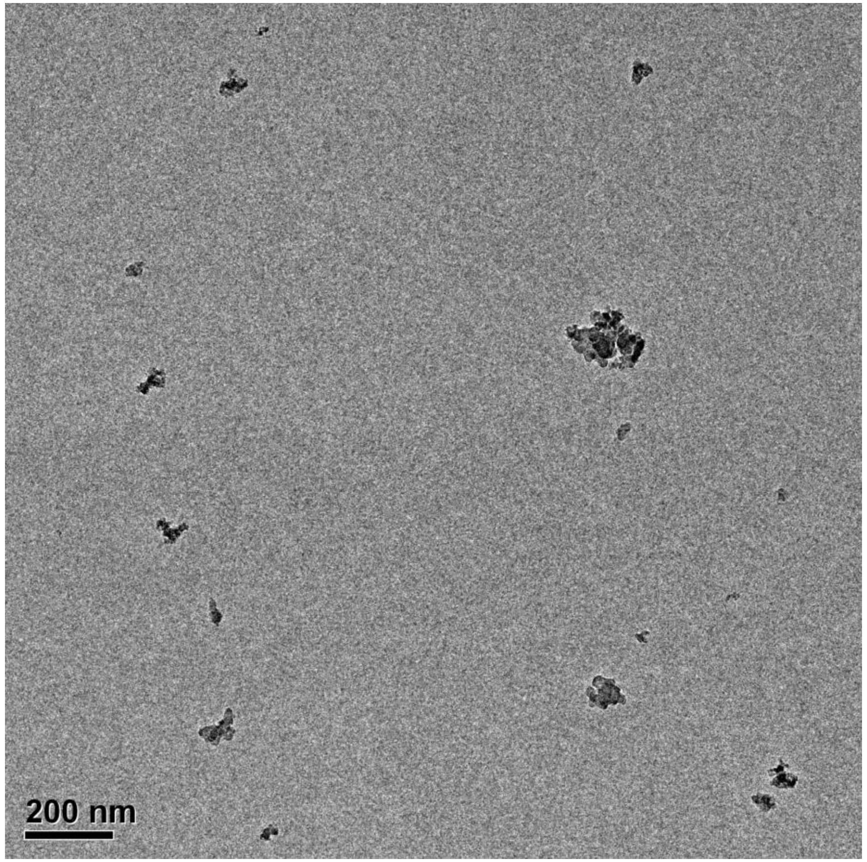


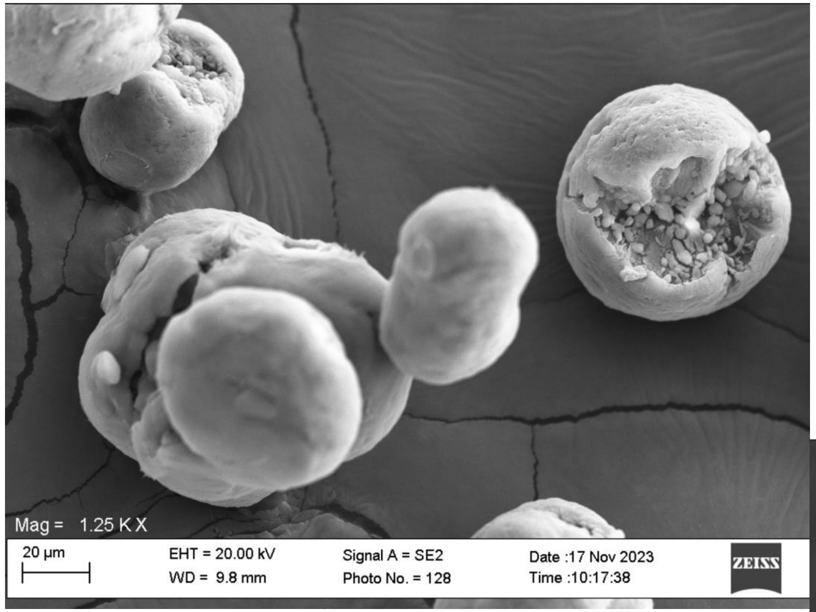
The synthetic audio was rendered for a 360° spatial sound and decoded in 4 channels. With 360-surround sound, the viewer can experience what is going on around them (considering X and Y axis).



