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Workshop on Nanoplastics in Marine Debris in the APEC Region

APEC Oceans and Fisheries Working Group

August 2022

Workshop on Nanoplastics in Marine Debris in the APEC Region

SUMMARY REPORT

Virtual Format | 13 – 15 December 2021

APEC Oceans and Fisheries Working Group

August 2022

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List of acronyms

µFTIR	Microscopy Fourier Transform Infrared Spectroscopy
APEC	Asia Pacific Economic Cooperation
ASTM	ASTM International, an international standards organization formerly known as American Society for Testing and Materials
ATP	adenosine triphosphate
ATR	attenuated total reflection
ATSDR	Agency for Toxic Substances and Disease Registry
CaPSA	Canada's science plastic agenda
CEN	*Comité Européen de Normalisation* (The European Committee for Standardization)
D/R	dose response assessment
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DOE	US Department of Energy
EA	exposure assessment
EAF	Electric Arc Furnace
EC	European Commission
EFSA	European Food Safety Authority
EU	European Union
FAQ	Frequently Asked Questions
FTIR	Fourier Transform Infrared Spectroscopy
GCMS	Gas Chromatography Mass Spectroscopy
GI	Gastro-Intestinal
HDI	Human Development Index
HI	hazard identification
ILC	Interlaboratory comparison
IMR-90	human lung fibroblast cells
ISO	International Organization for Standardization
ISO/TC	International Organization for Standardization/Technical Committee
LCA	life cycle analysis
LDH	lactate dehydrogenase

MP	Microplastics
MPW	Mismanaged Plastic Waste
NALDI	Nanostructure-Assisted Laser Desorption/Ionization
NGOs	Non-Governmental Organizations
NGOs	Non-governmental Organizations
NIST	US National Institute of Standards and Technology
NP	Nanoplastics
OECD	Organization for Economic Co-operation and Development
OFWG	Oceans and Fisheries Working Group
OTC	over the counter drug-cosmetics
PAEs	phthalate acid esters
PE	polyethylene
PET	polyethylene terephthalate – belongs to the group of polyester
PHA	Polyhydroxyalkanoate - a class of biodegradable plastics
PIT	Polymer Injection Technology
PMMA	polymethyl methacrylate (i.e., plexiglass)
PNEC	predicted no effect concentration
POPs	Persistent Organic Pollutants
PP	polypropylene
PS	polystyrene
PS-MPs	polystyrene microplastics
PVC	polyvinyl chloride
ROS	Reactive Oxygen Species
SAM	EU Scientific Advice Mechanism
SAPEA	Science Advice for Policy by European Academies
SEM	Scanning Electron Microscopy
STED	Stimulated Emission Depletion
TGA	Thermogravimetric analysis
UN	United Nations
US	United States
US FDA	US Food and Drug Administration
UV	Ultra Violet
WHO	World Health Organization

1. Introduction

This report outlines the outcomes of the ***APEC Workshop on Nanoplastics in Marine Debris*** held 13 – 15 December 2021. The agenda of the workshop is located in Annex A.

The main objective of the workshop was to promote communication and cooperation among policymakers and scientists from across the APEC region in addressing the emerging challenge of micro- and nanoplastics in marine debris, avoiding redundant efforts, and accelerating the development of this critical area of marine debris science for the benefit of the entire APEC community. The project to deliver the workshop was co-sponsored by Chile, Chinese Taipei, Thailand, Korea and the United States.

Dr Anil Patri, of the US FDA (Food and Drug Administration) chaired the organizing committee and moderated the workshop, with support from a number of individual session chairs from the organizing committee and invited guests. The workshop was broken down into plenary sessions, and parallel discussion sessions on specific technical topics where panel speakers shared their experiences and research. The workshop opened with an address by Jacqueline Salas, member of the Chilean delegation in APEC on behalf of Alicia Gallardo, Lead Shepherd for the Oceans and Fisheries Working Group (OFWG).

About 230 participants from 19 member economies attended during the course of the 3 day virtual workshop. This included official APEC delegates, Non-Member guests from academia, public entities, private industries and Non-governmental Organizations (NGOs). A post-workshop participant survey was sent virtually to all confirmed attendees, which had a limited uptake but provided insightful results. A summary of the workshop attendance and survey analysis is located in Annex B.

The workshop materials have been archived on YouTube by the workshop contractor. Details of the biographies of speakers and links to the pre-recorded sessions can be found in Annex C.

2. Workshop and project background

As outlined in the APEC Roadmap on Marine Debris, "Marine debris, including plastic litter in the marine environment, is an increasing global challenge in need of a cooperative response." Macroscale and microscale plastic debris and particles are found in the air, soil, rivers, streams, lakes and marine environments all over the Pacific region and the world. Most of the plastic waste enters the oceans through waste streams and rivers. In marine environments, macroscale plastic debris tends to gradually break down into smaller particles. While the scientific literature on the identification, characterization, and risk assessment of microscale (1 micrometer to 5 mm in size) plastic particles are being explored in recent years, these particles are inevitably destined to break down into even smaller, nanometer scale (1-1000 nm sized) particles. These particles are taken up by marine organisms through the food chain and end up in seafood, food, and water, resulting in human exposure. The potential ecotoxicity, longer-term effects on marine ecosystem, fate and transport, and human exposure to nanoplastics through air, water, and food is unknown.

The science on identification, characterization, and risk assessment of micro- and nanoplastics (hereinafter "nanoplastics") is in its infancy. The workshop therefore was designed to bring together communities of researchers and practitioners from across the APEC region to assess current activities and gaps in nanoplastics implications research, as well as identifying economic opportunities for innovation in remediating, mitigating, and reducing plastics waste.

This work and resultant outputs are designed to benefit all APEC economies, since the workshop was designed to result in ease of communication and advancement in scientific innovation related to nanoplastic occurrence, including characterization and identification of nanoplastics from environmental matrices and the effects these particles may have on the ecology and human health. This project sought to advance the development of consensus on terminology and best practices surrounding nanoplastic occurrence, effects, and methodology.

The overall objective of the project was to create an APEC-wide community of researchers, policymakers, and industry representatives dedicated to improving understanding of, and identifying opportunities for remediating or eliminating, the problems associated with micro- and nanoplastics in marine debris. This included:

a) Sharing of best practices for identifying, characterizing, assessing risk from, and reducing or remediating nanoscale plastic waste.

b) Leveraging of scientific resources, and sharing in the development of alternate technologies, products, capabilities, and facilities. Building capacity across APEC economies by sharing existing knowledge in this emerging field.

c) Initiating a draft framework for addressing short- and long-term issues associated with micro- and nanoplastics in the environment.

2.1 Organizing Committee

The workshop was organized by the following organizing committee, with support from the project contractor WRc Ltd.

Anil Patri, Food and Drug Administration, US (Chair)

Keith Chanon, National Science Foundation, US

Jung Chun-Hao, Ocean Affairs Council, Chinese Taipei

Nick Fletcher, Food Standards Australia New Zealand, New Zealand

Kay Ho, Environmental Protection Agency, US

Geoff Holdridge, National Nanotechnology Coordination Office (contract staff), US

Åsa Jämting, National measurement Institute, Australia

Matthew Kupchik, Agency for International Development, US

Jennifer Lynch, National Institute of Standards and Technology, US

Van Reidhead, Department of State, US

Greg Zarus, Agency for Toxic Substances and Disease Registry, US

Shan Zou, National Research Council, Canada

3. Opening Remarks and Plenary One - Goals, Outcome, Expectations

The workshop opened with an address by Jacqueline Salas, member of the Chilean delegation in APEC on behalf of Alicia Gallardo, Lead Shepherd for the OFWG. She commented on the importance of the issue, the work on marine debris carried out by the APEC fisheries and ocean working group. She concluded that APEC promote communication and cooperation among policy makers and scientists from across the APEC region in addressing this emergent challenge.

The Plenary One session was chaired by Dr Anil Patri, Nanocore Director of the US Food and Drug Administration. This plenary session introduced the overarching goals of the workshop and the global challenges associated with micro- and nanoplastics. It set the tone for the rest of the workshop and included the Chair's welcome remarks to the workshop attendees. Presentations were provided to view in advance as videos on the online platform and questions from participants were discussed by the speaker panel. A keynote presentation about ocean micro- and nanoplastics was followed by perspectives and presentations on various projects to understand and alleviate the issues associated with this global problem. It provided global perspectives from different APEC economies, and included academic, government, industry and non-profit organization perspectives to set the stage for the workshop discussion sessions.

3.1 The emerging science of global microplastics and nanoplastics

The plenary session for the workshop started with a keynote by Dr Kara Lavender Law, Research Professor of Oceanography, Sea Education Association, US, on 'The emerging science of global microplastics & nanoplastics'. Dr Law outlined the rapid increase in global production of plastics with an estimated 8.3 billion metric tons produced between 1950 and 2015, leading to increased generation of plastic waste. Bulk plastics found floating in oceans from early 70s, along with microplastics captured in plankton net tow. Microplastics result when plastics are broken down from UV radiation or shed during the use. There is abundance of evidence that microplastics (and potentially nanoplastics) contaminate the ocean surface, sediments, arctic sea ice, freshwater lakes, rivers, streams, air, drinking and bottled water. Microplastics are not uniform in abundance from the ocean studies resulting from plankton tows from northern Pacific and northern Atlantic regions with high concentrations found in sub-tropical patches and low concentrations are found below subtropical zones. This can be explained by ocean physics. Significant knowledge gaps exist and public interest on this topic is increasing. The total amount of microplastics and nanoplastics in the environment, their transport, transformation, fate, effects on wildlife, environment and humans is unknown. However, we know enough to take action for prevention, mitigation, and remediation at local, regional, domestic and global level.

3.2 Monitoring and effects of Microplastics in Marine Biota

The second speaker was Dr Cristobal Galban-Malagon from Universidad Mayor, Santiago de Chile, who presented on 'Monitoring and effects of Microplastics in Marine Biota'. He outlined efforts in Chile and the southern Pacific. While most of the work on plastics in general and microplastics in particular is monitored in the northern Pacific Ocean, very little is known about their abundance in the southern Pacific Ocean. Resource availability and instrumentation are also limited for monitoring microplastics with majority of the studies utilizing optical microscopy. He outlined some of the digestion methods, advantages, and limitations for detecting microplastics in organisms. Studies in aquatic species dosed with microplastics in a controlled laboratory environment showed low mobility, less activity in predation process, growth inhibition and maturation process, compared to corresponding controls without microplastics. The effects cause by commercial microplastics in the aquatic species are different from the same compositions isolated from natural environment that have undergone weathering/degradation. This is attributable to biofilm formation and chemical contaminants adsorbed to these microplastics. A survey conducted on Chilean continental coast on the microplastics presence in fish present in coastal tidal pools suggested that blue color plastics are the most predominant plastics consumed by fish with higher levels of microplastics found in omnivores vs herbivore fish. Microplastics were also found in marine mammals in Chile and Peru with microfibers predominantly present in virtually all animals tested. Due to the lack of information, greater monitoring is needed in the southern Pacific Ocean.

3.3 Assessment of environmental microplastics: opportunities and challenges

The third speaker in this session was Dr Chihhao Fan from National Taiwan University (NTU), Chinese Taipei. He presented on the 'Assessment of environmental microplastics: opportunities and challenges'. He provided a literature review on the occurrence of microplastics, compositions, their characterization and impact on environment. He presented on some of the methods for isolation of microplastics, including visual inspection of larger microplastics and separation from soil samples. He also outlined the sample preparation through pretreatment through oxidation with hydrogen peroxide and separation through gravitation floatation, followed by identification through Scanning Electron Microscopy (SEM), Infrared spectroscopy (FTIR) and quantitation through gas chromatography mass spectroscopy (GCMS), Thermogravimetric analysis (TGA) and pyrolysis GCMS. He reviewed toxicity studies using zebrafish and mice resulting in ambiguous results. He presented on their own research from NTU where they collected samples from the surface of water bodies on the campus and analyzed through physico-chemical characterization. They developed calibration curves using UV-Vis and fluorescence spectroscopy for different common polymers and found that these curves can be utilized for the quantitation of microplastics in the samples they collected. He also outlined the challenges associated with applying data from pristine commercial material to those found in the environment post weathering effects. Standard protocols and analytical standards are needed, as are the comprehensive databases, including characterization and toxicological data.

3.4 Plastic pollution research and monitoring in Canada

The fourth speaker was Dr Jennifer Provencher from Environment and Climate Change Canada, who presented on 'Plastic pollution research and monitoring in Canada'. Plastic pollution has been identified as a priority for the Government of Canada, with an aim towards circular economy that would reduce the impacts on the environment. Research is moving from large plastic pollution to smaller microplastics and nanoplastics. Under Canada's science plastic agenda (CaPSA), which was published in 2019, several collaborative research programs have aimed to improve detection, quantitation, and characterization of plastics in the environment to better understand the impacts on wildlife and the environment. A focus of recent research is on three themes 1) ingestion and accumulation of microplastics 2) birds as vectors for plastics and 3) plastics as a vector for contaminants. In the Northern Contaminants Program, that monitors health of wildlife, the research undertaken for several years is on which species are most vulnerable for ingestion of plastic pollution. Variation in plastic ingestion in sea birds is seen across large spatial scales. Based on monitoring of 50-100 Northern Fulmars, an excellent species and tool for monitoring ocean plastics trends, they are found to have more than 0.1 g or more plastics in their stomach. Plastic particles are also found in the poop of different kind of birds. The morphology, color, and polymer type were characterized. More than 45 million pieces are analyzed every year. Recent projects include studying the impacts of vessel traffic in the arctic, studying paint chips from different vessels and their prevalence. Studies are also being conducted by applying biosolids to soil/lawn to investigate how microplastics are changing in the soil. The Government of Canada is involved in many global efforts by coordinating, harmonizing effects across the board. While microplastics have been a focus in the past few years, there is a growing need to understand the presence of nanoplastics in biota, especially species that are consumed by humans, from crops to harvested species.

3.5 Microplastics Reference Materials – Industry perspective

The fifth speaker was Dr Brett Howard from the American Chemistry Council presented on 'Microplastics Reference Materials'. He provided industry perspective and efforts in developing reference material, making them available to researchers for better Quality Assurance and Quality Control (QA/QC) to support robust methods and methodology development for the characterization of micro- and nanoplastics. Industry is interested in identifying issues of importance, areas of risk, and actively engage for responsible development. Unlike chemical risk assessment microplastics pose challenges as they are inherently heterogeneous mixtures of all kinds of particles, sizes, and resins. Before traditional hazard and exposure assessment, there is a need to have quality assurance and protocols in place. Predominantly most studies utilize commercially available standards such as polystyrene particles, which are not typically found in environmental samples. Industry is developing resins with known morphology, and size of PVC, PE, PP, PS, and PET in short term. Currently, a polymer kit 1.0 composed of 22 resins is produced and made available through Hawaii Pacific University for researchers to calibrate instruments. In longer term they are interested in providing reference material that resemble particles most likely to be found in environmental compartments, including those with weathered surfaces. New methods that utilize UV degradation, sonication is being explored to address the challenges associated with producing material that resemble environmental samples. A tool for sharing analysis results is the open specy website[1] a spectral library of microplastics particles.

3.6 A brief overview of what we know and don’t know about micro- and nanoplastics in the environment

The sixth speaker was Dr Britta Denise Hardesty from Commonwealth Scientific and Industrial Research Organization, Australia. Plastic production is increasing, as is our knowledge about plastic in the environment. She presented on ‘Plastics in environment. What we know, and don’t know’. Dr Hardesty first got interested in plastics while studying Albatrosses (birds) as an ecologist and found myriad of plastics in deceased birds. She started exploring this topic further. With global increase in plastic production, it is important to gain a deeper understanding of the sources and drivers behind how, why and where plastic is lost, transport through environment and the impacts on wildlife, people and communities and how policies are enacted and whether they work or not. The trends show that 1.5-3% plastics end up in oceans accounting for 4-12 million metric tons lost to ocean each year. Packaging comprises a large component of this plastic waste. Over the last decade, there has been a substantial increase in scientific knowledge and communication about micro- and nanoplastics, and a shift in public awareness and opinion of plastics as a growing environment, social, and economic issue. Some of the plastics break down quickly and cause hazard, leading to marine organism toxicity. Different type of products on the market has additives that are micro- and nanoplastics, such as facial cleansers, toothpaste etc. Case studies show that floating ocean plastic is tracking cumulative plastic production, though the amount of microplastics on the seafloor appear to be many times higher in mass than that present on ocean’s surface. These are in the depths of 3000 m and 380 km offshore, remote areas and not close to urban environment.

Recent technological advances increase our ability to quantify and measure lethal and sublethal impacts of plastics ingestion. Microplastics exposure is known to occur in babies and adult humans. Presence is not equal to harm, but given the many endocrine disruptors present in these plastics, we do not need to have a clear demonstration of harm, but a careful, cautious approach is appropriate to take to minimize the potential impact. Current evidence and patterns

[1] www.openspecy.org

are sufficient to support international, domestic and local decision making to address this complex, transboundary problem.

3.7 The scale of microplastic leakage to the environment and potential solutions

The seventh speaker of this session is Dr Winnie Lau from The Pew Charitable Trusts, US, and presented on 'The scale of microplastic leakage to the environment and potential solutions.' Plastic pollution problem is one of the most urgent problems we are facing with investments in new refineries far outpacing management of the waste globally. She presented The Pew Charitable Trusts publication 'Breaking the Plastic Wave' that analyzed global macroplastics and microplastics leakage to the environment to understand the scale of the plastic pollution problem and offered potential solutions. They mapped key pathways for production, consumption, collection, sorting, recycling and mismanaged waste. Among 20 potential sources of primary microplastics, the research focused on four sources – tire abrasion/dust (which accounted for 90% of microplastics leakage), pellet loss, textile microfibers, and microplastics ingredients in personal care products, which all together represent an estimated 75-85% of primary microplastics. Despite their smaller size, the scale of microplastic leakage to the environment is substantial, accounting for 14% by weight (4.4 million metric tons) of the total plastics that entered the environment in 2016. Under the current trajectory, microplastic leakage to the environment is projected to more than double (9.9 million metric tons) by 2040.

Unlike macroplastics, fewer ready solutions exist for microplastics. The intervention frame for potential solutions include innovation in reduction, substitution, recycle and disposal. When all these solutions are put in place by 2040, only 60% of microplastic pollution could be avoided in contrast to over 80% of macroplastic pollution that could be avoided. Nonetheless, these known solutions that are scalable and affordable can be put in place now to reduce microplastic pollution significantly. The most feasible and cost-effective solutions are those that reduce microplastics at the source versus clean-up of waste that has escaped into the environment. Urgent action and increased investment in innovation are needed to stop microplastic leakage into the environment.

3.8 Summary

Following delivery of the presentations the Chair asked the speaker panel to answer questions from the participants. The discussion ranged from human health, standardization of methods and the need to have different methods for the broad range of compositions and sizes of microplastics. The key messages were:

- Abundance of evidence suggest that microplastics are pervasive in the environment with increasing presence of microplastics in terrestrial, fresh water and marine ecosystems – including primary particles and secondary microplastics.

- In oceans, they tend to accumulate in sub-tropical regions; the amount of microplastics on the ocean floor appear to be many times higher in mass than on the ocean's surface.

- Predominant source of microplastics leakage was tire dust, followed by pellets, textiles and personal care products.

- High income economies contributed to greater microplastics pollution than middle and low-income economies.

- Cost-effective solutions to mitigate microplastics pollution include reducing microplastics at the source, compared with cleaning up in the environment.

- Research programs in some economies are aimed at improved detection quantitation and characterization of plastics in environment.

- Immediate research priorities: identification, quantitation, understand fate, environmental risks, and control strategies.

- Growing need to address significant knowledge gaps relate to nanoplastics.

- Need for reference material to conduct appropriate base line methods development for analytical work and biological studies is met by generation of 'test material' kits of common polymers from industry.

- Global collaborations, citizen science projects, environmental education are critical in better understanding of this problem.

- Current evidence and patterns are sufficient to take action right now at federal, state and local level to curb microplastics pollution and stop their leakage into the environment.

4. Discussion Topic 1 – Best Practices and Research Methods for the Collection and Characterization of Micro- and Nanoplastics from the Environment

The Discussion Topic 1 session was chaired by Dr Kay Ho from the US Environmental Protection Agency. Arguably, accurate and precise methods stand at the crux of many issues surrounding the fate and effects of micro- and nanoplastics. An objective of the conference is to determine the state of common methodology for collection, extraction and identification of microplastics.

This session allowed experts to share the state of microplastic methodology in their respective APEC economies. It set the stage for discussion, sharing and future collaboration on method development, standardization, shared geographical information and the possibility of shared sampling and joint projects within a common geographical area. The discussion and future collaborations allow us to develop strategies that will not only help the APEC economies, but scientists in the plastics communities worldwide.

4.1 Microplastics in Aotearoa - New Zealand

The session was started by, Dr Olga Pantos, Institute of Environmental Science and Research in New Zealand, who presented on ‘Microplastics in Aotearoa - New Zealand’. She summarized the multiple projects in her economy that addressed the fate, transport and effects of microplastics. The breadth and depth of the summarized projects was impressive. Throughout the presentation it was clear that lack of accurate standardized, reproducible methods made it difficult to interpret results within the economy and by extension outside of the economy. The speaker ended by stating that it was clear that not one method would be effective for the wide range of matrices and experimental objectives. In addition, standard reference materials were necessary to further develop methods.

4.2 Behavior of Microplastics in Urban Water Circulation Systems and Challenges to Nanoplastics around Coral Reefs

The second speaker was Dr Shuhei Tanaka, from Kyoto University, who presented on ‘Behavior of Microplastics in Urban Water Circulation Systems and Challenges to Nanoplastics around Coral Reefs’. He outlined methods used in his economy to identify and isolate microplastics as small as 10 μm. He outlined a project that summarized water circulation of microplastics in an urban lake. He also demonstrated an innovative method used to determine the degradation, fate and timeline for development of microplastics from larger plastic particles in an urban setting that encompassed both mechanical crushing due to “stepping” and ultraviolet light. Finally, he demonstrated that coral reefs around Thailand could be subjected to microplastics concentrations up to 1,000 mg/m^3 and that this level could cause effects now and in the future through increasing production of plastics.

4.3 Studies on the methods for analysis of microplastics and the degradation process of plastics

The third speaker, Dr Qinmei Li, Institute of Analysis and Testing, Beijing Academy of Science and Technology (Beijing Center for Physical and Chemical Analysis), China, presented on ‘Studies on the methods for analysis of microplastics and the degradation process of plastics’. She systematically discussed the advantages and disadvantages of reflection, transmission and attenuated total reflection (ATR) for microplastics identification. She also described a method developed to capture the degradation products of tire wear, including particles, gas compounds, and water-soluble compounds in the aging test chamber using abrasion, light, humidity, heat and oxygen. The speaker also discussed how standardization and lack of common methods hinder the comparison of results among studies.

4.4 Lessons learned from quantifying microplastics from Hawaiian beach sand, deep-sea sediment, and gastrointestinal tracts of marine animals: A path toward nanoplastic quantification

The fourth speaker Dr Jennifer Lynch, National Institute of Standards and Technology and Hawaii Pacific University's Center for Marine Debris Research, presented on 'Lessons learned from quantifying microplastics from Hawaiian beach sand, deep-sea sediment, and gastrointestinal tracts of marine animals: A path toward nanoplastic quantification'. She gave an overview of current methods commonly used to identify microplastics. In addition, she demonstrated innovative methods used to extract microplastics from beach sand, deep-sea sediments, and reef fish. The speaker also summarized the results of a study that compared different solutions for digesting organic and other interfering matrices in environmental studies. The speaker discussed the need for more standardized reference materials and outlined the availability of currently available materials. She also stated that not one method would fulfil all of the extraction and identification needs of microplastics from different matrices and a suite of methods validated through standard and internationally accepted reference materials is necessary.

4.5 Advancing methods for analysis of microplastic and microfibers in urban watersheds: Insights from multi-partner research

The fifth speaker, Dr Anna Posaka, Ocean Diagnostics Inc, Canada, spoke on 'Advancing methods for analysis of microplastic and microfibers in urban watersheds: Insights from multi-partner research'. She focused on the issue of fibers. She gave evidence that polyester microfibers were the most commonly ingested in the species examined and estimated 900 metric tons per year of microfibers entered oceans from North America via treated wastewater. She emphasized the need to understand optimal sampling volumes and the impact of contamination in the field on data quality. She highlighted current gaps in methodologies for sampling and analysis of microplastics and microfibers in complex environmental matrices. The speaker emphasized that not one method would be effective for all volumes and that attention to QA/QC is critical. She outlined methods to streamline spectroscopy methods to identify fibers.

4.6 Complex investigation of the microplastics pollution in the Don river

The sixth speaker, Dr Tatiana A. Lastovina, Southern Scientific Center of the Russian Academy of Sciences, presented on 'Complex investigation of the microplastics pollution in the Don river'. She discussed the fate and transport of microplastics and linked them to sources and land use practices in her APEC economy. She noted that fibers were the most prevalent microplastics found in the system. Potential sources included fishing nets and synthetic ropes and fibers from clothes. She also noted an unusual number of polyurethane foam particles. Future research included monitoring of microplastics through seasonal changes and investigation of weather events.

4.7 Summary

In the closing discussion led by the Chair Kay Ho several speakers noted that due to the differing matrices and objectives of studies, that a suite of methods that encompass different matrices and particle types (particularly fibers) need to be used. For these methods to be accepted internationally, reference materials need to be standardized and used in appropriate QA/ QC exercises to support the use of differing methods. Speakers noted the need for data repositories and open sharing of methods and data across the economies. Finally, it was noted that technology for microplastic methodology is changing fast and we are all looking for faster, easier, and less expensive instrumentation and methods.

5. Discussion Topic 2 – Environment and human exposure, potential effects and mixtures toxicology

The Discussion Topic 2 session was chaired by Greg Zarus from the Agency for Toxic Substances and Disease Registry and Dr Sarva Mangala Praveena from Universiti Putra Malaysia. Microscopic plastic particles follow us. Microbeads placed in our personal care products were applied directly and continue to migrate into our environment. Polyester fibers wear away from our clothes, are washed into our drains, and exhaust from our dryers. Styrofoam cups blow in the wind to our storm drains and degrade as they enter our seas. Latex paint chips from our homes, thermoplastic paint wears from our streets, and acrylic paint flakes from our bridges. The micro- and nanoplastics abound near large populations and some travel great distances.

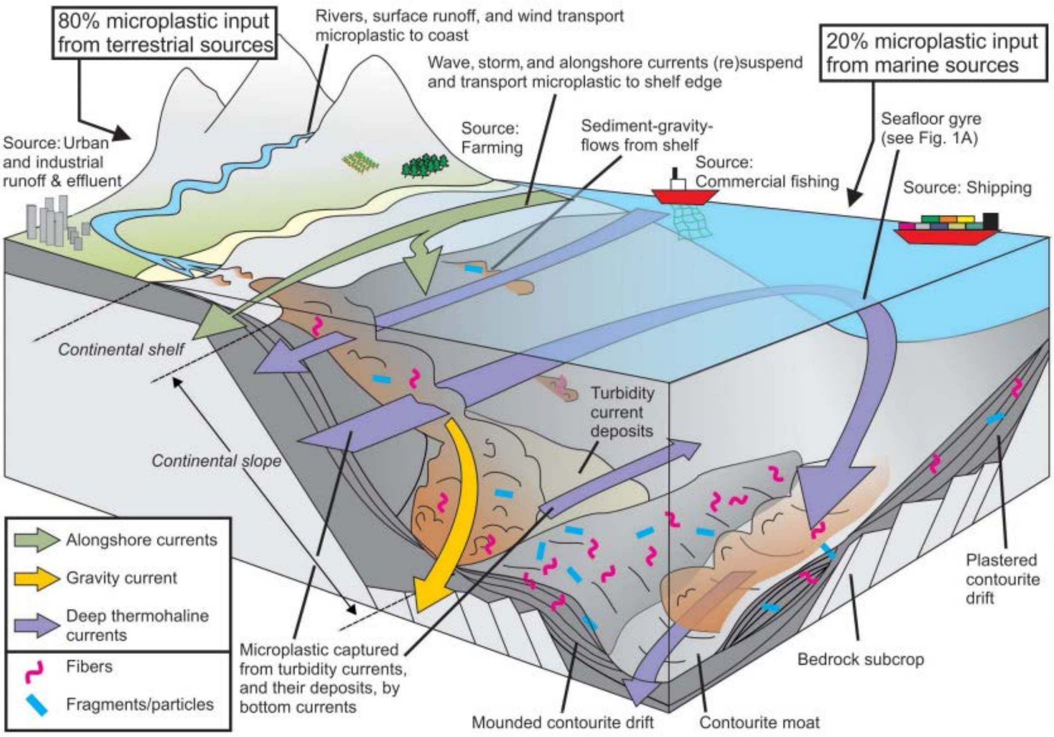
Remarkable concentrations of plastic particles have been found in the mussels and fish near population centers. More remarkable still is the discovery of plastics in pelagic fish collected far offshore. In recent years micro- and nanoplastics have been discovered in sea salt, sugar, honey, tea, water, and beer – also in our liver, spleen, and feces. What is our exposure and what does it mean?

5.1 Global Riverine Plastic Outflows

The first speaker was Dr Eddy Zeng, Jinan University, China, who presented on ‘Global Riverine Plastic Outflows’. Global marine plastic pollution obviously started on land and enters the sea as shown in Figure 5.1 (Kane, 2020). Most of the contribution is expected to be due to land-based plastic waste, yet the true amounts are unknown. The modelled estimates of global plastic pollution vary widely due in large part to the limited municipal solid waste management data and due to varying methods to estimate mishandling of plastic waste. Errors and variability occur on local, domestic, and international levels (Edelson, Håbesland, & Traldi, 2021). Field measurements of riverine inputs are also very limited (Mai, et al., 2020).

Professor Eddy Zeng discussed how efforts to fill the apparent data gaps between limited data to estimate riverine contribution (Mai, You, H. He, Liu, & Zeng, 2019). He explained it as a two-step approach, targeted sampling and robust model development. **Targeted Sampling**: His team conducted sampling at the eight major river outlets of the Pearl River Delta, South China with rapid economic growth and urbanization. Floating microplastics were collected with a Manta net (mesh size 0.33 mm) five times during 2018. Microplastic particles (0.3–5.0 mm) widely occurred in all sampling sites. The number and mass concentrations of microplastics were in the ranges of 0.005–0.7 particles m^{-3} and 0.004–1.28 mg m^{-3} and were positively correlated with water discharges. The annual riverine input of microplastics from the Pearl River Delta was estimated at 39 billion particles or 66 tons, which converts to 2400–3800 tons of plastic debris. **Model Development:** His team then formulated a robust model using the Human Development Index (HDI) as the main predictor. The modelled riverineplastic outflows were calibrated and validated by available field data from the Pearl River Delta and other river systems around the world. The model estimated that the global plastic outflows from 1,518 main rivers were in the range of 57000–265000 (median: 134000) tons $year^{-1}$ in 2018, approximately one-tenth of the estimates by mismanaged plastic waste (MPW)-based models. A conceptual model is of contributions is presented below. With increased plastic production and human development, the global riverine plastic outflow is projected to peak in 2028 in a modelled trajectory of 2010–2050. The HDI is a better indicator than MPW to estimate global riverine plastic outflows, and plastic pollution can be effectively assessed and contained during human development processes.

Figure 5.1 Conceptual model of riverine microplastics contribution to the sea (I. A. Kane, et al., 2020)

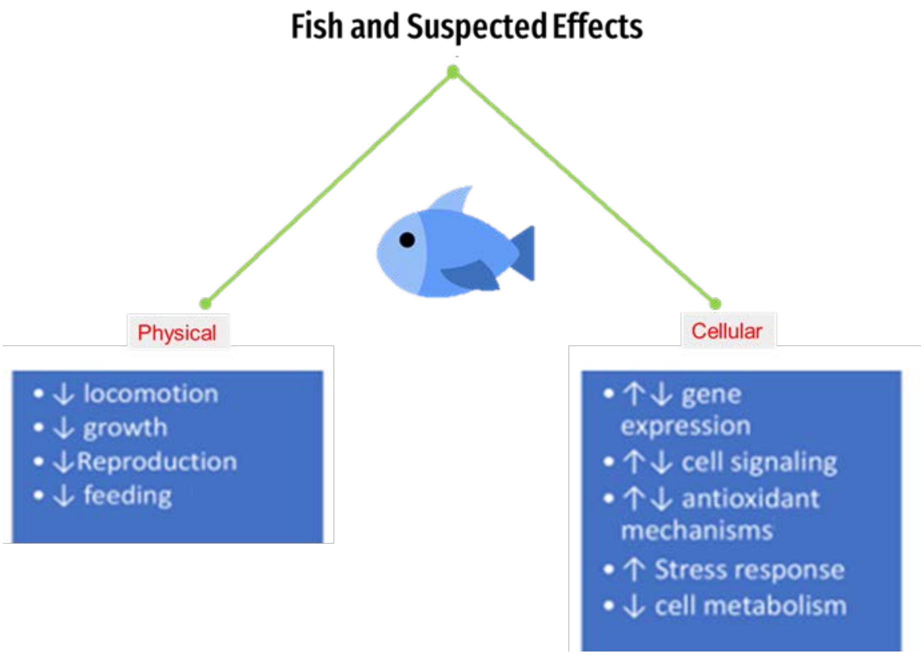


5.2 Fish and suspected effects

The second speaker was Dr Sarva Mangala Praveena, Universiti Putra Malaysia, who presented on 'Fish and Suspected Effects'. It is estimated an average of 9 million metric tons of plastic waste will enter aquatic environment and by 2050. This weight of marine plastics will exceed the weight of the fish population. In the aquatic environment, these plastics wastes will further breakdown and are known as secondary microplastics. What is the effect in fish and what could it mean for humans?

Dr Praveena described the recent increase in studies examining the effects of such exposures on aquatic organisms, especially fish. She explored the findings of several studies including her own. She listed actual and suspected effects, including both physical and cellular as shown in Figure 5.2. Studyfindings on combined effects of microplastics in fish were highlighted to provide a better understanding the potential impact of micro- and nanoplastics contaminants on aquatic organisms (Huang, et al., 2021), (Wang, Ge, & Yu, 2020). In this light, she also highlighted the need to understand microplastics along with plastics additives and pollutants sorbed onto microplastics on aquatic organisms and trophic transfer in real exposure condition.

Figure 5.2 Physical and cellular effects observed in fish exposure to microplastics (Modified from (Franzellitti, Canesi, Auguste, Wathsala, & Fabbri, 2019))



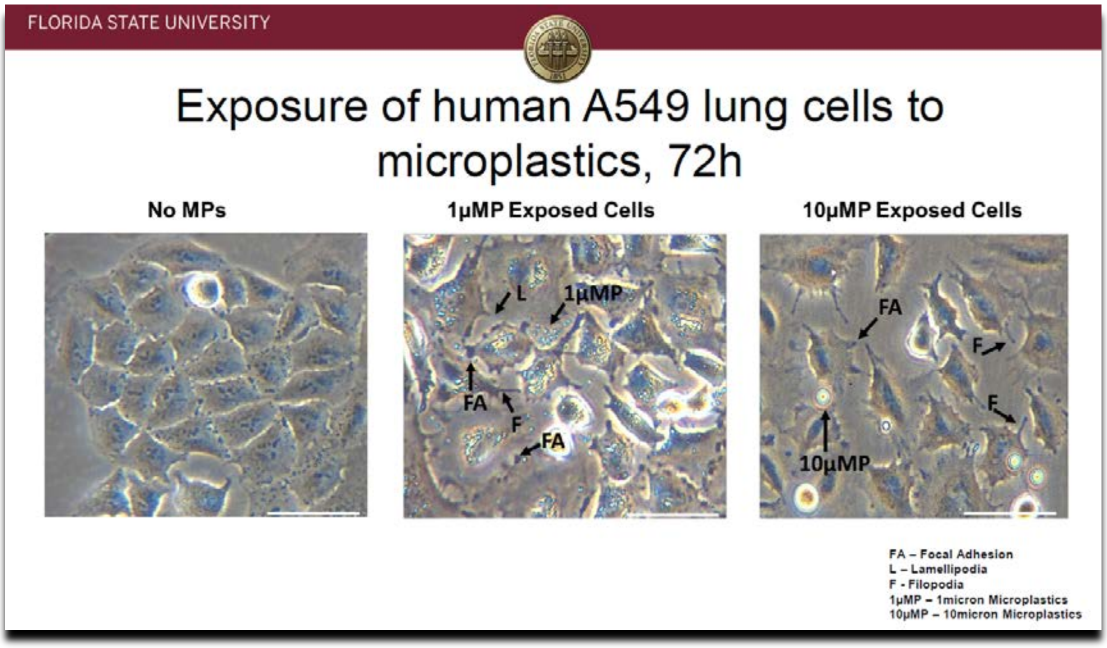
5.3 Potential Cytotoxic Effects of Microplastics on Human Lung Cells

The third speaker Dr Qing-Xiang Amy Sang, Florida State University, US presented her own and colleagues work on 'Potential Cytotoxic Effects of Microplastics on Human Lung Cells'. Dr Sang examined her evidence of morphic changes to lung cell associated with exposures to Polystyrene microplastics (Goodman, Hare, Khamis, Hua, & Sang, 2021). To examine the potential cytotoxic effects of microplastics on human cells, the cultured human lung alveolar A549 cells were exposed topolystyrene microplastics (PS-MPs) of 1 micron and 10 micron diameter. Both sizes caused a significant reduction in cell proliferation but not cell viability. Experiments revealed a population level decrease in metabolic activity parallel in time with a major decrease in proliferation rate in PS-MP exposed cells. Phase contrast imaging of live cells at 72 hours revealed major changes in the morphology of cells exposed to microplastics, as well as the uptake of multiple 1 micron PS-MPs into the cells. The cells appeared to be de-clustered and more mobile in the presence of PS-MPs.

Confocal fluorescent microscopy at 24 hours of exposure confirmed the observation of 1micron PS-MPs inside the cells and their localization near the cell nuclei. The microphotographs presented in the figure below reveals the cell effect following polystyrene exposure.

These results showed that exposure of humancells to microplastics has resulted in inhibition of cell proliferation and major changes in cell morphology, suggesting that exposure to microplastic pollution may have detrimental effects on human cells.

Figure 5.3 Microphotographs of human lung cells under exposed to microplastics compared to and controls (Goodman, Hare, Khamis, Hua, & Sang, 2021)



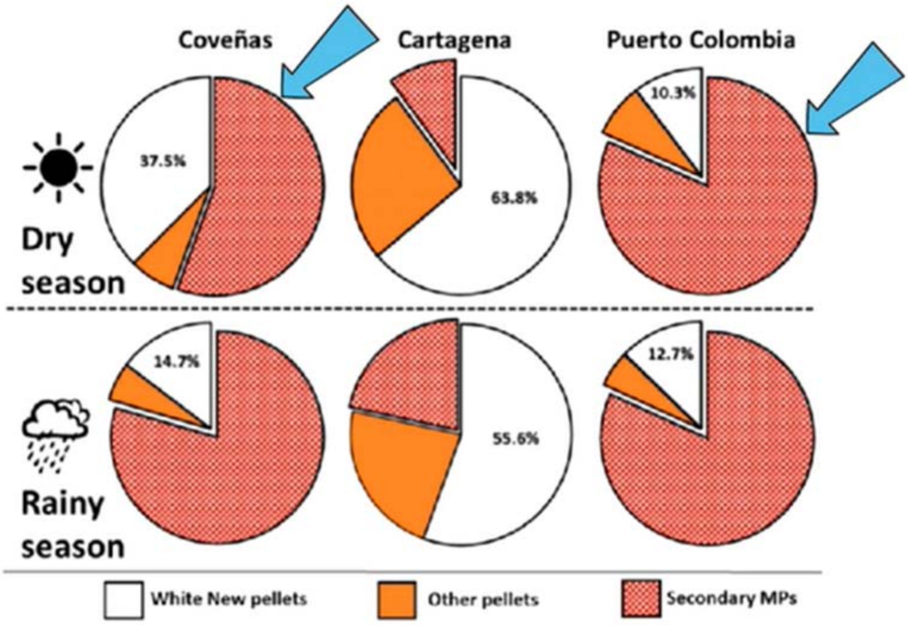
5.4 From microplastics to plastic houses: biological impact from a hotspot

The fourth speaker was Dr Jesus Olivero-Verbel, University of Cartagena, Colombia, who presented on ‘From microplastics to plastic houses: biological impact from a hot spot’. He showed the results of a monitoring program of microplastics in the Colombian Caribbean. Pellets and secondary microplastics were collected in several beaches along the coast, characterized by FTIR and their aqueous extracts employed to explore associated toxicity using Caenorhabditis elegans (roundworm about 1 mm in length) as a biological model. He also presented how microplastics are released from a plastic rope undergoing degradation by sunlight, humidity and temperature. Rope microplastics were chemically and morphologically characterized, and then subjected to uptake by alevins (newly spawned) of Prochilodus magdalenae, a common freshwater fish in Colombia.

Microplastics collected in beaches from Cartagena, a city with several plastic factories were mainly pellets, whereasthose from other sampling sites far from the source were secondary microplastics, the result from the breakdown of plastic products carried by the Magdalena River, the largest in the economy. Microplastics type percentages differed by location and season (seasonal differences by location are provided in Figure 5.4 below).

All types of microplastics were able to induce physiological changes in C. elegans, especially secondary microplastics. Although lethality was low, locomotion of the nematode (roundworm) was the most sensitive marker of pollutant leaching from microplastics, which were enriched by several metals such as Hg, Ba and Cr, among others. Microplastics released from the rope were polypropylene fibers, and these were easily taken up by the freshwater fish P. magdalenae. Finally, it is clear that plastic-related threats to humans are greater than it can be imagined, for instance, plastic houses are being built for vulnerable communities. There is no doubt that scientists, in particular environmental toxicologists, need to be more proactive and try to engage in plastic- associated issues that require scientific attention, as the number of implications from exposure to microplastics and chemicals from plastics increases on a daily basis.

Figure 5.4 Percent distributions of microplastics found at select locations during dry and wet seasons (Acosta-Coley, et al., 2019)



5.5 Human exposures to micro- and nanoplastics

The fifth speaker was Greg Zarus, Agency for Toxic Substances & Disease Registry, US, who presented on 'Human Exposures to Micro- and Nanoplastics'. He discussed the dose estimates made based on published results from numerous researchers, including several of the APEC participants. He reported data for ingestion, inhalation, and subcutaneous absorption exposure. He then discussed the unique health effects observed based on people with extremely high exposures to Microplastics and Nanoplastics. Health effects observed differed by plastic type and size, and he summarized evidence that higher and longer doses had greater response – a critical step to inform future lower dose studies.