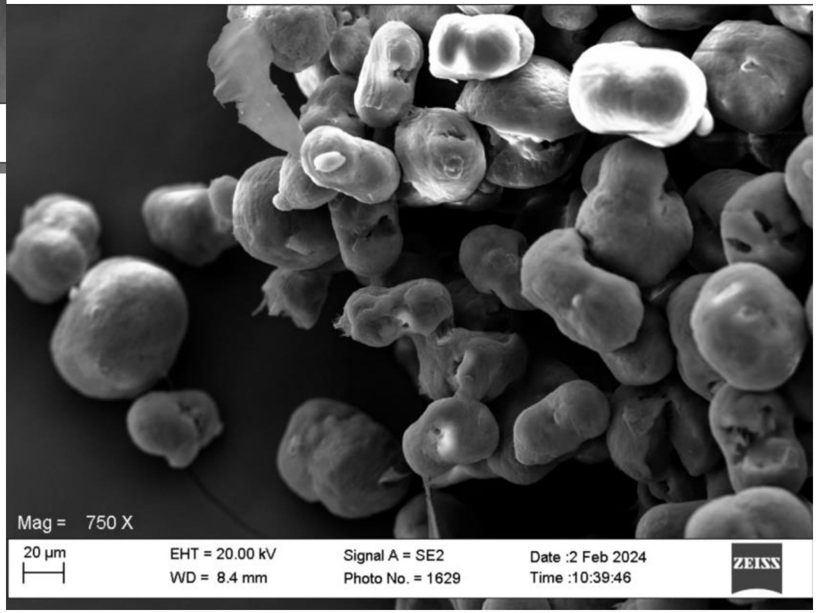
HD
Layers
Default
Hierarchy
FireScenve*
XR Interaction Manager
XR Origin
Ground
Plane
Plane (1)
Plane (2)
Plane (3)
Particle System
Plane (4)
Particle System (1)
EventSystem
DontDestroyOnLoad
Scene
Game
2D
Back
Inspector
Plane (2)
Static
Tag Untagged
Layer Default
Transform
Position X 4.93 Y 4.9 Z 0.07
Rotation X 90 Y -180 Z -90
Scale X 1 Y 1 Z 1
Plane (Mesh Filter)
Mesh Plane
Mesh Renderer
Materials 1
Element 0 Screen
Lighting
Cast Shadows On
Static Shadow Caste
Contribute Global Illu
Receive Global Illum Light Probes
Probes
Light Probes Blend Probes
Anchor Override None (Transform)
Additional Settings
Medium
PM2.5
Nanoparticle
Low
High
RISK