Table 5.1 summarizes the human endpoints associated with micro- and nanoplastic exposure showing relative data quality. The best studied source of exposure is seafood, yet the least studied effects in humans exposed to microplastics are those associated with ingestion. The best studied health endpoint is the lungs in workers, yet very few studies have examined the air pathway for fine nanoplastics. Little or no data is available to look at the most bio-active sized particles <10 microns. Rarer still are toxicity studies of plastic mixtures, a topic for discussion by our panelists. He closed with some results of proof-of-concept evaluations that his team performed on the air pathway, showing that nanoplastics are released into the air and can be collected to assist with addressing the air pathway.

Table 5.1 Summary of Human Endpoints Associated with MP & NP Exposure (relative data quality is color coded good, ok, bad) (Modified from (Carroll, et al., 2020)

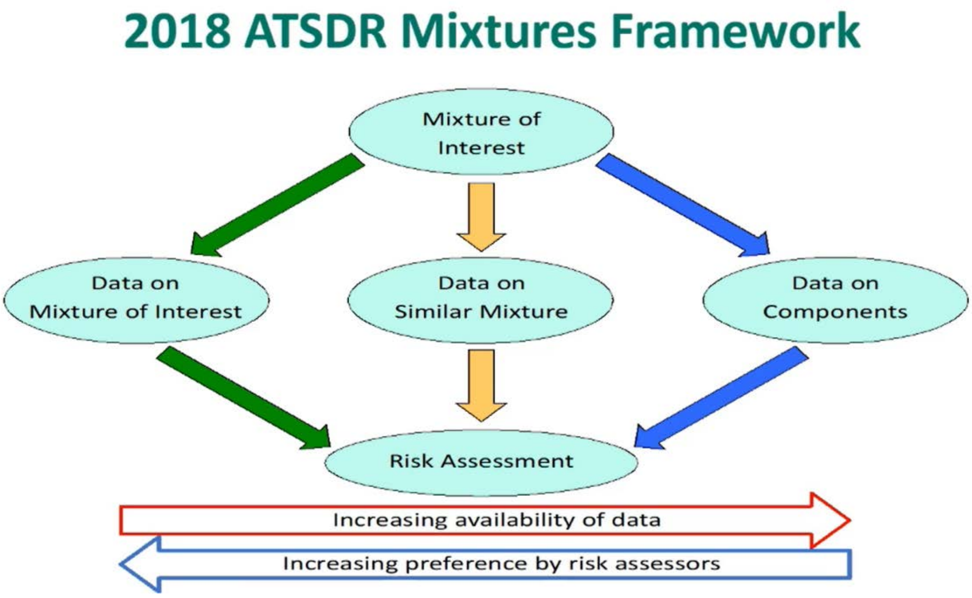
Uptake & Absorption	Evidence	MP data	NP data	Critical Data Needs
Lungs	MP was measured in workers with health effects	Measured in workers and air	Measured in workers lungs	Not studied in non-workers
Immune system	PE was found in lymphatics in implant patients & related to immune response (and markers)	Translocated in implant patients and found in lymph nodes of workers	Translocated in implant patients and animals	Not measured in general population. PE should represent other nano.
Neurologic	PS alters neurologic mouse cells only. Polyethylene association with dopamine in humans	Measured in biota, but effects might be associated with nano size	Enters cells when applied with effects	Not measured in general population and uptake not demonstrated.
GI system	MP was measured in feces of general population, implied by association with health effects in workers; GI cancers.	Measured to translocate in animals after inserted and cancers associated to work environment	Not measured, but suggested by movement of other nano particles	Human GI absorption unknown, but associated with effects; feces MP and urine PAEs are non-specific indicators
Liver	Implied by association with health effects in workers only	Injected particles circulate to liver. MP in liver and spleen of implant patients.	None	Measured implant patients, but not in workers, animals, or general population.
Biomagnification of other toxicants	Measured directly as a factor >1x in marine environment, in few cases. PAEs in mammals suggest >1x.	Other marine animals show a decrease in the trophic levels.	None	Data for food supply is needed; however, total exposure to many POPs is known.

MP: Microplastics, NP: Nanoplastics, PE: Polyethylene, PS: Polystyrene, GI: Gastro-Intestinal, PAEs: phthalate acid esters, POPs: Persistent Organic Pollutants

5.6 General Mixtures Toxicology and Microplastics

The sixth speaker was Dr Moiz Mumtaz, Agency for Toxic Substances and Disease Registry (ATSDR)/Centers for Disease Control and Prevention (CDC), US, presenting on 'General Mixtures Toxicology and Microplastics'. As we learned in the earlier presentations, the nanoplastics and microplastics found in the environment are comprised of or contain various substances. Modern environmental toxicology has strategies to address this given the right data as environmental exposures are often complex and include chemical mixtures. Dr Mumtaz explained how mixtures can be partially or completely characterized. Given the existence of different types of mixtures as well as the many factors that impact the overall toxicity of such mixtures, no single approach can be suitable for every toxicity assessment. Thus, the Agency for Toxic Substances and Disease Registry framework ((ATSDR), 2018) recommends three broad approaches for evaluating toxicity of environmental chemicals. Figure 5.5 offers a means to formulate the exposure problem for single substances, approximate estimates for mixtures, and refined assessment of mixture toxicity.

Figure 5.5 2018 ATSDR Mixtures Framework



An ideal assessment would be based on a mixture for which health effects have been well characterized. The second approach is used for a mixture that has similarity with a tested mixture. These two methods have been used for worker exposures to complex but stable mixtures. The most-often used approach to assess mixture toxicity is the hazard index (HI) approach, based on additivity of single chemical toxicity data. The toxicity assessment process must encompass all available toxicologic data and scientific evidence on the plausible toxicities of chemical mixtures. For emerging pollutants such as microplastics, problem formulation might, by necessity, involve identifying and characterizing simple mixtures and collecting appropriate data to study their toxicity in *in vivo* and *in vitro* systems to gain insight into their mechanisms of toxicity.

Microplastics are widely recognized as potentially hazardous to aquatic fauna and humans. They cause their effects through chemical and particulate toxicity. Their environmental exposures are as mixtures, continuous, and their health effects are recognized, but their mechanisms poorly understood. Pollution is often controlled by performing risk assessment a 4-step process: hazard identification (HI), exposure assessment (EA), dose response assessment (D/R) and risk characterization. Most of the presentations at the workshop have been in the area of HI and minimal information was presented in EA and D/R. In fact, the toxicity of microplastics is far from sufficient to implement the risk assessment process. Problem formulation precedes even the risk assessment process and very little if any was presented on defining the problem and seeking solutions. In the problem formulation step a target community/population is identified, exposures are defined, and health concerns enumerated. The global problem, should be apportioned judiciously into smaller, clearly defined problems, studied thoroughly, researched and solutions sought. In conclusion, for microplastics, we might want to identify smaller geographic areas and related problems, identify specific health/toxic effects, study them and seek research solutions locally. Ultimately, knowledge gained from well-defined problems can lend insights to formulate generic principles and strategies to address the global microplastics problem.

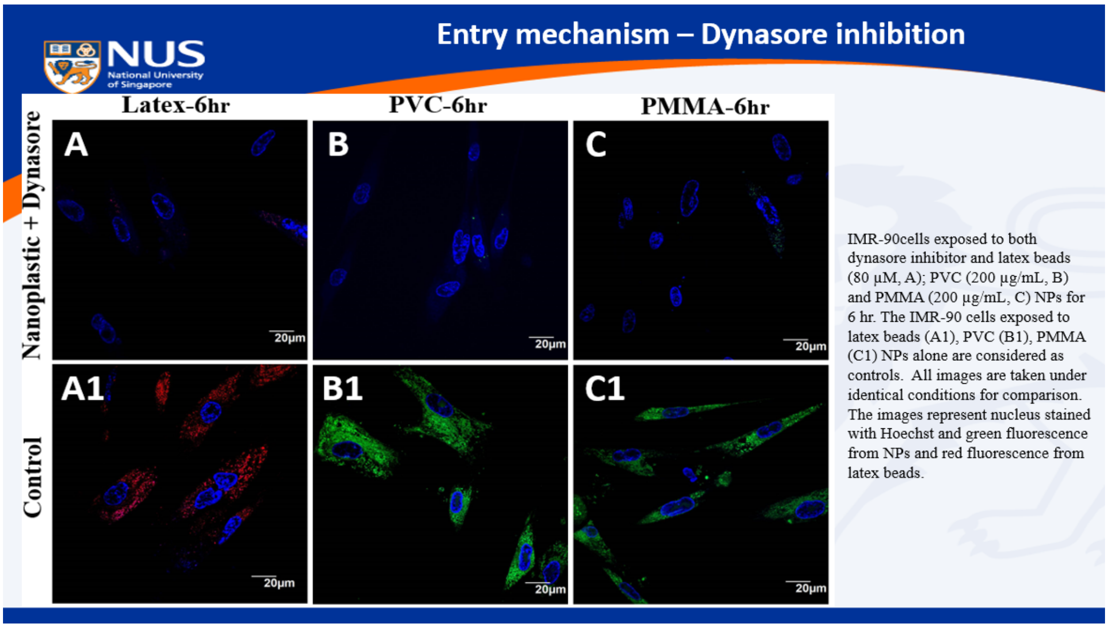
5.7 Cytotoxicity of polyvinyl chloride and polymethyl methacrylate nanoparticles on normal human lung cell line

The last talk of the session was given by Dr Suresh Valiyaveettil, National University of Singapore, Singapore on ‘Cytotoxicity of polyvinyl chloride and polymethyl methacrylate nanoparticles on normal human lung cell line’. He started with the point that there is a global distribution of microplastics and his concern that humans eat foods like seafood that are contaminated with microplastics. There are various models to understand the impact of plastic particles on the living organism. He discussed the synthesis and characterization of luminescent polyvinyl chloride (PVC) and polymethyl methacrylate (PMMA; i.e., plexiglass) nanoparticles. He investigates their interaction with commercially available normal human lung fibroblast cells (IMR 90) to understand the uptake, translocation and toxicity of PVC and PMMA nanoparticles. The synthesized particles are in the size range of 120 – 140 nm with a negative surface potential. Cellular internalization was investigated using colocalization and dynasore inhibitor tests, which showed that the PVC and PMMA nanoparticles enter the cells via endocytosis. Fluorescent images of stained IMR-90 cells exposed to latex, PVC, and PMMA reveal differing effects in Figure 5.6 below.

The polymer nanoparticles induced a reduction in viability, decrease in adenosine triphosphate (ATP), increase in ROS and LDH concentrations - these results indicate stress in the cells. In addition, the polymer nanoparticles caused cell cycle arrest, followed by apoptotic cell death. The results reported here are important to the emerging data on understanding the impact of polymer particles on human health. Further results can be referred to (Mahadevan & Valiyaveettil, 2021)), (Yip, Lee, Neo, Teo, & Valiyaveettil, 2021) and (Bhargava, et al., 2018).

This method using luminescent particles from similar polymers overcomes the difficulty of studying the impact of microplastic particles collected from the environment. The method has been tested with human cells (*in vitro*) and with marine animals like barnacle larvae.

Figure 5.6 Fluorescent images of stained IMR 90 cells exposed to latex, PVC and PMMA (G. Mahadevan, 2021)



5.8 Summary

Discussion Topic 2 explored the micro- and nanoplastics concentrations observed in the environment, how the amount that enters our rivers depends on a population's development level; how the small plastics travel through rivers, enter the marine species, and are taken up by humans. Early evidence was presented on possible toxic effects and the great uncertainty of that data. The session closed with a panel discussion led by Chairs Greg Zarus and Sarva Mangala Praveena where topics included the processes where biota take up micro- and nanoplastics and the challenge of describing transfer within biota when particles have very different sizes.

6. Plenary Two discussion panel - Regulatory and regional perspectives

Plenary Two was chaired by Matthew Kupchik, United States Agency for International Development. The session looked at both regional trends and impacts from microplastics, as well as some of the existing and emerging regulatory trends and how systems thinking can be used to address the problem. With microplastic pollution forecast to be fifty times higher by the end of the century, identifying specific interventions to limit impacts to ecological systems and human health is imperative.

Presentations (videos available in advance) included a global review of regulations on sources of primary microplastics (e.g. microbead bans); how circular economy approaches can help address leakage; how the current extent of microplastics in the North Pacific helps to identify the scale of the problem; and regulatory and legislative actions at local, domestic, and regional scales provide examples of ongoing action to address the problem. These perspectives provided context for the later 'Discussion Topic 6 – Approaches for Nanoplastics' around current efforts in establishing a common terminology and nomenclature within the micro- and nanoplastics community and the session 'Discussion Topic 4 – Strategies for micro- and nanoplastics mitigation, remediation, and recycling' on emerging strategies for mitigating and remediating micro- and nanoplastics pollution.

6.1 Regulation of Microbeads in Cosmetics

The first speaker was Dr Prashiela Manga, Office of Cosmetics and Colors, US Food and Drug Administration, who spoke on 'Regulation of Microbeads in Cosmetics'. She covered the uses of plastic microbeads as abrasives in cosmetics and other over-the-counter products such as hand-cleansers, toothpaste, face scrubs, shampoos, and soaps.

These plastic microbeads began to be substituted for inorganic and natural materials in cosmetics in the early 1970s. One of the earliest patents (US3645904) for plastic microbeads as skin cleaners was awarded in 1972. Microbeads in cosmetics are typically 1-5 mm in size. Smaller microbeads provide mild abrasion and are used in face wash; larger microbeads provide intense abrasion and are used in body scrubs. Composition varies, from polyethylene (>90%), to polypropylene, methyl methacrylate, polystyrene, and polyethylene terephthalate. Purposes include removing dead skin cells for cleansing, removing plaque when used in toothpaste, and improving the appearance of the product. Definitions of microbeads vary by jurisdiction.

A 2017 survey of microbead content in cosmetics in China found nine facial scrubs containing microbeads at a density of 5,219 to 50,391 particles/g and estimated that 209.7 trillion microbeads (306.9 metric tons) were being released/year. (Cheung & Fok, 2017). A 2019 survey in Spain found 19 personal care products (comprising mainly scrubs); the highest counts found were 2,136 particles/g and 2,315 particles/g (Godoy, Martín-Lara, Calero, & Blázquez, 2019). A 2020 survey in the United Arab Emirates found 37 body scrubs, with highest counts of 6,889 particles/g and 12,412 particles/g (Habib, et al., 2020).

Increased public concern about environmental issues, specific concerns about environmental effects of single-use plastics, and efforts to reduce ocean plastic pollution, with microbeads as a particular concern, have led to calls to ban their use. Microbeads are single-use plastics that are released into wastewater and are too small to be trapped in sewage treatment plants. There are biodegradable alternatives available, including cocoa beans, ground apricot pits, and sea salt.

The US State of Illinois was the first government agency to ban non-biodegradable microbeads from personal care products in 2014, followed by the Netherlands the same year. In the United States, HR 1321, the Microbead-Free Waters Act, was signed into law on 28 December 2015. It prohibits the manufacture, introduction or delivery for introduction into interstate commerce of rinse-off cosmetics that contain intentionally added solid plastic microbeads. The US Microbead-Free Waters Act defines plastic microbeads as solid plastic particles less than five millimeters in size intended to be used to exfoliate or cleanse. The Act bans manufacturing after 1 July 2017 for cosmetics and after 1 July 2018 for over the counter (OTC) drug-cosmetics. It also bans introduction or delivery into interstate commerce after 1 July 2018 for cosmetics and 1 July 2019 for OTC drug-cosmetics, and includes a federal pre-emption of state laws. These bans fall under US FDA's authorities to regulate cosmetics, drugs, and dual products that function as both cosmetics and drugs. US FDA has posted a Frequently Asked Questions (FAQ) about the law on its cosmetics website home page.[2]

A number of other jurisdictions have since taken actions to ban or reduce the use of plastic microbeads in cosmetics and other products. These bans vary from jurisdiction to jurisdiction in a number of ways, including the precise definition of a microbead, the specific prohibitions on their manufacture, sale and import, as well as exemptions to the bans. The United Nations published a review of such regulations on single-use and microplastics in 2018 (United Nations Environmental Programme, 2018). A review of microbead regulation specifically was published in 2021 (Anagnosti, Varvaresou, Pavlou, Protopapa, & Carayanni, 2021). The map of global regulations on microbeads continues to change as additional jurisdictions impose similar types of restrictions on the use of microbeads in the future. However, the effectiveness of bans remains to be determined. A 2017 Australian survey (when there was no ban in place) inspected 4400 cosmetic products; 94% did not contain microbeads.[3] The Republic of Korea banned microbeads in 2017, but a 2019 survey of three wastewater treatment plants found microbeads predominant in plastics that were found, in samples from all three plants (Hidayaturrahman & Lee, 2019).

In addition, some jurisdictions have worked with industry on voluntary actions to reduce the use of microbeads. Major cosmetics industry companies have declared their intention to participate in the phase-out of solid, synthetic plastic microbeads, and to develop alternatives (e.g., biodegradable polymers; naturally occurring polymers such as cellulose; inorganic compounds such as silica or clay; natural compounds such as corn starch, walnut powder, seaweed, tapioca; and chemical alternatives such as fruit enzymes, lactic acid, salicylic acid).

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[2] https://www.fda.gov/cosmetics/cosmetics-laws-regulations/microbead-free-waters-act-faqs

[3] https://www.awe.gov.au/environment/protection/waste/publications/assessment-sale-microbeads-within-retail-market

The presentation showed how working with industry and other stakeholders can be successful in addressing some of the regulatory and management solutions for microbeads.

6.2 Can a more Circular Economy Stem the Flow of Plastic Particles?

The second speaker was Dr Kathryn Beers, Circular Economy Program, US National Institute of Standards and Technology (NIST), who presented on 'Can a more Circular Economy Stem the Flow of Plastic Particles?'. The circular economy concept is invoked in the recently enacted Save Our Seas 2.0 Act, which defines it as 'an economy that uses a systems-focused approach and involves industrial processes and economic activities that (a) are restorative or regenerative by design; (b) enable resources used in such processes and activities to maintain their highest values for as long as possible; and (c) aim for the elimination of waste through the superior design of materials, products, and systems (including business models)'.[4] NIST has refined the definition somewhat, to provide a clearer, more measurable metric, as 'keeping atoms and molecules inside the economy, producing value, and out of unwanted sinks such the environment (air, water, soil, etc.).' NIST is looking at all materials classes broadly, but the primary focus initially is to start with plastics and polymers. It is looking at opportunities to increase/improve both traditional mechanical recycling, as well as new and emerging technologies that promise opportunities for developing higher value applications for those materials, e.g., purification to remove additives that are problematic for mechanical recycled resins currently and breaking the polymers apart into more diverse small molecule feedstocks.

At a high level, this concept applied to polymers and plastics should reduce the flow of material into the environment, including plastic particulates. The reality is much more complex. When considering the full supply chain, from design and manufacture, to use and retrieval, the system is full of challenges and potential for leakage. The only way to ensure progress is to design changes to the system with these fundamental goals in mind, and to build the measurement and data frameworks that can support difficult decision-making and confidence in the results. There are many gaps and needs to adequately support the decision-making process. Some of the data and tools needed to support good choices in business and government are being addressed by the current NIST, Department of Energy, and National Science Foundation research programs related to circular economy and polymer upcycling, promoting research partnerships between materials science and economics. The Environmental Protection Agency has also recently released a new National Recycling Strategy[5] that will support building a circular economy.

Key questions for the NIST program include: (1) how to address use-phase losses (a key design challenge—what are the worst/highest priority products?); (2) innovating new materials and processes vs. action now using existing materials and technologies (simplifying vs. diversifying

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[4] US Public Law No: 116-224: https://www.congress.gov/bill/116th-congress/senate-bill/1982/text

[5] https://www.epa.gov/recyclingstrategy

the materials stream—recovering or requiring resorption?); (3) regulating production (tradeoffs in a complex supply chain—intimate connections with climate and social justice); and (4) data: what we do/don't know? (global vs. local challenges—scientific, supply chain, and economics data—uncertainty analysis). Although this is a global problem, there is much that can be done domestically, to connect science and technology, to collect the right kinds of data across the supply chain and promote the exchange of information in accurate, reliable ways, to provide a more measurable economy and mass and material flow through our businesses, to help us understand how to get better. Of particular importance to NIST is how to address uncertainty in the data.

Research underway at NIST related to nano-/microplastics by the circular economy environmental impacts team includes (1) environmental sampling methods (Jennifer Lynch and colleagues: sediment, beach sand, & fish guts—extraction and recovery method verification—reporting formats and uncertainty analysis); (2) laboratory models and testing technologies (Li-Piin Sung et al.: accelerated aging to understand degradation pathways in aquatic environments, prototype in-situ weather cell, etc.); and (3) standards and reference materials (Samuel Stavis and Andrew Madison: nanoplastics standards hide measurement 'surprises', heavy demand for 'good' samples and relevant plastics). There is a need for collaboration and coordination in all this work. All measurements will feed into spectral identification and other databases, coordinated with analysis of polymer and environmental standard reference materials for microplastics/additives, etc. NIST is doing some economic assessment work in this area, e.g., a review of life cycle analysis (LCA) applied to plastics, and evaluation of LCA modeling tools and databases. NIST is also participating in international standards developments related to plastics at both ASTM and ISO and is partnering with other US government agencies and international organizations on these issues.

In summary urgent actions on system design are necessary to limit further increases in microplastic pollution to the marine environment. Towards that end, NIST's Circular Economy Program supports the need *to transition away from a model in which materials are extracted from the environment, manufactured into products, used, then discarded (a so-called "linear economy") toward one in which the atoms and molecules that make up those products repeatedly cycle within the economy and retain their value*. The program's main elements include data and decision tools, materials science, and environmental impact assessment. The materials classes currently of interest include plastics/polymers, high tech waste (e.g. electronic, solar and battery waste), textiles and concrete.[6]

6.3 Microplastics in seawater across the North Pacific: A review and preliminary ecological risk assessment

The third speaker was Dr Wonjoon Shim, Korea Institute of Ocean Science and Technology, Korea, who presented 'Microplastics in seawater across the North Pacific: A review and

[6] https://www.nist.gov/circular-economy

preliminary ecological risk assessment'. He presented unpublished data from a study he conducted recently with colleagues Seung-Kyu Kim and Ji-Su Kim (Incheon National University) and Soeun Eo (Korea Institute of Ocean Science and Technology) that included a literature survey and meta-data analysis, monitoring methods and contamination levels for marine floating microplastics, comparing the North Pacific and the other world ocean basins.

Key questions for the study were: (1) Is the North Pacific the most microplastic polluted region? To address this, microplastic abundance was compared in the world's oceans through literature review. (2) Is there a particular sampling technique well suited to become a long-term monitoring program in the North Pacific? The most frequently used sampling/monitoring methods were reviewed and compared to inform recommendations for a long-term monitoring program. (3) Are the current microplastic levels in seawater of the North Pacific harmful to marine organisms? Preliminary ecological risk assessment was conducted with the proposed predicted no effect concentrations (PNEC) and the metadata extracted from the literature survey. The methodology included a literature survey of SCOPUS (1972-2020) + alpha. Search keywords were [(microplastic) + (marine, coastal, or ocean) + (water, saltwater, seawater, or water column) + (occurrence, distribution, accumulation, pollution, monitoring, or characteristics)]. A total of 175 papers / 204 data sets was reviewed (*some papers contain data with multiple methods or multiple regions). The mean value available was 130 papers / 163 data sets (filtered—checking sampling and analytical methods). Combining the exposure and effect data extracted from the literature, a preliminary assessment was conducted of ecological risk posed by microplastics to inform further action plans. The minimum cut-off size in sampling and/or analysis of microplastics was very crucial in comparison of monitoring data.

In answer to the key questions posed above, (1) Yes / Comparable with the other northern hemisphere regions. The North Pacific was most actively monitored for microplastics and showed relatively high levels compared to other regions of the world. Among 64 extracted mean abundance data of microplastics in seawater of the North Pacific, only 2 data exceeded the lowest predicted no effect concentration of 6.65 particles/L suggested so far. However, predictions are that microplastic pollution will increase to 50-fold by 2100 at the current rates, and in this scenario, the exceedance probability of PNEC might reach 21% of the North Pacific waters in 2100. The abundance of marine floating plastics which can reflect current pollution status as well as exposure levels of marine organisms is a useful abiotic pollution indicator for marine plastic pollution.

For question (2), Neuston or Manta net and pump or grab sampling are best suited for this purpose. For floating microplastics, firstly, monitoring using neuston or manta net with 300-355 µm mesh size is useful for global assessment of microplastic pollution status over space and time. Secondly, grab or pump sampling with minimum cut-off size 10-20 µm is required for ecological risk assessment of waterborne microplastics. With preparation of harmonized methods, increasing efforts are required to gather monitoring data for floating microplastics in the North Pacific.

For question (3), the answer is yes, probably in some polluted coastal regions. It would be worse in the future under a business-as-usual scenario. It is urgent to take precautionary actions to prevent a further increase in waterborne microplastic concentrations to protect marine ecosystems.

In summary, the North Pacific Ocean, including marginal seas, is one of the world's 'hot spots' for floating microplastic pollution. Harmonization of 'at least' minimum-cut off size for microplastic sampling and analysis is essential for assessment of global microplastic pollution. And precautionary action to reduce waterborne microplastic pollution is required to protect marine ecosystems.

6.4 Management of Microplastics in Ecosystems and Drinking Water in California

The fourth speaker, Dr Scott Coffin, California State Water Resources Control Board, US, presented on 'Management of Microplastics in Ecosystems and Drinking Water in California'. He set out how recent findings of microplastics in drinking water prompted the California legislature to pass Senate Bills 1422 and 1263 requiring the California State Water Resources Control Board (State Water Board) to address human health impacts in drinking water and impacts to coastal ecosystems. Both bills require the development of standardized analytical monitoring methods, risk assessments for humans and ecosystems, and monitoring to determine the extent of contamination.

In collaboration with the Southern California Coastal Water Research Project and 40 participating laboratories, the State Water Board conducted an inter-laboratory method validation study to determine the strengths and weaknesses of microplastics analytical methods. Findings from this study indicate that spectroscopic methods including Raman and infrared can provide accurate and precise enumeration of microplastic particle counts in drinking water for particles as short as 20 micrometers. The State Water Board is currently evaluating the performance of these spectroscopic methods in additional matrices, including fish tissue, sediment, and high turbidity waters.

Health impacts of microplastics have been relatively well documented in a range of aquatic organisms, with limited information regarding direct human health impacts through drinking water. To assess the available evidence for human health hazards of microplastics in drinking water and impacts to aquatic ecosystems, an expert workshop and systematic literature search were conducted. Studies were screened for quality criteria, including particle characterization, experimental design, and applicability for risk assessment prior to undergoing additional expert evaluation. Twelve mammalian toxicity studies were prioritized and subjected to a Tier 2 qualitative evaluation by external experts, of which 7 reported adverse effects on male and female reproductive systems, while 5 reported effects on various other physiological endpoints. No single study met all desired quality criteria, but collectively toxic effects with respect to biomarkers of inflammation and oxidative stress represented a consistent trend. It was not possible to extrapolate a human–health-based threshold value for microplastics, which is largely due to limited studies on polymers and shapes other than polystyrene spheres, uncertainties with measured apical endpoints, and missing exposure information. The expert workshop identified 167 toxicity studies for microplastics in aquatic organisms, of which 21 were deemed fit for purpose based on quality screening. Risk-based thresholds were developed using species sensitivity distributions to determine increasing certainty in adverse ecosystem impacts. Findings from these risk assessments are informing monitoring and risk management strategies for microplastics in California's drinking water supplies and in the marine environment.

California Senate Bill 1263 requires that the State Water Board and the California Ocean Protection Council to develop a statewide microplastics strategy by 2022 and by 2026 to develop a risk assessment framework and standardized methods, establish baseline occurrence data, investigate sources and pathways, and recommend source reduction strategies. The California Statewide Microplastics Strategy was published in early 2022[7]. Senate Bill 1422 requires the development of a definition of 'microplastics' by 1 July 2020, and by 1 July 2021, the development of standard methods, a four-year testing program, health-based guidance levels, and the accreditation of laboratories to conduct the tests. The resulting definition of 'Microplastics in Drinking Water' is '*solid polymeric materials to which chemical additives or other substances may have been added, which are particles which have at least three dimensions that are greater than 1 nanometer and less than 5,000 micrometers. Polymers that are derived in nature that have not been chemically modified (other than by hydrolysis) are excluded*.'

It is not currently possible to set drinking water regulations. Challenges include: (1) effects databases are inadequate (poor particle characterization, limited polymers, shapes, sizes tested); (2) effects mechanisms are unknown (necessary for extrapolation to diverse particle types); and (3) incomplete exposure data (limited information on food). So far, the recommended health-based guidance language is as follows: '*Studies of rodents exposed to some types of microplastics through drinking water indicate potentially adverse effects, including on the reproductive system. However, more research is needed to understand potential human health implications and at what concentrations adverse effects may occur. Therefore, California is monitoring microplastics in drinking water and supporting ongoing research*.'

Towards developing standard methods, a Southern California Coastal Water Research Project inter-laboratory validation study has been undertaken, with 26 participating labs from 6 counties. The study will measure blind samples processed by participating labs (using standard protocols for several candidate methods, quantify accuracy and precision); quantify method capabilities and limitations (from same laboratory, from experienced laboratories, from labs with

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[7] https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20220223/Item_6_Exhibit_A_Statewide_Microplastics_Strategy.pdf

different levels of experience); and quantify feasibility by tracking resources needed (costs and personnel time). Methods used include: (1) visual microscopy (+ -Nile red); (2) infrared spectroscopy; (3) Raman spectroscopy; (4) pyrolysis-GC/MS. The study is using blind samples of four polymers (polystyrene, polyethylene, polyvinyl chloride, polyethylene terephthalate); four size fractions (1-1000 µm, 1-20 µm, 20-212 µm, 212-500 µm, >500 µm); four shapes (pellets, fragments, spheres, fibers); and false positives (e.g., sand, shell fragments, cotton, cellulose, bunny fur). A standardized analytical method for microplastics in drinking water is now posted on the State Water Boards website.[8] There is ongoing method development on additional matrices. A two-phased approach is under development for monitoring drinking water through 2026, applying the ASTM D8332-20 Sampling Protocol.

In summary, as plastic pollution increases exponentially, widespread risks may be inevitable. Framing the problem will drive solutions, which include circular economy; awareness, bans, and less consumption; pricing, taxes, and subsidies, better feedstocks, recycling/reuse; and cleanups and better waste management. Towards those ends, California banned overseas dumping of plastic in 2021, and a new California Recycling and Plastic Pollution Act will appear on the November 2022 ballot.

6.5 Micro(nano)plastics: European Union actions to address the problem

The last speaker, Dr Birgit Sokull-Kluettgen, European Commission Joint Research Centre, Ispra, Italy presented on ‘Micro(nano)plastics: European Union (EU) actions to address the problem’. The Joint Research Centre is the science and knowledge service of the European Commission (EC) in support of EU policies. She described the EU measures on micro- and nanoplastics, tackling microplastic pollution by mitigation measures and closing the knowledge gaps.

Microplastic particles are widespread in the environment (air, soil, waters, plants, animals, human diet), and even smaller plastic particles, nanoplastics, have been observed. There is concern that accumulation of these particles could have an impact on the environment and on human health. For example, micro-/nanoplastics are widespread across the air, soil, sediments, freshwaters, oceans, plants, animals and parts of the human diet; their small size facilitates ingestion by organisms; there is risk of bioaccumulation through the food chain; various adverse effects have been reported in literature in biota (including direct ‘particle’ effects and (eco)toxicological effects via additives, impurities); and these materials can be very resistant to (bio)degradation, leading to a long term, irreversible, environmental stock—(bio)degradation, where this occurs, is via progressive fragmentation to nanoplastics. Until now, the extent and impacts of said accumulations have not been well understood.

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[8] waterboards.ca.gov/drinking_water/certlic/drinkingwater/microplastics

Major knowledge gaps are also acknowledged in independent scientific reviews (EFSA[9], WHO[10], SAPEA[11], SAM[12]). These include environmental and human exposure levels, internalization and biological effects, and interaction at cellular level. A recurring theme is that many of the gaps result in part or in whole from limitations of current analytical methods. Furthermore, the EU Chief Scientific Advisors[4] concluded (2019): "*Although the currently-available evidence suggests that microplastic pollution at present does not pose widespread risk to humans or the environment, there are significant grounds for concern and for precautionary measures to be taken*".

EU actions so far on microplastics fall into two categories: (1) closing the knowledge gap (e.g., monitoring of microplastics in seawater, drinking water; supporting research and innovation through H2020 and Horizon Europe research projects) and (2) mitigation measures (e.g., reducing primary microplastic particles—deliberately manufactured particles, intentionally added to products such as cosmetics, detergents, paints, etc.; and secondary microplastic particles from mechanical, chemical, and light-induced breakdown of bulk plastic litter as well as tire wear debris and fibers from textiles unintentionally released microplastics).

The overarching policy frame in the EU is the so-called "Green Deal[13]", one of the EC's priorities aiming to combat climate change and environmental degradation. Its Zero-Pollution Action Plan[14] sets ambitious targets concerning the reduction of plastic litter and microplastic pollution: to reduce by 2030 plastic litter at sea by 50% and microplastics released to the environment by 30%. The Green Deal provides a Circular Economy Action Plan[15], which besides others addresses micro- and nanoplastics pollution. Actions include the implementation of the Single Use Plastic Directive[16] aiming at reducing marine litter, and the restricting of intentionally added micro- and nanoplastics[17] via the EU chemicals legislation, REACH. A cost/benefit analysis of

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[9] https://www.efsa.europa.eu/de/efsajournal/pub/4501 EFSA: European Food Safety Authority

[10] https://www.who.int/publications/i/item/9789241516198 WHO: World Health Organization

[11] https://www.sapea.info/topics/microplastics/ SAPEA: Science Advice for Policy by European Academies

[12] https://op.europa.eu/en/publication-detail/-/publication/f235d1e3-7c4d-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-108645429 SAM: Scientific Advice Mechanism

[13] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[14] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en

[15] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

[16] https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en

[17] https://echa.europa.eu/es/-/echa-proposes-to-restrict-intentionally-added-microplastics

possible measures to reduce unintentionally released microplastics[18] is underway, focusing on pellets, tires, and textiles. Furthermore, the EU water legislation is under evaluation, including possible measures on microplastics. The revised Drinking Water Directive[19] aims to adopt a methodology on measuring microplastics in drinking water by January 2024. To support research and innovation to close the knowledge gaps the EC has funded the European Research **C**luster to **U**nderstand the health impact**S** of micro- and nano-**P**lastics (CUSP)[20].

In summary the presentation showed how regional policy actions, supported by expanding research and policy work, need to address the costs and benefits of all components and solutions within the system to ensure the best approach to avoid environmental degradation.

6.6 Summary

In the closing discussion led by the Chair Matthew Kupchik, speakers reflected on the increase in global attention that has been given to micro- and nanoplastics around ecotoxicology and regulation. The microbead bans are seen as the regulations that have led the way with the public interest focused on the marine impact. The more recent findings of plastics in drinking waters are likely to lead to more regulations as have been seen in California's microplastics in drinking water regulation. Consumer awareness of marine plastics is a driver for the science and has a positive effect; with the caveat that the science to inform the decision-making process is complex. There are data gaps across the whole APEC region when characterizing the spatial distribution of microplastics and there is a need to harmonize sampling size cut-offs and standardize reporting. There is a historic record from legacy/archived samples that can add to the temporal record by using the latest techniques to take measurements. Harmonization involves collaborating with others and being critical of techniques to ensure continuous improvements in method development. Key messages from the plenary discussion were:

- Increased coordination and collaboration between researchers, policy makers, and other stakeholders is necessary to develop robust solutions to address micro- and nanoplastics.

- Ongoing research will be needed to support the refinement of definitions that underpin regulatory and management systems for micro- and nanoplastics, and those regulatory systems will ultimately impact the scale, scope, and direction of research going forward.

- Approaches and solutions, such as circularity, will require thoughtful thinking to address the many potential data gaps, incorporate the large range of stakeholders across

[18] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12823-Microplastics-pollution-measures-to-reduce-its-impact-on-the-environment_en

[19] https://ec.europa.eu/environment/water/water-drink/review_en.html

[20] https://cusp-research.eu/

several sectors outside of plastics, and develop solutions that minimize overall effects to both the environment and human systems.

- The types and scales of micro-and nanoplastics will be important for understanding the potential impacts to ecosystems and for human health, with particular focus on making sure researchers have access to relevant reference materials that mirror the particles seen in the environment – including a whole range of polymers and formulated plastics.

- Normalizing reporting and methods is important to ensure that results can effectively provide a full-body of work that is consistent and useable.

7. Discussion Topic 3 – Terminology, nomenclature and harmonizing methods: efforts towards consensus

The Discussion Topic 3 was chaired by Åsa Jämting, National Measurement Institute Australia. This discussion session focused on current efforts in establishing a common terminology and nomenclature within the micro- and nanoplastics community. Recent results from interlaboratory comparisons and developmental work in harmonizing test methods and protocols was also presented. With the current high interest in the micro- and nanoplastics field, the need for more formal approaches to establishing frameworks to support regulatory, governance and standards development work is of high importance and this was clearly reflected in this discussion session.

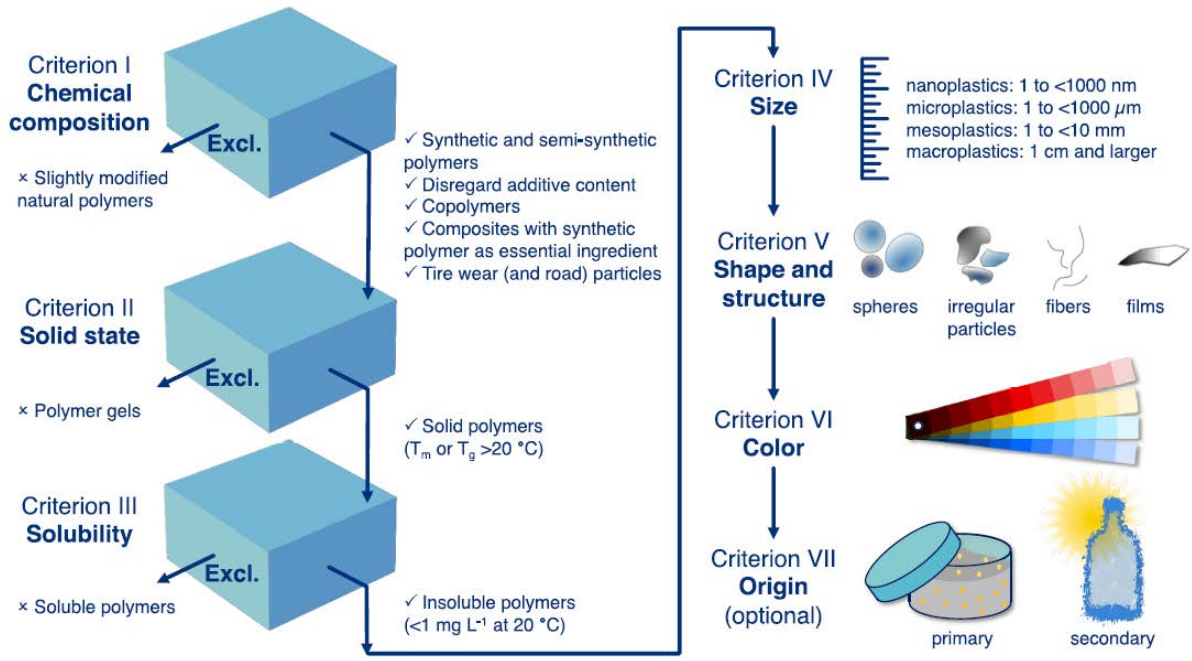
In this session, the speakers presented various approaches from their respective agencies/research centers to tackle issues related to the session topic. Two of the presentations shared useful insights into setting up and performing measurements of micro- and nanoplastics and the challenges associated with choosing methods suitable for the task. Three of the presentations focused more on the actual development of and need for documentary standards, both for terminology and nomenclature. All the speakers in this session highlighted the need for harmonized test methods to ensure that robust research data can be established and communicated. There are indeed advantages and disadvantages with a unified terminology, and one of the speakers recommended a more framework-based approach for definition and categorization. One of the speakers clearly addressed some of the issues related to challenges with experimental design, including sampling, and the requirement for more comparable data to support statistical analysis, modelling and prediction of future trends.

Some insight into these issues was illustrated in the presentation of the results from a large interlaboratory comparison (ILC) focused on determination of microplastics in drinking water. Some of the conclusions from that ILC show that whilst a large number of different analysis techniques were applied in this ILC, no group of methods could be identified that systematically seem to give results that are more consistent with the indicative ranges of expected values than others. The need for standardized test methods was also confirmed by the large spread of measurement results, even when comparing individual techniques, as a great variety of experimental practices were applied.

From a documentary standardization point of view there was a call for a unified approach between standardization bodies, as well as for experts to join in this important work.

In terms of definition and categorization, definitions may not need to be based on size, but also include aspects such as chemical composition, shape and structure, color etc. as shown in Figure 7.1. From several of the speakers, the need for limits of the quantities (concentration and type) of plastic being encountered was expressed. This issue may provide guidance on what type of technique is required to generate the data.

Figure 7.1 Proposed definition and categorization framework (N. Hartmann, 2019)



Excl. = excluded

7.1 Micro- and nanoplastics (MPs/NPs) in food: analytical developments and challenges

The session began with Dingyi Yu, Singapore Food Agency (SFA), Singapore, presenting on 'Micro-/Nanoplastics (MPs/NPs) in Food: Analytical Developments and Challenges'. He discussed the concerns of his agency in the micro- and nanoplastics field, where in food related applications risks has been identified and presented some of the knowledge gaps they have identified. A potential path forward has been proposed, and he showed some of the recent activities that has been carried out to, including their instrumental multi-technique based analytical set-up and results from studies of products likely to contain microplastics, such as table salts and bottled water. The Singapore Food Agency recently participated in the European Union Joint Research Centre interlaboratory comparison on Microplastic in Water. This study is presented in the next talk in this session by Susanne Belz and he reported on this by sharing the testing approach and the submitted results. Finally, efforts into toxicity testing of microplastics using a 3D tissue culture was presented.

7.2 Challenges of microplastics analysis in water – Results of an Inter-laboratory comparison on the determination of microplastics in water'

The second speaker was Susanne Belz, Joint Research Centre Ispra, Italy, presenting the results from a recent interlaboratory study on 'Challenges of microplastics analysis – Results of an Inter-laboratory comparison on the determination of microplastics in water'. More than 100 sets of data were submitted, reporting on either number of particles/liter or mass of particles/liter (or both of these measurands). The participants received a bottle of clean water, a vial of PET particles in NaCl carrier and a rising solution for cleaning. A range of techniques (17 in total) were used on this study, including microscopy Fourier Transform Infrared Spectroscopy (µFTIR), Raman microscopy, mass spectrometry based techniques and optical and fluorescence microscopies. A range of sample preparation steps were also applied, and she reported on the effects of some of these on the results. The results, both number and mass based were scattered around a central value, rather than converging to one. The conclusions included the observation that there are a large range of applicable methods, each with their strengths and weaknesses. No single technique or group of techniques systematically performed better than others. The lack of inter laboratory comparability became apparent, and the need for harmonization to improve comparability was clearly identified.