SEM/TEM Imaging of Pure Nylon-12 for 3D Printing

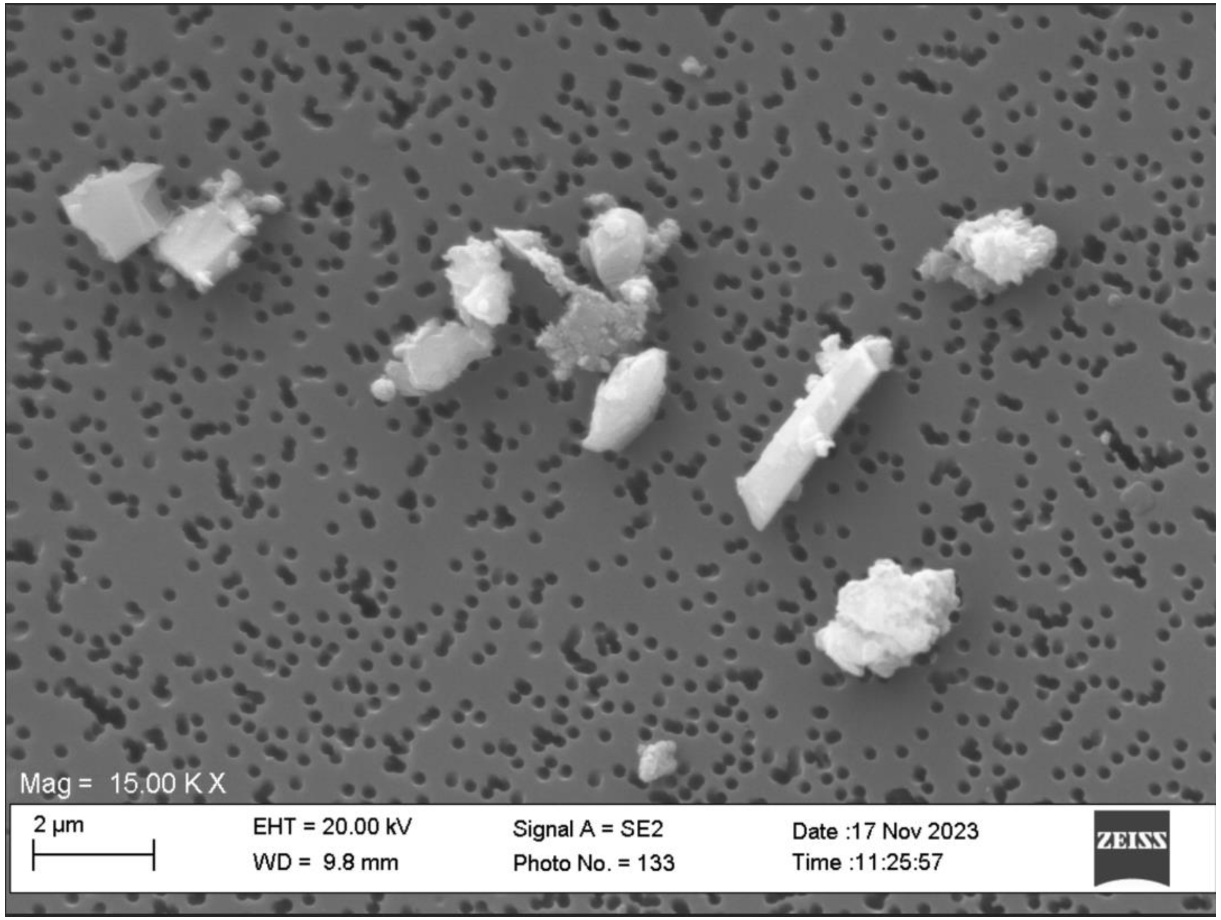


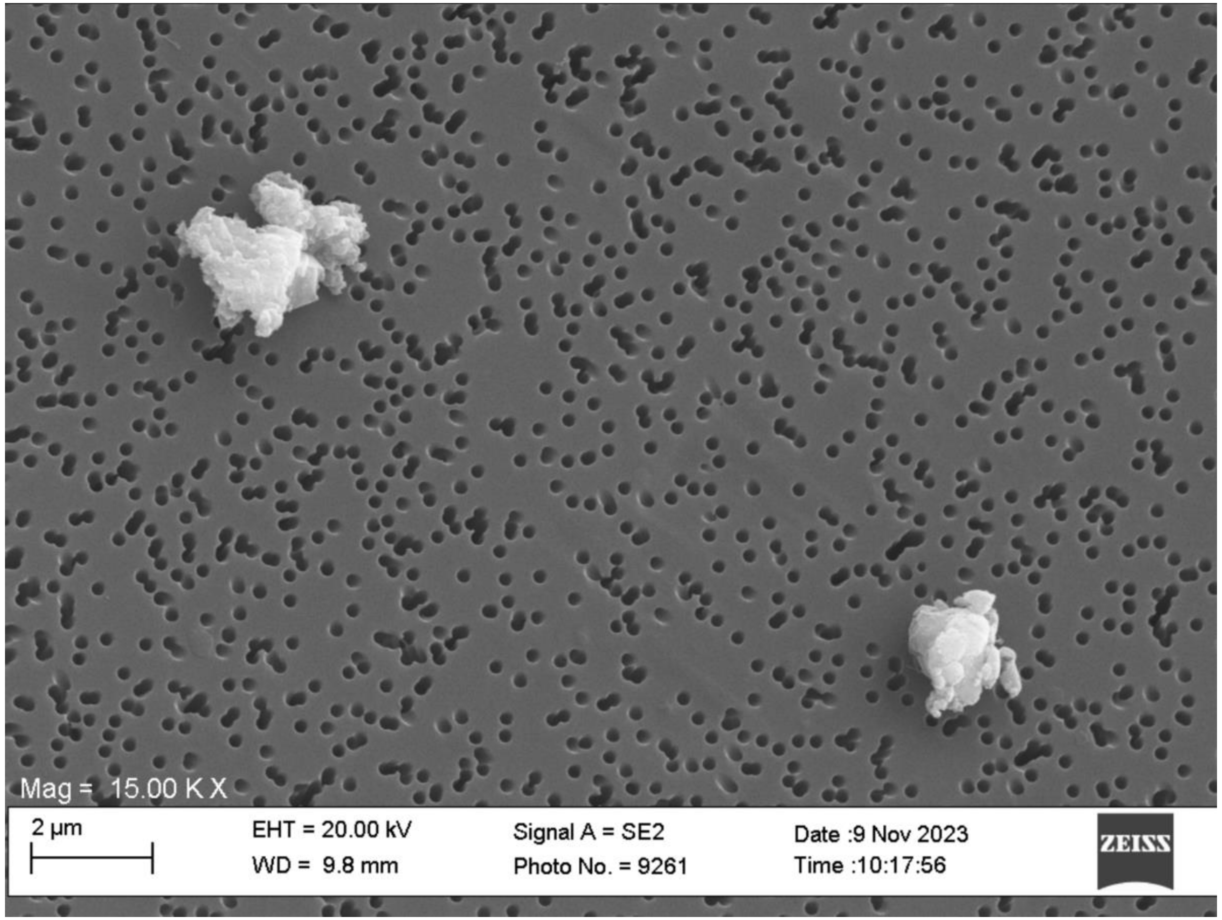


- ✓ Imaging of Pure Nylon-12 Powder.
- ✓ Size ranges from nanometer up to about micrometer



SEM/TEM Imaging of Aerosol Particles during Printing