7.3 Towards globally harmonized definitions and categorization of plastic debris

The third speaker was Dr Nanna Hartmann, Technical University of Denmark, Denmark, presenting on 'Towards globally harmonized definitions and categorization of plastic debris'. This was a comprehensive discussion around the need for a definition and categorization framework for plastic debris. She discussed what makes plastic 'plastics', whether we need definitions or not, if size cut-offs are a good way of categorization or not and elaborated if we are moving towards consensus or not. She commented on the advantages and disadvantages of globally harmonized efforts, such as avoidance of miscommunication, clarity in legal and regulatory frameworks but also questioned if this field is too immature. Perhaps there is still a need to be more adaptive and for caution regarding misinterpretation related to expected behavior of microplastics, their uptake and associated risks. Finally, she presented a potential framework to be applied, based on a range of criteria, from chemical composition, state, solubility to size, shape, color and origin.

7.4 Microplastic analytics: Challenges, Possibilities and Limitations in the World of Standardization

The fourth speaker was Dr Claus Gerhard Bannick, German Environment Agency, Germany, who presented on ‘Microplastic analytics: Challenges, Possibilities and Limitations in the World of Standardization’. He presented work towards documentary standardization of microplastics from a Deutsches Institut für Normung (DIN, German Institute for Standardization) and International Organization for Standardization (ISO) perspective, in particular some recent work by a joint effort by ISO/TC 61/SC 14/WG 4[21] and ISO/TC 147/SC 2[22]. This joint working group are planning a series of standards related to water quality, looking at sampling, measurement methods, ecotox and sample preparation. For this work, there is a clear need for harmonized terms and definitions, also when considering guidelines from other international standards organizations such as OECD, ASTM and UN. In his conclusions, he identified microplastics in the environment as being an international challenge, that there is a need for standards for analysis of plastics in environmental matrices, that a fundamental challenge is how to handle overarching horizontal topics (such as the various different technical committees within ISO), the microplastics are *not* considered a top-priority issue (so far) and that the primary goal is to avoid contradictions at the technical level in the various standardization organizations (DIN/CEN[23]/ISO etc).

7.5 Problems and practicalities of harmonizing terminology, nomenclature and methods for microplastic and nanoplastic

The fifth speaker was Mark Browne, University of New South Wales, Australia, who presented on ‘Problems and practicalities of harmonizing terminology, nomenclature and methods for microplastic and nanoplastic’. He shared a comprehensive presentation looking at the need for generation of comparable data. He pointed out that survey methods need to be comparable in aims, hypothesis, analyses and conclusions. This includes sample collection, which needs to be representative of entire area of interest not just sampled where convenient and the need for replicates of the samples. He also covered some of the dangers related to sample preparation methods, for example the use of plastic equipment to sample plastics. He also explored what it is that needs to be analyzed (physical, chemical, biological, ecological or statistical properties). Then there are also questions about the accuracy of sampling and measurement methods and how to assess and address uncertainties. The take-home message from the presentation was that most surveys do not provide robust enough data to allow comparable assessments, examine trends or certainty about the quantities for polymers being encountered and that there

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[21] ISO/TC: International Organization for Standardization/Technical Committee. Working group ISO/TC 61/SC 14/WG 4: Characterization of plastics leaked into the environment (including microplastics) and quality control criteria of respective methods

[22] Physical, chemical and biochemical methods. Joint ISO/TC 147/SC 2 - ISO/TC 61/SC 14 WG: *Plastics (including microplastics) in waters and related matrices*

[23] The European Committee for Standardization

is a clear need for logically harmonized terminology and nomenclature, standardized methods and statistical tests as well as linked structured surveys to determine patterns.

7.6 Microplastic assessment: Issues of harmonization and guideline development

The sixth speaker was Nikolai Kozlovskii, Pacific Geographical Institute of Far Eastern Branch of Russian Academy of Sciences, Russia, who presented a brief overview of issues that may occur during harmonization and development of guidelines, especially when considering micro- and nanoplastics. Some of these issues relate to misunderstandings among researchers and analysts and the need to improve on this. There is a need for understanding of pollution on a global scale, for prioritization of monitoring activities to clarify research tasks and enabling of a faster transition of such tasks once more information/knowledge becomes available. Some of the complications arise from sampling from various compartments in the environment, matrices associated with those, the sampling methods used as well as sample preparation steps. Classification issues are also important, including both size and morphology, and well as chemical identification. He presented results from FTIR and Raman analyses, along with optical and UV light microscopy, and highlighted some of the issues relating to each of these techniques. In his summary, he expressed the potential need for a level of maximum acceptable concentration for differently sized micro- and nanoplastics or polymer type to assist in prioritization.

7.7 Microplastics terminology from ISO perspective

The last speaker was Dr Denis Koltsov, Brec Solutions, UK and chair ISO/TC (International Organization for Standardization/Technical Committee) 229 Nanotechnologies, who presented on ‘Microplastics terminology from ISO perspective’. He noted that many issues facing the microplastics community compare well with what has been facing the nanotechnology community over the past 15 years. The presentation opened by addressing the use of standards in representing best practice, consensus based, allowing compatibility and intercomparison of products, facilitate consumer acceptance by providing safety standards for products and the cost effectiveness in the long run. He discussed the development process for documentary standards and the role of domestic and international organizations in this process; and he described how ISO/TC 229 Nanotechnologies is structured, with its various joint working groups and areas of interest. He then proceeded to parallel some of the efforts in TC 229 with what development of micro- and nanoplastic standards is facing, especially in terms of terminology and definitions. The definition should be tied to one or two scientifically defendable attributes. Other attributes (such as linguistics, history or fashion) may influence the choice of the terms and definitions but should not be prioritized. In his conclusions, he pointed out that since the terms “microplastic” or “nanoplastic” carry size and material information the definitions for these terms *must* use at least these two attributes. In regard to terms and definitions, as they should be developed for the appropriate use and user community, there is a real need to include academia, industry, regulators, NGOs and consumer groups in the development of this framework. Finally, he stressed the importance that terms and definitions should not be circular or in contradiction with other terms and definitions in ISO.

7.8 Summary

From these presentations, there is clearly a need for harmonized methods, in terms of terminology and nomenclature, as we need definitions that work. There is also a demand for suitable reference materials and interlaboratory comparisons, both of which help to underpin development of documentary standards and test guidelines.

8. Discussion Topic 4 – Strategies for micro- and nanoplastics mitigation, remediation, and recycling

Discussion Topic 4 was chaired by Dr Christy Payne, National Science Foundation, US. Pre-recorded presentations highlighted the prevalence of macro-, micro- and nanoplastics pollution, the growing evidence of its impact on aquaculture and ecosystems, and the challenge of understanding pathways of environmental emissions. Innovation is needed in preventing and mitigating leakage, effectively remediating environments, and redirecting and reusing plastic waste.

8.1 Microplastic-specific solutions to plastic pollution

The first speaker was Dr Chelsea Rochman, University of Toronto, Canada, who presented on 'Microplastic-specific solutions to plastic pollution'. This talk under the theme of sources, prevention, and mitigation covered how microfiber, micro- and nanoplastic pollution is pervasive - it arises from many sources - and is transported through both liquid and air in planetary cycles. Correlating emissions to the environment with a source is difficult (except near wastewater treatment plants) and monitoring pathways into the environment can inform local mitigation strategies. She commented that globally as plastic production has increased, so has plastic waste. Over the years, very little of this plastic has been recycled (9%), and much of it goes to landfill or the environment, with some of it entering our rivers, lakes and oceans. Predictions (Jambeck, et al., 2015) have motivated action on the global stage (Borrelle, et al., 2020) by describing how much of our plastic waste enters our oceans. This is critical, but one thing to note is that these predictions of plastic waste do not account for several sources of microplastics. These other sources include wastewater (e.g., microbeads, microfibers), agricultural runoff (e.g., films, microfibers), stormwater runoff (e.g., tire wear particles) and/or industrial runoff (e.g., pre-production pellets). In response, when we design solutions, we need to include those relevant to plastic waste, but also some that are more specific to other sources of microplastics. In addition to managing plastic waste, solutions may target microfibers in wastewater and/or tire dust entering via stormwater runoff. These may include putting filters on washing machines to trap microfibers before they enter wastewater treatments plants (Erdle, Parto, Sweetnam, & Rochman, 2021). A solution for stormwater runoff can be to treat it via bioretention cells like raingardens. In summary she concluded that by tackling solutions that capture plastic waste, and target microplastics, we can more holistically manage our plastic problem and more meaningfully reduce plastic emissions to terrestrial and aquatic ecosystems.

8.2 Microplastics Mitigation Plan in Coastal Aquaculture Input Chains for Seafood Safety

The second speaker was Dr Hatim Albasri, Center for Fisheries Research, Ministry of Marine Affairs and Fisheries, Indonesia, who presented on 'Microplastics Mitigation Plan in Costal Aquaculture Input Chains for Seafood Safety'. He explained how the evidence demonstrating that micro- and nanoplastic pollution has an impact on aquatic biota and coastal aquaculture is growing. It has been estimated (Van Cauwenberghe & Janssen, 2014) that an individual could ingest 11,000 particles of Microplastics annually through seafood consumption. This estimate was later on popularized widely by National Geographic in 2019 sparking concerns about the safety of seafood products including from aquaculture for human consumption. The estimate might be overly generalized to all regions and economies. However, this safety concern could discourage seafood consumption leading to a reduced market share of seafood products exported by most APEC economies. In particular, aquaculture seafood products of APEC economies have greater risks from microplastics contamination due to the following reasons. **First**, most literature regarding microplastics in coastal environments focuses on wild fish and other wild organisms. In contrast, microplastics distribution in the coastal aquaculture input chains is relatively unknown. **Second**, farmed fish are kept in a controlled environment for a certain period of time. Thus, the farmed organism can be exposed to microplastics during the entire farming cycle. **Third**, coastal aquaculture input chains that involve use fish meal, feed lining packaging and farming practices that are susceptible to microplastics contamination. For example, ten APEC economies imported at least 2.4 million metric tons of fish meal used for various purposes, including for fish feed. Current literature has confirmed that fish meal contains high microplastics. Yet, microplastics contamination has only been reported from China and Malaysia. In addition, microplastics in other input chains of coastal aquaculture are still unknown. **Fourth**, there is no standard regulatory framework within the APEC economies directly related to microplastics in the coastal aquaculture input chain. Such missing regulatory components could put the APEC economies at a disadvantaged position if future Global Aquaculture Practice requires minimal microplastics in aquaculture products. He concluded by considering the issues above and the current trend of microplastics policy and research in which aquaculture receive less attention, it is vital to start involving aquaculture aspects, especially its inputs chains, in the policy making and research activities regarding microplastics. This is to ensure that aquaculture products especially from coastal regions of APEC economies are safe for human consumption and increase the bargaining position of APEC economies in competing with other major producers of aquaculture outside of APEC region.

8.3 Microfiber Pollution: A path of science and solutions

The third speaker was Rachael Miller, Rozalia Project for a Clean Ocean; Cora Ball, US, who presented on 'Microfiber Pollution: A path of science and solutions'. She looked at the remediation options for capturing fibers from washing machines and the need for filter technology on clothes dryers to be developed. When the problem of microfiber pollution from fiber fragmentation first emerged, washing machines dominated the conversation. Since then, it has become evident that while washing machines are a significant source of this problem, they are not the only source. Additionally, science and solutions are needed in the emerging areas of clothes drying and the particularly difficult to study category of emissions while wearing clothes. The team at the nonprofit Rozalia Project for a Clean Ocean have been addressing the problem of microfiber pollution since 2013 with the concurrent goals to contribute scientific knowledge to this problem, develop a solution to help prevent microfiber from reaching the environment and raise awareness to people in myriad industries to inspire and hasten innovation to get ahead of this problem. She showed results from a quantification of dryer vent emissions from a fleece blanket (Kapp & Miller, 2020). The importance of contamination control in microplastics studies was highlighted by an investigation into contamination from researcher clothing (Gwinnett & Miller, 2021) with and without anti-contamination protocols. The Rozalia team's consumer solution for washing machines, the Cora Ball was presented; along with education, citizen science and seeing consumers as part of the solutions to microfiber pollution. The problem of microfiber pollution in our ocean and public waterways is a big one that comes in tiny packages and the more science-backed strategies that are focused on it, the better. In summary there are opportunities for innovation within a circular economy: Prevent leakage (resilient clothing); Stop leakage (washing machine filters, reduced dryer emissions, consumer actions); and Close the loop (upcycling mixed fibers).

8.4 Commercial Plastics (Macro and Micro) Collection and Separation Technologies for Beach Cleanup

The fourth speaker was Jean-David Lantagne, Hoola One Technologies, Canada, who presented on 'Commercial Plastics (Macro and Micro) Collection and Separation Technologies for Beach Cleanup'. He set out that the problem of microplastic pollution problem is growing and alarming. It is therefore important to act quickly on this problem starting directly by the different sources of pollution such as plastic consumption, waste and wastewater management. However, we must realize that our environment is already polluted by this material and that we must not only stop the problem at the source, but also clean up the damage that has already been done. Beaches are not spared this problem, since 97% of floating plastics that end up in the ocean end up on beaches (Lebreton, 2019) and as a result, the most beautiful beaches around the world are covered with plastic. The presence of this waste on the shores has important consequences on ecosystems, human health and on the economy of communities dependent on tourism (Thorbecke, 2021). Existing beach clean-up machines are not able to meet the needs for technological solutions to act on this specific problem as they are not able to collect small plastic particles (microplastics), are intrusive to the ecosystems and are not able to work on uneven beaches. There is therefore a lack of solutions to effectively recover microplastics especially without endangering beaches and marine ecosystems. Hoola One Technologies is a startup which develops and offers technological solutions to sites affected by macro and microplastics to preserve and restore ecosystems affected by plastic pollution. Over the years, Hoola One has developed four technologies which have been specially designed for this purpose and respond in a complementary way to the very different needs of the market which vary according to the different types of coastal environments as well as the customers' motivations to clean. To conclude: Surface-level plastic marine debris deposits on beaches/shores and must be thoughtfully remediated. The key technological gap is the ability to collect microplastics while maintaining ecosystem health. There is no single solution to the problem and there is a lot of work to be done to fill this gap.

8.5 Polymer sustainability - End-of-Life and Biopolymers

The fifth speaker was Assoc. Prof. Bronwyn Laycock, University of Queensland, Australia, who presented on 'Polymer sustainability - End-of-Life and Biopolymers'. She looked at the post-capture and end-of-life plastic waste management theme. Given the very large and increasing volumes of plastics entering the plastics value chain annually, there is an inevitable and increasing volume of macro-, micro- and nanoplastics leaking into our marine, riverine, land and air environment. While a holistic solution to this issue needs to be multi-faceted and incorporate data, policy, legislation, supply chain, social, techno-economic and human/consumer behavior considerations, there are a wide range of technical solutions being adopted. This presentation provided an overview of some of the end-of-life options for plastics waste as well as an introduction to the alternative class of plastics – the bioderived and biodegradables (Chan, et al., 2019). Work at The University of Queensland includes the study of biodegradation of waste in the marine environment (Dilkes-Hoffman, Lant, Laycock, & Pratt, 2019) showing a PHA (polyhydroxyalkanoate) biodegradable bottle has a mean lifetime of 1.5–3.5 years, a PHA thin film lasts 0.1–0.2 years. In summary, there are many possible stages for intervention/redirection of plastic waste and end-of-life management: Materials (renewable feedstocks, novel materials); Manufacturing (holistic product design, fewer additives); Supply Chain (commercial behavior & logistics); Consumption (consumer behavior & incentives); Disposal (intercepting waste, circularity).

8.6 Aligning Recycling and Manufacturing: SMaRT@UNSW Green Steel and Microfactories Using Waste as Resources

The final speaker was Prof. Veena Sahajwalla, University of New South Wales, Australia, who presented on 'Aligning Recycling and Manufacturing: SMaRT@UNSW Green Steel and Microfactories Using Waste as Resources'. She described how due to the rapid growth in the use of plastics, and the throw-away mentality associated with these plastics, major challenges are faced by our current systems for solid waste management, with adverse flow-on impacts on our natural environment. One way to overcome this challenge is to convert waste plastics into value-added materials and products. Our traditional approach towards the waste plastics management, the '3R' approach of 'reduce' 'reuse' and 'recycle', needs a fourth R of 'reform' where innovations can enable us to reform waste materials into new things beyond merely recycling them back into bottles and pellets etc. One of the successful breakthroughs to reform waste plastics is SMaRT@UNSW Green Steel™ *Polymer Injection Technology* (PIT) which leverages high temperature reactions in Electric Arc Furnace (EAF) steelmaking (Sahajwalla, et al., 2010) to transform waste tires and plastics in the production of high-quality steel, as a replacement for coke and coal. This was a world-first, patented process and Professor Sahajwalla demonstrated that a mixture of coke and recycled polymers produced a more stable foamy slag compared to coke only – greatly improving furnace energy efficiency, improving yield and reducing raw material cost (without detriment to furnace functioning or the finished product). PIT's 'green steel' is in commercial production around the world. Being able to release carbon and hydrogen from waste as a resource improves overall efficiency and helps us move towards decarbonization because hydrogen is present in waste.

Another challenge to be addressed is how best to establish decentralized, small-scale systems for plastic waste, which are based on microrecycling technologies (Sahajwalla, 2018), (Sahajwalla & Hossain, 2020). Large-scale, industrial processing operations are expensive and energy-intensive. These processes also depend on extensive collection and transport operations to deliver waste to recycling centers. Providing smaller operators with technology to process most of their own waste locally would reduce transport need and use of raw materials – as well as producing value-added, recycled, and reformed renewable materials. The SMaRT Centre's novel MICROfactories™ could be established in cities as well as small towns, rural and remote areas to reduce their reliance on centralized recycling industries. Decentralised MICROfactories™ could transform e-waste into value-added materials at a local level via selective thermal transformation and contribute to global supply chains as well as meeting local manufacturing needs with locally recovered materials. These solutions could contribute to 'economies of purpose' by empowering the small operators. Sustainable materials technologies could convert problematic waste plastics into products or input for another manufacturing process, such as transforming plastic toys (Nur-A-Tomal, Pahlevani, & Sahajwalla, 2020) and e-waste (Gaikwad, et al., 2018) plastic into filaments for 3D printing. This approach of sustainable materials research creates win-win outcomes for Engineering, Environment and Economics and goes beyond conventional recycling and supply chains. She concluded that problematic waste plastic can be a resource for new, green solutions (technologies, products, and materials) and provide local community benefits through job creation and economic growth.

8.7 Summary

In the presentations there was agreement that regulation on pellets and loss, downstream effluents, all sources and harmonizing standards is needed. The most pressing challenges are research around standards harmonization, life cycle assessment and assessing new materials for sustainable plastics circular economy. There is a need for novel materials design including resilient fabric, tires and films aligned with environmental performance requirements and testing standards from manufacturers.

The discussion found there must be a range of approaches to mitigate plastic waste lost to the environment and to remediate polluted environments. While the prevalence and hazards of micro- and nanoplastics are becoming more apparent, we must continue to consider plastic pollution along a continuum length-scale. APEC member economies-specific considerations and opportunities exist (e.g., addressing ghost fishing nets, acting locally to solve a global problem, job creation, build understanding of varying market conditions by economy). Global-scale citizen science initiatives should be approached from a "watershed" perspective rather than a bifurcated coastal/oceans versus inland perspective. Manufacturers must play a role in mitigating airborne micro- and nanoplastic pollution: need for harmonized "environmental performance" standards, implementation of effective control measures, avoiding polymeric materials that are not fit-for-purpose, redesign/alternative materials for high-priority, problematic polymers, focus on resiliency in materials design. In summary industry-academic partnerships across multiple industries are vital for the acceleration of science and achievement of technological outcomes.

9. Discussion Topic 5 – Current and proposed regulations on intentionally used plastics

Discussion Topic 5 was chaired by Matthew Kupchik, United States Agency for International Development. The session covered regulations and private sector engagement to address marine plastics. The pre-recorded presentations looked across several sources for micro- and nanoplastics in the marine environment and the regulatory, management, and private sector solutions to address some of those pollution challenges. While potential solutions vary based on the specific sources or plastic type, the video presentations highlighted issues with research and potential solutions as a suite of options that can be helpful for APEC economies in developing solutions to address pollution from micro and nano-plastics.

9.1 Sustainability and Circular Economy in Plastics and Waste Management Policies

The first speaker, Rachel Meidl, Baker Institute for Public Policy, Rice University, US, presented on 'Sustainability and Circular Economy in Plastics and Waste Management Policies'. She described how global energy demands, environmental concerns, and the plastic waste crisis have increased focus on decarbonization efforts and waste reduction strategies such as advanced recycling of plastics. Managing plastic waste throughout life cycles and supply chains, increasing plastics sustainability, and transitioning to a circular polymer future can generate new opportunities for modernization, competitiveness, and job creation, consistent with global economic, energy, and environmental objectives. However, the world cannot progress to circularity and a sustainable future without an agenda that recognizes the value of plastics from cradle to grave. A circular economy has the potential to interrupt the current linear model of unsustainable production, consumption, and waste generation by encouraging system innovation that designs out waste, increases resource efficiency, keeps materials in use, and decouples growth from the consumption of finite resources—thereby achieving a healthier balance between the economy, the environment, and society.

Transforming the plastic and waste management system and evolving to a circular economy will only be sustainable if impacts along the entire value chain are appropriately identified and measured. With a domestic and global focus on a climate plan that prioritizes clean energy, circular economy and sustainability, it is critical to integrate life cycle dimensions and a systems perspective into future policies to identify, quantify, and assess the social, environmental, and economic implications of products, processes and technologies across their life cycles. If circularity is the preferred way forward, policies should consider a range of resource management solutions, including advanced recycling technologies that transform plastic waste into value-added commodities that can be used as a feedstock for production of new chemicals, virgin-grade polymers, lower carbon fuels, and other materials. In stemming the tide on the plastic waste crisis, it is essential to invest in and incorporate emerging technologies, shift consumer behaviors, design for circularity, and utilize fiscal instruments, government standards, voluntary measures and partnerships across the entire value chain. Regardless of the configuration, plastics management requires the underpinning of informed and balanced policies that keep pace with technologies across their entire life cycle and account for impacts along the global supply chain.

Sustainability is a core concept for decision making and policy development, where an integrated approach to environmental, social, and economic impact issues leads to long-term, sustainable balance and profit growth. There is very a little understanding of this approach in current government policies and business decision making, which follow a linear economy that extracts materials and discards them. Demand for plastic keeps increasing, and common plastics generally have no or limited end-of-life solutions. In a circular economy, there are five predominant business models: circular supplies/circular design, resource recovery (recycle), remanufacture/resell/repair/upgrade, sharing, and viewing a product as a service. A life cycle model is challenging but is required to improve the recovery or recycling plastics to mitigate the plastic pollution. Advanced recycling has been developed and applied in the system by considering plastics as molecular constituents. Sustainability is a balance between social, environmental, and social economy considerations.

9.2 Perspectives on microplastic Regulatory Challenges

The second speaker was Dr Andrew Bartholomaeus, University of Queensland, Daimantina Institute, Australia, who spoke on ‘Perspectives on microplastic Regulatory Challenges’. He set out that although microplastics present a significant environmental challenge and risk there is a *negligible* food safety risk despite their presence in sea food and other food commodities. The level of microplastics in the edible portions of most sea food is very low and absorption from the human gastrointestinal tract is also very low. Humans have been exposed to non-biodegradable micro and nano-particulates for all of our evolution (such as clay and silicate particulates) and the absorption of particulates from the gastrointestinal tract as such is not novel. In his background in food and pharmaceutical risk assessment and regulation he has seen first-hand the risk generating consequences of excessive risk aversion and blinkered regulatory responses that fail to consider the broader context within which the regulations operate.

The study and manipulation of ultrafine and nanoparticles is much older than generally recognized. For example, some of these issues were addressed in Jerome Alexander’s *Colloid Chemistry*, published in 1919 (Alexander, 1919). Direct “persorption” of µm size particulates (15-75 µm optimum) across the GI tract wall was first observed in 1844 (Volkheimer, The phenomenon of persorption: persorption, dissemination, and elimination of microparticles,

2001) (Volkheimer, 1974). Particles of starch, charcoal, sulphur, rabbit hair, silica, etc., were variously studied in rabbits, dogs, or frogs and found to be taken up into blood, bile and urine. Transport of persorbed particles from the gut to the systemic circulation is primarily via the chyle (lymphatic system) rather than via portal blood. Absorption pathways for nanoparticles may differ to that of microparticles but their uptake is not novel per se (in itself).

Data on the impact of micro-nanoplastics on mammals is limited. The literature contains many poor papers. Limitations include inappropriate/misleading dose metrics, poor grasp of the differences between particle and small molecule pharmacokinetics, and unrealistic exposure scenarios in *in vitro* experiments. Some are riddled with basic misconceptions, e.g., smaller particles in the nanometre to low micrometre range do not necessarily pass biological membranes better than larger ones in that range; there is no novel toxicity associated with particle size or surface area per se; smaller particles are potentially less toxic than larger ones of the same material. The non-medical literature has not assimilated the large body of clinical experience with parenterally administered nanoparticulate pharmaceuticals.

Good regulation needs a clear target that robustly identifies what is new, how it is new and what the specific risk is that needs to be mitigated or managed. Regulations, and the regulatory burdens imposed, that arise from this process need to be proportionate to the risk(s) identified and should consider the broader consequences of their introduction. Most importantly regulations need to be based on robust science and not vague theoretical hazards. This is unfortunately not always the case. The unscientific demonizing of Genetically Modified food crops for example and the disproportionate regulation arising from this in some jurisdictions has resulted in unnecessary burdens of death, disease and suffering in some of the poorest communities on earth and impeded the use of the most responsive and powerful suite of tools to address challenges of climate change to food production.

Ethical regulation must embody balance, proportionality, pragmatism, cost effectiveness, impartiality, and most importantly - scientific integrity. As the systemic exposure to microplastics in food is negligible even under extreme worst-case assumptions, and as plastics play an important role in the supply of safe food and the prevention of food waste, any phase out or substitution with other less environmentally damaging materials needs to be progressed in a manner that does not increase other (greater) food safety or food security hazards. As recommended in the EU SAM[24] report (European Commission, 2019) regulatory intervention to address the environmental issues should therefore be embedded in a “reduce – reuse – recycle” circular-economy logic, should be politically and socio-economically feasible and based on quantitative analyses of broader factors (trade-offs; substitution strategies/alternatives; life-cycle assessments; and cost-benefit calculations - and impact on food safety - packaging).

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[24] Scientific Advice Mechanism (SAM)

9.3 The Waterborne Plastics Assessment and Collection Technologies (WaterPACT) Project

The third speaker was Ben Maurer, National Renewable Energy Laboratory (NREL), US, who presented on 'The Waterborne Plastics Assessment and Collection Technologies (WaterPACT) Project'. Funded by the US Department of Energy (DOE), the project is currently proceeding with ~thirty researchers at NREL, Pacific Northwest National Laboratory (PNNL), and Battelle. The vision is cleaner waterways and healthier communities by 2040 through by reduction in US waterborne plastic emissions into the ocean and the reintroduction of plastics into the circular economy.

The US economy generates the most plastic mass per capita of any economy worldwide, and the US may have been among the top three contributors of plastics waste into the coastal environment in 2016. Rivers are a key pathway in concentrating, transforming, and transporting plastics debris from the watershed into the marine environment, and there is a growing body of literature on the characterization of this ocean-bound plastic debris. However, many data and analyses remain difficult to compare across studies; while the assessment and collection of waterborne plastics debris continues to focus primarily on floating or beached macroplastics. While this is clearly an excellent start, nanoplastics and microplastics are a considerable proportion of the United States' emissions into the global oceans, and technology solutions are needed to better sense, collect, and convert both macro- and micro-/nanoplastics debris; reclaiming valuable feedstock back into the circular economy and remediating costly effects of plastics pollution.

The WaterPACT project is a multiyear, cross-disciplinary, multi-laboratory effort to develop a portfolio of technology solutions for the detection and measurement, harvesting and conveyance, re-/upcycling, and redesign of waterborne plastics in US emissions. The initial phase of WaterPACT focuses on characterizing the broad spectrum of plastic debris and associated leachates in five key river mouths and across the spectrum of sizes, shapes, and chemistries. Within this two-year assessment phase, these foundational sampling data and laboratory analyses will feed fate-and-transport modeling, rigorous valuation of both reclamation and remediation, and centralized dissemination of generated knowledge. Following the assessment phase, the subsequent technology development under WaterPACT will seek to actively reduce the cumulative US plastic debris emissions into the world oceans by 50% by 2040.

The team will collect microplastic samples from five US rivers: Mississippi, Delaware, Sacramento, Los Angeles, and Columbia. Sampling will be repeated over the course of a year to collect data on river conditions (flow rate, kinetic energy, depth and water lever, pH, etc.) for making a transport model; plastics content (total mass, water column position, additives/elemental analysis, sources, etc.); and locality (piers and ramps, dams or weirs, facilities, industrial activities, etc.) to establish a high-quality, cross-watershed, full-spectrum dataset. The collected samples will be distributed to three partners (NREL, Battelle, and PNNL's Environmental Molecular Sciences Laboratory) for analyzing the properties of microplastics in the samples. A 3D energy, fate, and transport model of the river will be made to estimate along-river model of sources, sinks, transports, and transformations of plastics. Finite valuation will be conducted to obtain economic, carbon, energy, social, health, and environmental valuation of measured plastics. Based on the collected/analyzed data a data portal and visualization atlas will be prepared to provide an accessible and actionable dataset. The timeline for this phase of the project runs from fiscal years 2022 through 2024; the initial data portal is expected to be available by late in fiscal year 2022.[25]

Another example of broader US government efforts to address plastic waste and the circular economy is Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment (BOTTLE™)[26], a DOE-led multi-organization consortium focused on developing new chemical upcycling strategies for today's plastics and redesigning tomorrow's plastics to be recyclable-by-design. DOE is interested in plastics emissions to marine as renewable energy uses a lot of plastics in solar panels, wind turbines and housing materials (e.g. foam). There is also the opportunity to use renewable energy in powering the plastic debris collection solutions in river or off-shore ocean locations.

9.4 The Microfiber Innovation Challenge: addressing long-lasting microfibers through upstream, scalable solutions

The fourth speaker, Dr Barbara Martinez, Conservation X Labs, US, spoke on 'The Microfiber Innovation Challenge: addressing long-lasting microfibers through upstream, scalable solutions'.

Conservation X Labs designed a global prize-backed competition to source innovative, upstream solutions to prevent and replace the sources of plastic (and long-lasting) fibers emitted from textiles. Fibers break off or shed from finished textiles, both synthetic and natural materials, and the microfibers are found in air, soil, and water around the world. A recent model (Gavigan, Kefela, Macadam-Somer, Suh, & Geyer, 2020) estimated that between 1950-2016, about 5.6 Mt of synthetic microfibers were emitted through laundering apparel. And, based on an extensive analysis of peer reviewed studies (Athey & Erdle, 2021) found that "anthropogenic" microfibers (semisynthetic and treated natural fibers) in the environment are being underestimated. In the context of the Microfiber Innovation Challenge,[27] microfibers are considered to be long-lasting, small, and flexible particles derived from synthetic and natural textiles that end up in the environment through fiber fragmentation and fiber shedding.

Conservation X Labs launched the Microfiber Innovation Challenge in early 2021 to source and support innovations that (1) replace textile sources of plastic microfibers with alternatives and/or

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[25] https://www.waterpact.org/

[26] www.bottle.org

[27] https://www.microfiberinnovation.org/

(2) improve textile manufacturing to decrease the shedding of microfibers. All the eligible innovations submitted to the Challenge are at or beyond a prototype stage (the average self-assessed technology readiness level is 6), but none of the innovative fibers or manufacturing processes are at a scale to have a marked impact on microfiber pollution yet. There are numerous barriers and risks associated with early-stage companies that can slow or prevent growth. In the application process for the Microfiber Innovation Challenge, teams were asked to articulate their barriers and risks. Some of these barriers are unique to the team or their innovation, while others are more generalizable. For example, most of the teams are currently fundraising, as they are not at the stage of producing or selling enough product to cover their costs and generate a profit. Many teams noted that they want access to supply chain partners to collaborate on demonstrations of their innovations through pilots or capsule collections. Other teams stated that they need lab space, technical support, and capacity to validate or measure the impact of their innovation. In addition, some teams noted that their innovations would benefit if there were incentives, regulations, or policies related to the emissions of microfibers to incentivize the uptake of their innovations. Finally, at least one applicant alluded to barriers such as trade regulations or customs that are beneficial to fibers like cotton but are making it more difficult for new fibers to enter the global market.

There were 26 semi-finalists in the 2021 Microfiber Innovation Challenge competition.[28] Projects proposed covered fibers from agricultural waste, leather alternatives, natural fibers, textile construction & filtration, and biomaterials, biosynthetics, bioplastics. Twelve finalists[29] and five winners[30] are now posted on the competition website.

The data and suggestions presented in this talk were based on a subset of innovators in the textile industry who applied to the Microfiber Innovation Challenge, and are not indicative of the needs for all early-stage companies. However, the barriers expressed by the Challenge applicants offer a starting point for additional outreach to fiber and textile manufacturers in the APEC economies to better understand the best actions that will help innovations get to market.

9.5 Stopping Ocean Paint Microplastic Emissions from Surface Maintenance

The fifth speaker was Declan Mc Adams, Pinovo AS, Norway, who presented on ‘Stopping Ocean Paint Microplastic Emissions from Surface Maintenance’.

Technological innovation in a mundane area like rust removal can have a material positive impact on ocean health and biodiversity, which in turn considerably strengthens the capacity of the oceans to mitigate the negative impacts of climate change. Paint is plastic. The industrial and marine worlds are full of steel assets that are covered in paint to protect them from

[28] https://www.microfiberinnovation.org/semi-finalists

[29] https://www.microfiberinnovation.org/finalists

[30] https://www.microfiberinnovation.org/winners

corrosion. However, corrosion can only be slowed down, it cannot be stopped. When the steel corrodes, paint residuals fall into the sea or on land as microplastics. In addition, traditional methods of surface treatment prior to repainting involve either open grit blasting or high-pressure water jetting, with the result that the old paint residuals (now crushed into microplastics) end up in the environment if (typically) not collected.

Globally, an estimated 1.5–2.25 million metric tons of paint microplastics are dumped into the ocean every year, making it one of the most important sources of ocean microplastic leakage. Scientific research (Paruta, Pucino, & Boucher, 2022) will provide further perspective on this this issue. Scientific evidence of the presence of paint microplastics in water samples, and in marine life, including plankton, is now being published on a regular basis, most recently by Dr Andrew Turner at University of Plymouth.

Regulatory intervention is following the science but it is still work-in-progress. The European Commission has set a target of reducing microplastics by 30% by 2030. Will microplastics be included in the EU Sustainability Taxonomy as a "Do No Significant Harm" criteria? The Norwegian environmental authorities have required Equinor to seek alternatives to open grit blasting that will recover paint residuals to prevent paint microplastic leakage into the ocean.

Industrial surface treatment contractors are beginning to recognize this problem by measuring the impact of different surface treatment choices by customers under the headings of microplastic emissions and CO_2 emissions. On the basis that "what gets measured gets managed," this is a significant step forward. In Asia, the big issues on paint microplastic emissions turn around the level of mismanaged paint microplastic emissions at shipyards, dry docks, end-of-life ship "graveyards," and ports. How much of a contributor to this is "regulatory arbitrage" where European ship operators use Asian shipyards because environmental standards are lower or less policed in certain Asian economies than in Europe? This needs to be addressed.

The use of clean circular vacuum blasting, such as Pinovo's technology, combined with continual, rather than campaign, maintenance, has the scope to significantly reduce paint microplastic emissions, particularly in commercial and leisure marine, infrastructure, defense, shipyards, on-shore and offshore oil & gas, wind energy turbines, and in petro-chemical plants. With more sustainable surface maintenance practices, we can reduce paint microplastic leakage, and make a significant positive contribution to improved ocean health

9.6 Summary

The presentations showed the need to understand the accurate background of micro- and nanoplastics, their toxicity, and how they are interacting with impacts to human health. Circularity and circular solutions are extremely varied for plastics, and sustainability needs to balance the ecological, social, and economic benefits and impacts - including new methods like advanced recycling. The sources and types of microplastics, such as fibers and particularly marine paints, bring potentially increased toxicity such as additives for anti-fouling agents. Both government and private-sector efforts are continually being developed that can mitigate the flow of microplastics into the environment, while still addressing the needs and maintenance efforts for modern society. The transport and fate of plastics, including the recapture and inclusion, need to be investigated as options for plastics within the transport pathways from the land into the oceans.

Key Messages from the discussion session were:

- Understanding that circularity and sustainability are complex problems with multiple stakeholders and lots of potential pathways will be important to envision effective management and regulatory solutions.

- The private sector, innovators, and researchers can be effective in designing solutions and methods to address micro- and nanoplastic pollution; however, there is a role for regulation and enabling or incentivizing environments to be created through government action.

- Some of the largest impact solutions to address micro- and nanoplastics may be the easiest to implement, but to remediate an increasingly smaller fraction in the environment will require exponential increases in effort and funding to be effective in action.

- Options to de-risk new technologies and utilize research innovation can be useful in accounting for the complexity of the plastics lifecycle system, stakeholders available, financial incentives, and even consumer behavior patterns.

- To define a regulatory or management solution, understanding the problem to be addressed, or more specifically the direct harm, will be important to develop robust regulatory environments that are effective and not restrictive to innovation.

10. Discussion Topic 6 – Approaches for Nanoplastics

This session was chaired by Kay Ho from the US Environmental Protection Agency, US. The small size of nanoplastics represents a unique challenge for collection, extraction, and identification from environmental matrices. This session focused on the emerging field of nanoplastic analytical techniques. Topics covered included methodological considerations that are unique to nanoplastics; progress and challenges in developing nanoplastic standards and, nanoplastic separation and detection, including breakthrough instrumentation and methodology for difficult to detect and measure nanoplastics categories. This session shared best practices for identifying, characterizing, and assessing risk from nanoscale plastic waste. This will allow adoption of accepted consistent methods across the APEC region and allow for better communication between APEC member economies to monitor and detect nanoplastics.

10.1 The use of Pyrolysis-GC/MS for the identification and quantification of micro and nanoplastics

The first speaker was Dr Ludovic Hermabessiere, University of Toronto, Canada, who presented on 'The use of Pyrolysis-GC/MS for the identification and quantification of micro and nanoplastics'. He summarized the methodology used for pyrolysis-GC/MS in qualitative and quantitative assessment of microplastics. He concluded that pyro-GC/MS is effective to quantify and identify microplastics in environmental matrices with the exceptions of some polymers that may not dissolve using extraction techniques such as microwave assisted extraction. The speaker then summarized the limitations and advantages of pyro-GC/MS for nanoplastics. He concluded that pyro-GC/MS can be used to detect, then identify NP in collaboration with other techniques such as dynamic light scattering and ultra-filtration. He concluded that the quantification of NP using GC/MS is still in its infancy and that methods such as Raman, FTIR and pyro-GC/MS are complementary.

10.2 On-chip concentration and detection of Nanoplastics

The second speaker, Dr Andrea Valsesia, European Commission Joint Research Centre, Italy, presented the topic 'On-chip concentration and detection of Nanoplastics'. He demonstrated a novel method to concentrate, identify and quantify nanoplastics. Nanoplastic concentrations in the environment can be very low and often difficult to extract. He summarized the use of bioaccumulators (filter feeders) due to their capabilities of retaining and concentrating nanoparticles. The speaker demonstrated the use of bioaccumulators combined with advanced techniques of separation, filtration and purification to remove the nanoplastics from a complex organic matrix. The extract was concentrated on a novel hydrophobic nano- engineered silicon chip. Once on the chip, the nanoplastics were counted using SEM and identified via Raman spectroscopy. This method while effective poses new analytical challenges, due to the interference of the organic matrix with the separation and purification of nanoplastics.

10.3 Single particle-resolution fluorescence microscopy of nanoplastics

The third speaker, Dr Nathalie Tufenkji, McGill University, Canada, presented on 'Single particle-resolution fluorescence microscopy of nanoplastics'. She developed techniques to label nanoplastics using a dye compatible with Stimulated Emission Depletion (STED) microscopy. STED microscopy enables fluorescence imaging at resolution an order of magnitude higher than with conventional fluorescence microscopy currently applied in nanoplastic research. The speaker demonstrated that these methods can be applied to a variety of plastic types and are stable in both polar and non-polar environments, as well as a variety of more environmentally relevant conditions including soil water, pitcher plant digestive fluid, elevated temperature, and acidic conditions. The speaker imaged labeled nanoplastics after uptake in a model nematode worm. These techniques can be applied to precisely localize and quantify nanoplastics in complex matrices such as biological tissue.

10.4 Chemical and morphological degradation of textile fibers – from micron to submicron scales

The fourth speaker, Dr Shreyas Patankar, presented on ‘Chemical and morphological degradation of textile fibers – from micron to submicron scales’. He reported efforts in improving FTIR characterization of microplastics by building a library of infrared spectra of common textile fibers weathered under selected ambient conditions. Consumer textile materials including polyester, nylon, cotton, and other, were exposed to a selection of ambient conditions: ocean, air, and wastewater treatment stages, in a controlled weathering experiment. Infrared spectra were monitored for up to 52 weeks, with the resulting data illuminating the environmental fate and longevity of synthetic and natural fibers. Spectral changes caused by weathering were found to depend strongly on both the composition of the material and the specific ambient conditions. This library of weathered material spectra is useful not only in easier identification of environmental microfibers, but also helpful in estimating the duration and manner of weathering that a given environmental microfiber may have experienced.

10.5 Advancing the detection, quantification, physicochemical transformations and remediation of nano/microplastics

The fifth speaker, Dr Parisa Ariya, McGill University, Canada, presented on ‘Advancing the detection, quantification, physicochemical transformations and remediation of nano/microplastics’. She presented two novel technologies. First a novel automated inline instrumentation, nano-Digital In-line Holographic Microscopy (Nano-DIHM) that allows 4D tracking of nano/micro plastics in moving air and water, in-situ and in real-time, without the need for individual particle trapping They demonstrated this technology is capable of 4D tracking of nano/micro plastics as a single particle and as an ensemble of particles. The usage of the artificial intelligence and automation provide 3D size, shape, and surface analysis of single plastic particle or those that are coated with other materials. Furthermore, they developed quantification of nano and microplastics using in-lab built Nanostructure-Assisted Laser Desorption/Ionization (NALDI) techniques, for picogram quantification of micro/nanoplastics in water and snow matrices, without sample pre-treatment. The detection limit is ~5 pg for ambient snow. Their studies demonstrated that plastic waste can be efficient ice nuclei, and as plastic particles increase, this may have implications for climate change effects. Finally, they are examining the efficacy of sustainable technologies using airborne dust particles, and various clay minerals as interfaces for micro- and nanoplastic remediation and recycling.