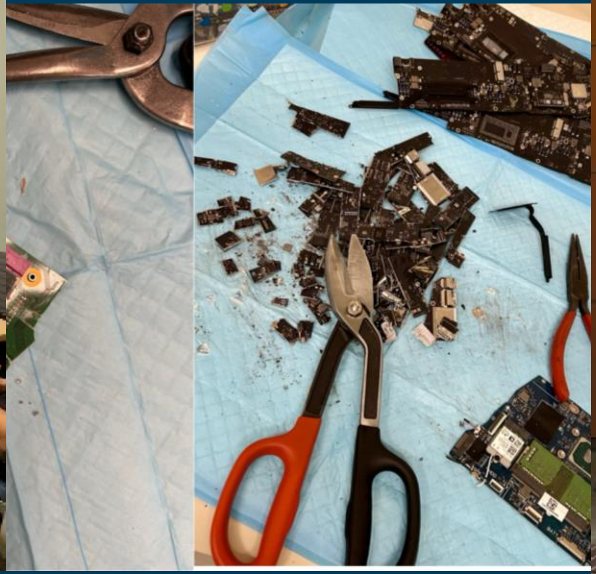
- Common particles captured during printing
- Apparent agglomerates of particles in the nanometer ranges

Q & A

PI: Candace Tsai, ScD, CIH

University of California, Los Angeles (UCLA)   candacetsai@ucla.edu

Grant No.: 1R25ES033043-01



UCLA Fielding School of Public Health