10.6 Surprising fluorescence of nanoplastic standards

The last speaker Dr Samuel Stavis, National Institute of Standards and Technology (NIST), US, presented on ‘Surprising fluorescence of nanoplastic standards’. He reported a new study of commonly used but poorly understood nanoparticle standards and model nanoplastics – polystyrene spheres sorbing hydrophobic fluorophores. To quantify joint histograms of steric diameter and fluorescence intensity, the study involved a measurement system that is analogous to a lateral flow assay, integrating nanofluidic replicas, localization microscopy, and statistical analyses. Steric interaction with nanofluidic staircases separates nanoparticles by size, enabling dimensional and optical metrology of single particles with high throughput by widefield imaging. A comprehensive calibration and statistical model of the measurement system discriminates size exclusion from surface adsorption, yielding the diameter distribution to within an error of a few nanometers, in comparison to reference data from transmission electron microscopy. A Bayesian statistical analysis of the fundamental structure–property relationship reveals a super-volumetric dependence of fluorescence intensity, scaling with nanoparticle diameter to the fourth power and confounding basic concepts of chemical sorption. This analysis also quantifies heterogeneous values of fluorescence intensity, limiting attempts to infer dimensional or chemical properties of nanoplastics from fluorescence intensity. These results significantly change expectations for optimizing nanoparticle products and applying nanoplastics standards to calibrate measurements involving fluorescence intensity.

10.7 Summary

During the discussion, it was evident that a wide range of methods exist for the isolation, extraction and identification of nanoplastics. This is in stark difference to the methods for microplastics that have largely coalesced around three-four standard instruments. The presenters were unanimous in agreeing that a single instrumentation or method was not effective for nanoplastic identification, instead accurate detection and identification would require multiple (hyphenated) methods. In addition, multiple lines of evidence should be used to ensure correct identification. The researchers agreed that innovative, diverse methods would have to be explored – many of which were presented in the talks, and that the use of artificial intelligence would be helpful in discerning patterns from the large data sets that are often generated. The researchers emphasized that coordination of many different approaches at an international level would be useful to prevent duplication and conserve resources. The researchers agreed that methods convenient, inexpensive and easy enough for field sampling nanoplastics in a monitoring program was years away; however, it was observed that since concentrations, sizes and shapes of nanoplastics is still vastly unknown, estimations even within a log would be helpful.

11. Concluding Plenary

The concluding plenary saw the Chairs of each session come together to share the highlights and key findings from across the three days of events. The workshop closed with the Chair Anil Patri who thanked the organizing committee and acknowledged the speakers and many contributors to the event. He noted that we need to address this global problem together in creating a community of citizens, scientists, stakeholders and policy makers. We also need to create common databases to compare common data sets. Then the Session Chairs presented their summaries. Finally, there was a request to join in the networking opportunities on the online platform to collaborate with each other.

12. Success summary

The overall objective of the project was to create an APEC-wide community of researchers, policymakers, and industry representatives dedicated to improving understanding of, and identifying opportunities for remediating or eliminating, the problems associated with micro- and nanoplastics in marine debris. This included:

a) Sharing of best practices for identifying, characterizing, assessing risk from, and reducing or remediating nanoscale plastic waste.

b) Leveraging of scientific resources, and sharing in the development of alternate technologies, products, capabilities, and facilities. Building capacity across APEC economies by sharing existing knowledge in this emerging field.

c) Initiating a draft framework for addressing short- and long-term issues associated with micro- and nanoplastics in the environment.

The workshop met the objective of creating an APEC-wide community of researchers, policymakers and industry representatives by bringing together about 230 participants including 49 speakers from 19 APEC economies to share their understanding of the current challenges in the area and the opportunities and options for management of the issue. The participants came from a wide background including academics, government officials, non-government organizations and industry. The workshop successfully attracted all genders to participate with female and male representation as chairs, speakers and attendees.

Alongside the workshop was originally planned a guided field trip to a nearby beach and a laboratory, along with a classroom training session to demonstrate how nanoplastics are collected, isolated, and characterized. With the move to all virtual event, this was replaced by the production of a video which creates a legacy from the work available to future researchers as a capacity building resource.

Networking activity was promoted at and after the workshop as the majority responding to the post-event survey made contacts at the event and planned to connect with other participants in the future. There was the opportunity on the online platform to share scientific papers and links to other events. This activity by participants helped to meet the overall objective of creating an APEC-wide community.

The presentations covered a wide range of topics with expert speakers and panel discussions on definitions of best practice for identifying, characterizing, assessing risk from, and reducing or remediating nanoscale plastic waste. The live online discussion sessions where a panel of speakers led by the chair included Question and Answer sessions so all participants could contribute.

The workshop was a stage for leverage of scientific resources and sharing in the development of alternative technologies, products, capabilities and facilities. The speakers offered to engage with their audience after the event and promoted opportunities for collaborative working.

Most delegates responding to the post-event survey reported that the event was well organized. The online platform Whova made best use of delegates availability to engage across time zones during the three-day workshop by providing pre-recorded presentations to view alongside the online delivery.

Th virtual format of the event delivery was not without challenges which should also be acknowledged. Delivering an event in a single, fixed time zone, without physical presence means audience attendees are more likely to drop in for specific sessions, rather than benefitting from participation from start to end. In addition, due to the multiple time zones from which speakers and attendees came, the event extended over three days, which meant that many participants attended only for one day – again reducing the cross-interest group collaboration which would have been experienced in person.

In summary the workshop has met the project objectives, led to an increase in awareness of the vision in the APEC Roadmap on Marine Debris and built a community round the micro- and nanoplastics topic. This will allow a draft framework on micro- and nanoplastics in the environment to be developed.

13. References

(n.d.).

(ATSDR), A. f. (2018). *Framework for Assessing Health Impacts of Multiple Chemicals and Other Stressors. Atlanta, GA: US Department of Health and Human Services, Public Health Service.* Retrieved from https://www.atsdr.cdc.gov/interactionprofiles/ipga.html

Acosta-Coley, I., Duran-Izquierdo, M., Rodriguez-Cavallo, E., Mercado-Camargo, J., Mendez-Cuadro, D., & Olivero-Verbel, J. (2019). Quantification of microplastics along the Caribbean Coastline of Colombia: Pollution profile and biological effects on Caenorhabditis elegans. *Marine pollution bulletin 146*, 574-583.

Agency for Toxic Substances and Disease Registry (ATSDR). (2018). *Framework for Assessing Health Impacts of Multiple Chemicals and Other Stressors.* Retrieved from Agency for Toxic Substances and Disease Registry (ATSDR): https://www.atsdr.cdc.gov/interactionprofiles/ipga.html

Alexander, J. (1919). *Colloid Chemistry: An Introduction with Some Practical Applications.* New York: D. van Nostrand Company.

Anagnosti, L., Varvaresou, A., Pavlou, P., Protopapa, E., & Carayanni, V. (2021). Worldwide actions against plastic pollution from microbeads and microplastics in cosmetics focusing on European policies. Has the issue been handled effectively? *Marine Pollution Bulletin 162*, 111883. doi:https://pubmed.ncbi.nlm.nih.gov/33310543/

Athey, S. N., & Erdle, L. M. (2021). Are We Underestimating Anthropogenic Microfiber Pollution? A Critical Review of Occurrence, Methods, and Reporting. *Environmental Toxicology and Chemistry*. doi:https://doi.org/10.1002/etc.5173

Bhargava, S., Lee, S., Ying, L., Neo, M., Teo, S., & Valiyaveettil, S. (2018). Fate of Nanoplastics in Marine Larvae: A Case Study Using Barnacles, Amphibalanus Amphitrite. *ACS Sustainable Chemistry and Engineering 6*, 6932-6940.

Borrelle, S. B., RINGMA, J., LAW, K. L., MONNAHAN, C. C., LEBRETON, L., MCGIVERN, A., . . . POLIDOR, B. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *SCIENCE Vol 369, Issue 6510*, pp. 1515-1518.

Carroll, Y. I., Zarus, G., Hunter, C., Muianga, C., Casillas, G., & Zarate-Bermudez, M. (2020). Identifying and Addressing Data Needs to Evaluate Human Exposures to Microplastics. International Society for Environmental Epidemiology (ISEE).

Chan, C. M., Vandi, L.-J., Steven Pratt, P. H., Richardson, D., Werker, A., & Laycock, B. (2019). Insights into the biodegradation of PHA/wood composites: Micro- and macroscopic changes. *Sustainable Materials and Technologies*, S2214-9937(18)30279-3.

Cheung, P. K., & Fok, L. (2017). Characterisation of plastic microbeads in facial scrubs and their estimated emissions in Mainland China. *Water Research 122*, 53-61. doi:https://pubmed.ncbi.nlm.nih.gov/28591661/

Dilkes-Hoffman, L. S., Lant, P. A., Laycock, B., & Pratt, S. (2019). The rate of biodegradation of PHA bioplastics in the marine environment: A meta-study. *Marine Pollution Bulletin*, Volume 142, May 2019, Pages 15-24.

Edelson, M., Håbesland, D., & Traldi, R. (2021). Uncertainties in global estimates of plastic waste highlight the need for monitoring frameworks. *Marine Pollution Bulletin 171*, 112720.

Erdle, L. M., Parto, D. N., Sweetnam, D., & Rochman, C. M. (2021). Washing Machine Filters Reduce Microfiber Emissions: Evidence From a Community-Scale Pilot in Parry Sound, Ontario. *Frontiers in Marine Science*, 8:777865. doi: 10.3389/fmars.2021.777865.

European Commission. (2019). *Environmental and Health Risks of Microplastic Pollution, Group of Chief Scientific Advisors, Scientific Advice Mechanism (SAM).* Retrieved from ec.europa.eu:

https://ec.europa.eu/info/sites/default/files/research_and_innovation/groups/sam/ec_rtd_sam-mnp-opinion_042019.pdf

Franzellitti, S., Canesi, L., Auguste, M., Wathsala, R., & Fabbri, E. (2019). Microplastic exposure and effects in aquatic organisms. *Environ. Toxicol. Pharmacol. 68*, 37– 51.

G. Mahadevan, S. V. (2021). Comparison of Genotoxicity and Cytotoxicity of Polyvinyl Chloride and Poly(methyl methacrylate) Nanoparticles on Normal Human Lung Cell Lines. *Chemical Research in Toxicology 34*, 1468-1480.

Gaikwad, V., Ghose, A., Cholake, S., Rawal, A., Iwato, M., & Sahajwalla, V. (2018). Transformation of E-waste plastics into sustainable filaments for 3D printing. *ACS Sustainable Chemistry & Engineering 6 (11)*, 14432-14440.

Gavigan, J., Kefela, T., Macadam-Somer, I., Suh, S., & Geyer, R. (2020). Synthetic microfiber emissions to land rival those to waterbodies and are growing. *PLoS ONE 15(9)*. doi:https://doi.org/10.1371/journal.pone.0237839

Godoy, V., Martín-Lara, M. A., Calero, M., & Blázquez, G. (2019). Physical-chemical characterization of microplastics present in some exfoliating products from Spain. *Marine Pollution Bulletin 139*, 91–99. doi:https://pubmed.ncbi.nlm.nih.gov/30686453/

Goodman, K., Hare, J., Khamis, Z., Hua, T., & Sang, Q. A. (2021). Exposure of human lung cells to polystyrene microplastics significantly retards cell proliferation and triggers morphological changes. *Chemical Research in Toxicology 34*, 1069-1081.

Gwinnett, & Miller. (2021). Are we contaminating our samples? A preliminary study to investigate procedural contamination during field sampling and processing for microplastic and anthropogenic microparticles. *Science Direct*, https://doi.org/10.1016/j.marpolbul.2021.113095.

Habib, R. Z., Abdoon, M. M., Meqbaali, R. M., Ghebremedhin, F., Elkashlan, M., Kittaneh, W. F., . . . Kindi, R. A. (2020). Analysis of microbeads in cosmetic products in the United Arab Emirates. *Environmental Pollution 258*, 113831.

Hidayaturrahman, H., & Lee, T. (2019). A study on characteristics of microplastic in wastewater of South Korea: Identification, quantification, and fate of microplastics during treatment process. *Marine Pollution Bulletin 146*, 696-702. doi:https://doi.org/10.1016/j.marpolbul.2019.06.071

Huang, W., Song, B., Liang, J., Niu, Q., Zeng, G., Shen, M., . . . Zhang, Y. (2021). Microplastics and associated contaminants in the aquatic environment: A review on their ecotoxicological effects, trophic transfer, and potential impacts to human health. *J. Hazard. Mater. 405*, 124187.

I. A. Kane, M. A., Miramontes, E., Wogelius, R., Rothwell, J. J., Garreau, P., & Pohl, F. (2020). Seafloor microplastic hotspots controlled by deep-sea circulation. *Science 368*, 1140–1145.

Jambeck, J. R., GEYER, R., WILCOX, C., SIEGLER, T. R., PERRYMAN, M., ANDRADY, A., . . . LAW, K. L. (2015). Plastic waste inputs from land into the ocean. *Science Vol 347, Issue 6223*, pp. 768-771.

Kane, M. A. (2020). Seafloor microplastic hotspots controlled by deep-sea circulation. *Science 368*, 1140–1145.

Kapp, & Miller. (2020). Electric clothes dryers: An underestimated source of microfiber pollution. *PLoS ONE 15(10): e0239165*, https://doi.org/10.1371/journal.pone.0239165.

Lebreton, L. (2019, September). *The Quest to Find the Missing Plastic - The Ocean Cleanup*. Retrieved from theoceancleanup: https://theoceancleanup.com/updates/the-quest-to-find-the-missing-plastic/

Mahadevan, G., & Valiyaveettil, S. (2021). Understanding the interactions of poly(methyl methacrylate) and poly(vinyl chloride) nanoparticles with BHK-21 cell line. *Sci. Rep. 11,* , Article Number 2089.

Mai, L., Sun, X. F., Xia, L. L., Bao, L. J., Liu, L. Y., & Zeng, E. Y. (2020). Global riverine plastic outflows. *Environmental Science and Technology, 54*, 10049-10056.

Mai, L., You, S., H. He, L. B., Liu, L., & Zeng, E. (2019). Riverine microplastic pollution in the Pearl River Delta, China: are modelled estimates accurate? *Environmental Science and Technology, 53*, 11810-11817.

N. Hartmann, e. a. (2019). Are We Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. *Environ. Sci. Technol. 53*, 1039-1047.

Nur-A-Tomal, M. S., Pahlevani, F., & Sahajwalla, V. (2020). Direct transformation of waste children’s toys to high quality products using 3D printing: A waste-to-wealth and sustainable approach. *Journal of Cleaner Production 267*, 122188.

Paruta, P., Pucino, M., & Boucher, J. (2022). *Plastic Paints the Environment.* EA-Environmental Action. Retrieved from https://www.e-a.earth/plasticpaintstheenvironment

Sahajwalla, V. (2018). Big challenges, micro solutions: Closing the loop in Australia's waste crisis. *AQ-Australian Quarterly 89 (4)*, 13-18.

Sahajwalla, V., & Hossain, R. (2020). The science of microrecycling: a review of selective synthesis of materials from electronic waste. *Materials Today Sustainability 9*, 100040.

Sahajwalla, V., Zaharia, M., Kongkarat, S., Khanna, R., Saha-Chaudhury, N., & O'Kane, P. (2010). Recycling Plastics as a Resource for Electric Arc Furnace (EAF) Steelmaking: Combustion and Structural Transformations of Metallurgical Coke and Plastic Blends. *Energy and Fuels, 24*, pp. 379-91.

Thorbecke, A. (2021). *The Economic Impacts of Marine Debris on Tourism-Dependent Communities | OR&R's Marine Debris Program*. Retrieved from NOOA National Oceanic and Atmospheric Administration: https://marinedebris.noaa.gov/research/economic-impacts-marine-debris-tourism-dependent-communities

United Nations Environmental Programme. (2018). *Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations.* United Nations. Retrieved from https://wedocs.unep.org/20.500.11822/27113

Volkheimer, G. (1974). Passage of particles through the wall of the gastrointestinal tract. *Environmental Health Perspectives. Vol 9*, 215-225.

Volkheimer, G. (2001). The phenomenon of persorption: persorption, dissemination, and elimination of microparticles. *Old Herborn University Monograph 14 Article 2, ISBN 3-923022-25-5*.

Wang, W., Ge, J., & Yu, X. (2020). Bioavailability and toxicity of microplastics to fish species: A review. *Ecotoxicol. Environ. Saf. 189*, 109913.

Yip, J., Lee, S., Neo, M., Teo, S., & Valiyaveettil, S. (2021). A comparative investigation of toxicity of three polymer nanoparticles on acorn barnacle (Amphibalanus amphitrite). *Science of The Total Environment*, 150965.

Annex A Workshop Agenda

The event ran over three days from the 13 – 15 December 2021, based in the Hawaii (GMT-10) timezone.

Day, Time	Session	Chair	Speakers
13 December 2021 12:45 – 14:00	Plenary One - Goals, Outcome, Expectations	Anil Patri	Dr Kara Lavender Law Dr Cristobal Galbán Malagón Dr Chihhao Fan Dr Jennifer Provencher Dr Brett Howard Dr Britta Denise Hardesty Dr Winnie Lau
13 December 2021 14:30 – 16:00	Discussion Topic 1 – Best Practices and Research Methods for the Collection and Characterization of Micro- and Nanoplastics from the Environment	Kay Ho	Dr Olga Pantos Dr Shuhei Tanaka Dr Qinmei Li Dr Jennifer Lynch Dr Anna Posaka Dr Tatiana Lastovina
13 December 2021 14:30 – 1600	Discussion Topic 2 – Environment and human exposure, potential effects and mixtures toxicology	Greg Zarus Dr Sarva Mangala Praveena	Dr Eddy Y. Zeng Dr Sarva Mangala Praveena Dr Qing-Xiang Amy Sang Dr Jesus Olivero-Verbel Greg Zarus Dr Moiz Mumtaz Dr Suresh Valiyaveettil
13 December 2021 16:30 – 17:15	Virtual lab tour	Dr Jennifer Lynch	
14 December 2021 13:00 – 14:00	Plenary Two discussion panel - Regulatory and regional perspectives	Dr Matthew Kupchik	Dr Prashiela Manga Dr Kathryn Beers Dr Wonjoon Shim Dr Scott Coffin Dr Birgit Sokull-Kluettgen

Day, Time	Session	Chair	Speakers
14 December 2021 14:30 – 16:00	Discussion Topic 3 – Terminology, nomenclature and harmonizing methods: efforts towards consensus	Dr Åsa Jämting	Dr Dingyi Yu Dr Susanne Belz Dr Nanna Hartmann Dr Claus Gerhard Bannick Dr Mark Browne Nikolai Kozlovskii Dr Denis Koltsov,
14 December 2021 14:30 – 16:00	Discussion Topic 4 – Strategies for micro- and nanoplastics mitigation, remediation, and recycling	Dr Christy Payne	Dr Chelsea Rochman Dr Hatim Albasri Rachael Miller Mr Jean-David Lantagne Assoc. Prof. Bronwyn Laycock Prof. Veena Sahajwalla
15 December 2021 13:00 – 14:30	Discussion Topic 5 – Current and proposed regulations on intentionally used plastics	Dr Matthew Kupchik	Dr Rachel Meidl Dr Andrew Bartholomaeus Dr Ben Maurer Dr Barbara Martinez Mr Declan Mc Adams
15 December 2021 13:00 – 14:30	Discussion Topic 6 – Approaches for Nanoplastics	Dr Kay Ho	Dr Ludovic Hermabessiere Dr Andrea Valsesia Dr Nathalie Tufenkji Dr Shreyas Patankar Dr Parisa Ariya Dr Samuel Stavis
15 December 2021 15:00 – 16:00	Concluding Plenary	Anil Patri	Dr Kay Ho Dr Matthew Kupchik Greg Zarus Dr Åsa Jämting Dr Christy Payne

Annex B Participant and survey summary

B1 Pre Workshop Registration and Survey

During the registration process participants were asked to fill out a survey that included demographic data on gender and APEC economy.

B2 Workshop Attendance

There were 312 participants including 49 speakers, the organizing committee and 8 Chairs in attendance overall. Of the 312 who initially registered 231 attendees downloaded the Whova app, 925 messages (private and community) were sent, 13 community board topic posts were made and 113 personalized agendas were set up. Access to the online event was made available through the Whova app and website.

Table B.1 shows the detail of attendance across the sessions which were available as recorded and live sessions and shows engagement was maintained over the three days of the workshop. The views of videos ranged from 48 to 168 and attendance for the sessions ranging from 31 to 89. The highest viewed video and best attended session was Plenary One. The platform does not report overall unique attendance across all sessions but it can be assumed from the statistics gathered that about 200 took part.

Table B.1 Recorded video views and session attendance

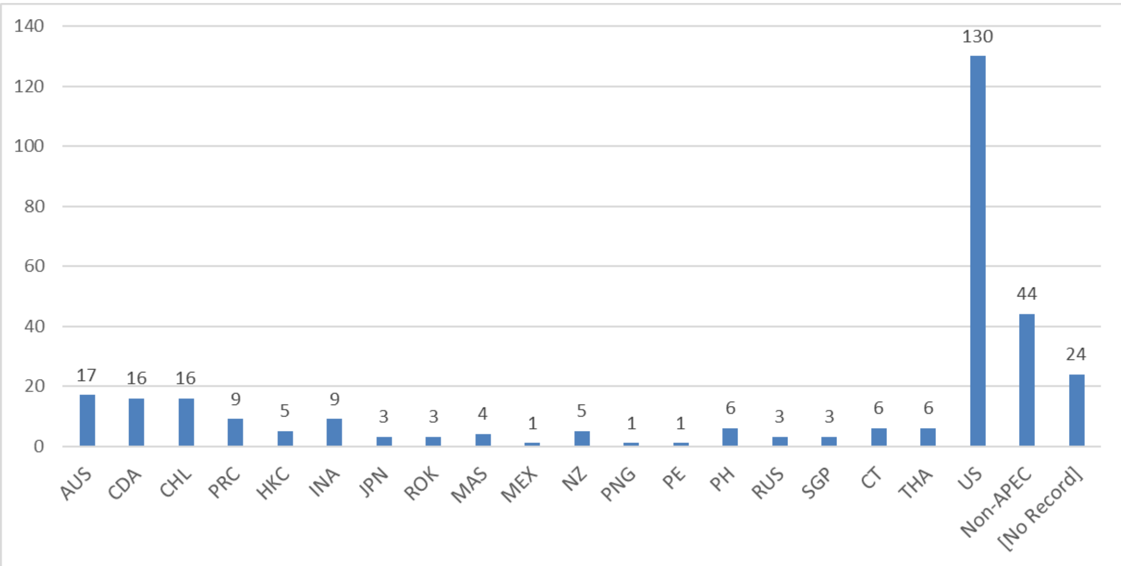
Sessions	Recorded video views	Total (unique) attendees at session
Plenary One	168	89
Discussion 1	122	74
Discussion 2	82	35
Virtual lab tour	-	57
Plenary Two	66	62
Discussion 3	81	42
Discussion 4	61	31
Discussion 5	48	33
Discussion 6	52	37
Concluding plenary	-	53
Range	**48 – 168**	**31 – 89**

B3 The demographics from the registration survey

When participants registered, they were asked to supply information on their economy and gender and this has been presented as charts Figure B.1 and Figure B.2 below.

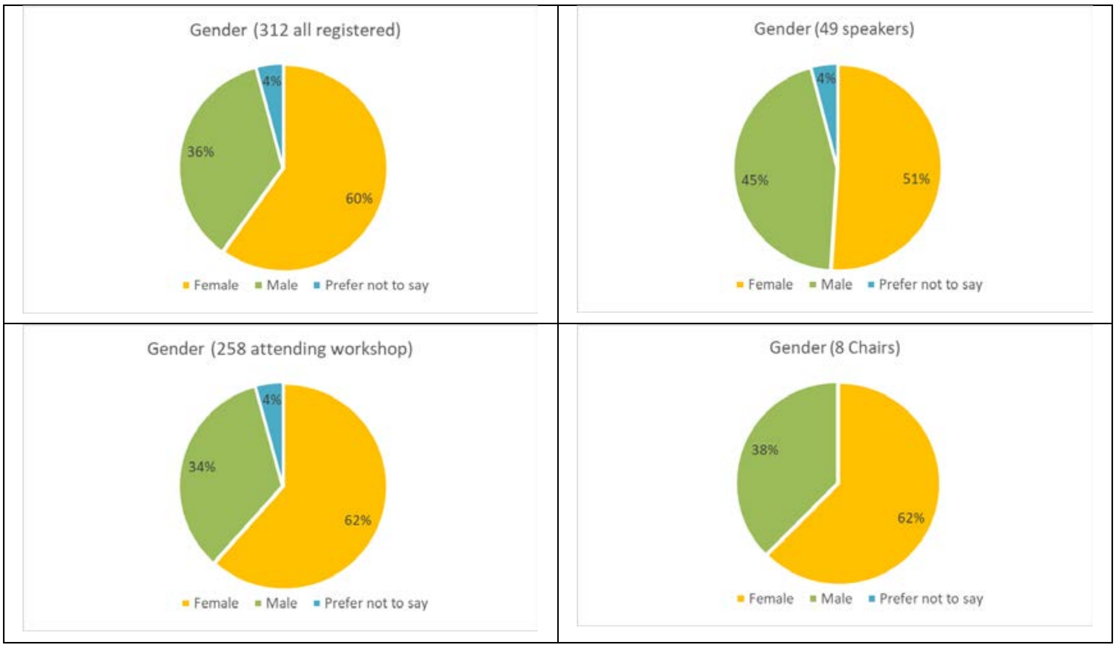
The participants work as academics, government officials and in non-government organizations and industry. There was representation from 19 APEC economies and Non-APEC economies (Figure B.1): Australia; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; Russia; Singapore; Chinese Taipei; Thailand; Philippines and United States. The majority attendance was from the United States.

Figure B.1 Chart of representation by Economy



The workshop had a representative balance of gender from the 312 respondents to the registration survey (Figure B.2) with 60% female, 36% male and 4% prefer not to say. The gender representation for speakers was 51% female, 45% male and 4% prefer not to say. The gender representation for attending the workshop was 62% female, 34% male and 4% prefer not to say; and gender representation for chairs was 62% female, 38% male.

Figure B.2 Charts of Gender representation for all registered as speaking, attending and chairs



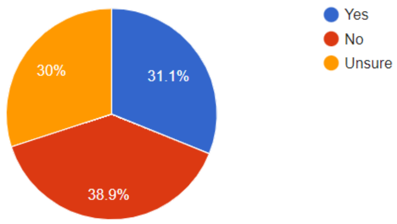
B4 Pre-Event Survey

There were 90 responses to the pre-event survey. Out of those 312 who initially registered this is a 29% response rate. The comments on areas to be addressed at this event was broad including comments like *"Connecting with other researchers and professionals, learning about current work"*. Of those surveyed only 66% had been to an event focusing on micro- and nanoplastics before. The responses to the survey are summarized in Table B.2 including a list of ongoing or planned projects that are addressing the global micro- and nanoplastics issues.

Table B.2 Pre-event survey responses

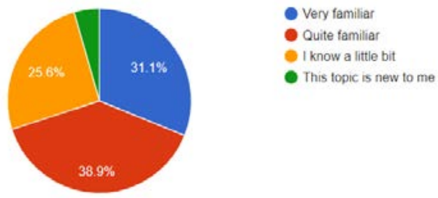
Are you aware of the vision laid out in the APEC Roadmap on Marine Debris?

90 responses



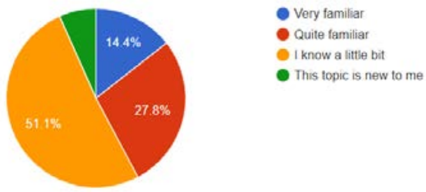
How well informed do you currently feel regarding micro- and nanoplastics in marine debris, and the issues surrounding them?

90 responses



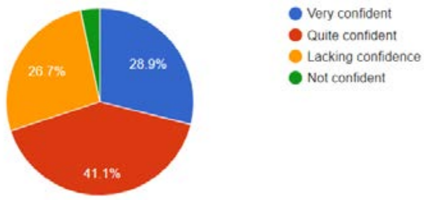
How well informed do you currently feel regarding current best practices and available scientific resources/capabilities (in other APEC economies or around the world) in identifying, characterizing, assessing risk from, and reducing or remediating micro- and nanoscale plastic waste?

90 responses



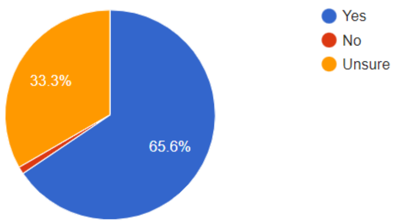
How confident do you feel interacting with contacts associated with the APEC community?

90 responses



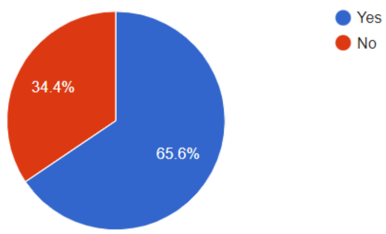
Do you plan to connect with others participating in the workshop?

90 responses



Have you participated in an event, workshop or discussion focusing on micro- and nanoplastics before?

90 responses



Are you aware of any ongoing or planned projects (in your economy, other economies, or collaborative projects with more than one economy) addressing the global micro- and nanoplastics issues that you'd like to make the organizing committee and other attendees aware of?

- UN Southern Ocean Decade Working Group 1
- Ongoing IKPP and DFO funded projects
- The strategy of marine plastics residues
- Marine Biodiversity Hub in Australia (NESP)
- VAMAS TWA 45 http://www.vamas.org/twa45/
- website called "The Plastiverse" which will serve as an index for open source and open data tools for microplastics researchers.
- Center for Marine Debris Research
- Canada is currently preparing 2nd phase of "Zero plastic waste" program.
- Global Ocean 2050 and IAEA Project related to microplastics in fisheries.
- AMAP litter and microplastics
- Collaborations within US across multiple agencies, and between Europe and US.
- PICES
- Red Micro & Nano Allpa Pacha. Scientific collaboration work on micro- and nanoplastics in Pacific coast of America. Including Chile Perú Ecuador Colombia Costa Rica and México
- California's Department of Toxic Substances Control is considering adding microplastics to its Candidate Chemicals List.
- Island off coast Jakarta Indonesia regarding marine debris impact
- UNESCO/CSIR-WRI Clean Ocean Project
- PICES Working Group 42 is developing recommendations on the best way to monitor plastic pollution in the North Pacific Ocean
- NIST's efforts on the circular economy
- Micro & Nano Allpa Pacha. From Chile Perú Ecuador Colombia Costa Rica and México
- Thailand have "Plastic debris Management plan" under The Pollution Management Strategy for 20 Years
- Local governments in Indonesia have imposed a ban on the use of plastic bags in shopping centers and traditional markets since early 2020
- GloLitter - The GloLitter Partnerships Project between the Government of Norway, IMO and FAO aims to help shipping and fisheries move to a low-plastics future. https://www.imo.org/en/OurWork/PartnershipsProjects/Pages/GloLitter-Partnerships-Project-.aspx
- EC initiative aims to tackle microplastics unintentionally released into the environment https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12823-Microplastics-pollution-measures-to-reduce-its-impact-on-the-environment_en
- Circular Cleveland, other Great Lakes microplastics funded research
- University of New South Wales project on fibres and filters https://www.cmsi.unsw.edu.au/research-projects/anthropogenic-and-climate-change-impacts-and-interactions/clothes-fibres-and-filters-reduce-pollution-micro-and-nano-debris

B5 Post-Event Survey

At the end of the workshop participants were emailed a post-event survey which repeated the questions about awareness to compare with the pre-event survey and asked for detail on how they found the event. There were only 29 responses to the post-event survey; based on an assumed 200 active participants this is a 15% response rate. A summary of the survey is shown in Table B.3.

B5.1 What went well?

There were a wide range of topics highlighted as interesting/useful by respondents. Awareness of the vision in the APEC Roadmap on Marine Debris increased from 31% to 52% when comparing the pre-event and post-event survey results. Most of the respondents attended All or Most of the sessions.

The survey shows that networking activity was promoted by the workshop as the majority (86%) plan to connect with individuals associated with APEC and 76% made specific contacts at the event. The number who plan to follow up with other workshop participants they met at this workshop has increased from 65% pre-workshop planning to connect to 86% post-event. There was an improvement pre- and post-workshop in the confidence felt about making contacts. Pre-workshop 30% felt they lacked/no confidence in feel interacting with contacts associated with the APEC community; while post-workshop 90% feel more confident in connecting with individuals associated with the APEC community.

B5.2 Suggestions for improvement

There was a low response rate to the post event survey that could be improved with a review of the survey design and a planned follow up for more engagement.

Compared to the pre-event survey there was not an improvement in the proportion saying they feel well informed on current best practice and available scientific resources/capabilities (pre-event 70%, n=90, post-event 65%, n=29). This difference is not statistically significant and is likely due to the low response rate to the survey. This also indicates that further dissemination of current best practice and available scientific resources/capabilities is required.

A few respondents had issues with using Whova finding it complex to access the live event.

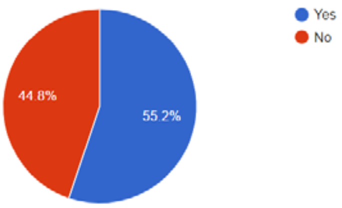
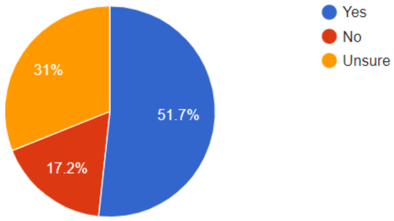
Requests were made in the survey for access to view the recorded sessions and these videos have now been made available to watch online.

There were many responses to the question on topics to cover in more detail suggesting there is a lot to learn in this area and possibly some respondents found the options for engagement in the topics (such as the online Q&A discussion forum) were limiting.

B5.3 What comes next?

The recordings of the workshop sessions are available on YouTube. There were requests for another event to follow up the contacts made and suggestions of topics for further events to address.

Table B.3 Post-event survey responses

<table>
<tr>
<td>1. Had you participated in an event, workshop or discussion focusing on micro- and nanoplastics prior to this event?
29 responses

</td>
<td>2. Are you aware of the vision laid out in the APEC Roadmap on Marine Debris?
29 responses

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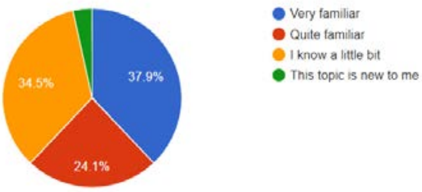
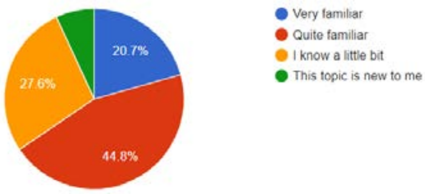
<tr>
<td>3. How well informed do you feel regarding micro- and nanoplastics in marine debris and the issues surrounding them?
29 responses

</td>
<td>4. How well informed do you currently feel regarding current best practices and available scientific resources/capabilities (in other APEC economies or around the world) in identifying, characterizing, assessing risk from, and reducing or remediating micro- and nanoscale plastic waste?
29 responses

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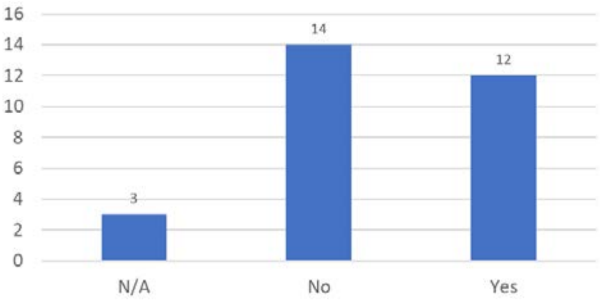
</table>

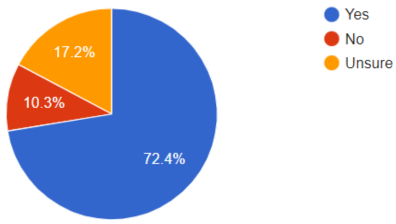
5. Are you aware of any ongoing or planned projects (in your economy, other economies, or collaborative projects with more than one economy) addressing the global micro- and nanoplastics issues that you'd like to make the organizing committee and other attendees aware of?



Comment: "*Yes, two APEC projects regarding mitigating the distribution of microplastics in aquaculture input chain".*

6. Did you learn about ongoing or planned projects (in your economy, other economies, or collaborative projects with more than one economy) addressing the global micro- and nanoplastics issues that you were not previously aware of?

29 responses



7. Which topics or aspects of the workshop did you find most interesting or useful?

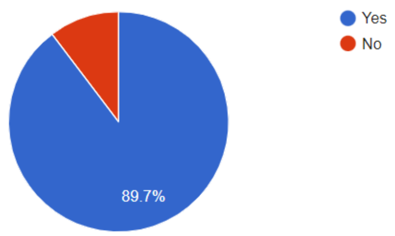
- Topics: Toxicology and impact on human health, discussion of micro- and nanoplastic sampling and analysis methods, harmonization
- Aspects: The organization of the sessions was very helpful (methods, effects on humans, solutions, etc.), Panel discussions, Virtual lab.

8. Which topics do you wish would have been covered in more detail?

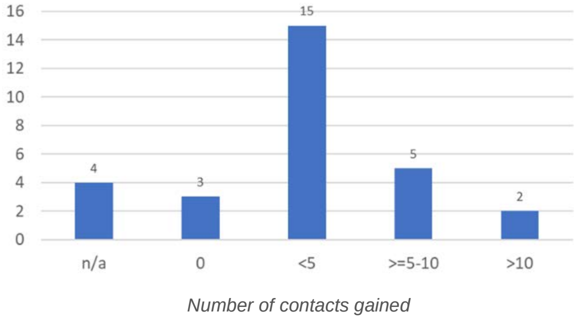
- Best Practices and research methods for collection and characterization.
- Best practices for efficient handling of small micro- and nanoplastics in environmental samples.
- Conversion of micro- and nanoplastics into useful fuels using microbial based catalysts
- Current and proposed regulation on plastic used especially in southeast asia region
- Ecological impacts and environmental impact assessment with regards to experimental design and statistical analyses.
- How to develop reference materials in a collaborative manner?
- It was the right length (longer would have been too much), so I am happy with what was covered.
- Methods in determining microplastic contamination.
- Opportunities for public/private partnerships
- Recycling and upcycling specifically of microplastics
- Sampling and analysis
- Scalability of methods - lots of different methods, too many options...how do we cover the whole world with homogeneous methods?
- Solutions to reduce the emissions of nano-plastics
- Test method for monitoring microplastic in human body, and fragment type MPs/NPs RM development.
- The "regulatory arbitrage" that takes place when European and US ship owners send their ships to Asia for dry docking or end-of-life and do not ensure that environmental standards are respected.
- Tire particles

9. Do you feel more confident connecting with individuals associated with the APEC community after participating in this workshop?

29 responses

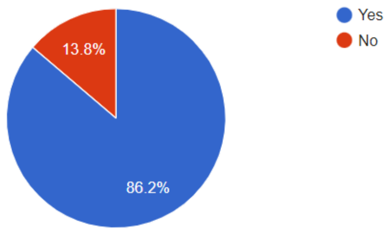


10. How many contacts have you gained in the APEC community from attending the workshop? 22 out of 29 respondents (76%) made contacts.



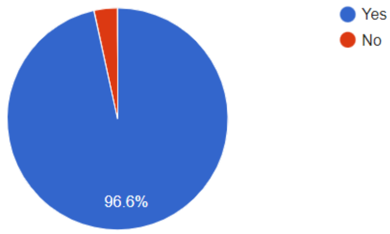
11. Do you plan to follow up with other workshop participants you met at this workshop, e.g., to develop future collaborations or scientific exchanges addressing the issues associated with micro- and nanoplastics in marine debris?

29 responses



12. Do you feel that the workshop helped to develop an APEC-wide community of researchers, policymakers, and industry representatives dedicated to improving understanding of, and identifying opportunities for remediating or eliminating, the problems associated with micro- and nanoplastics in marine debris?

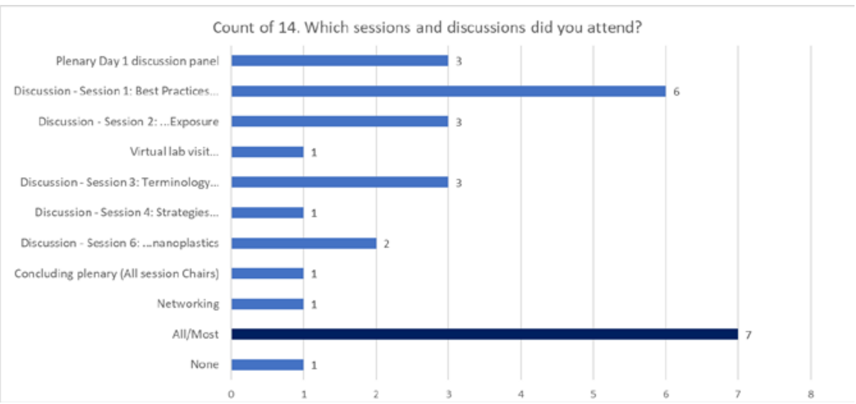
29 responses

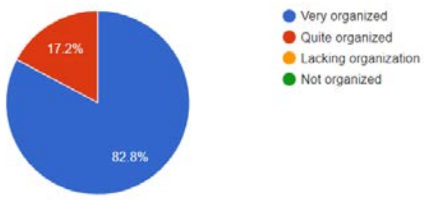


13. How was the experience of using Whova and Zoom to attend the virtual workshop?

55% mentioned *"Good"* and 14% mentioned *"easy to use"*, one said *"Excellent, but I still prefer face-to-face meeting"*. Some respondents noted Whova was complex or confusing with too many notifications, for example: *"A bit complex using Whova but it offers really good features on how to connect to other people and manage activities once I know how to use it"*.

14. Which sessions and discussions did you attend? Survey design only allowed one tick



<table>
<tr>
<td>15. How well organized was the workshop?
29 responses

</td>
<td>16. Is there anything else you'd like to share about the event?
• It's an eye opener workshop for Societal importance
• Great Workshop, very informative, learned a lot! Do it again in Hawaii next time.
• As a speaker, I was impressed by your organization and support - well done!
• Interesting and informative workshop
• I enjoyed the material presented and I learned a lot in area of research.
• I hope the conversations keep going and I look forward to the next event.
• Thank you, I hope the recordings will remain available.</td>
</tr>
</table>

Annex C Speaker biographies and links to archived session materials

This annex contains the speakers' affiliations and biographies ordered by session. Session Chair biographies are at the end of this annex.

Plenary Session One[31]

Dr Kara Lavender Law, Sea Education Association, US

Dr Kara Lavender Law studies the distribution, behavior and fate of plastic debris in the ocean. Trained as a physical oceanographer, she has more than 12 months of sea time on oceanographic and sailing research vessels, including in the eastern North Pacific and western North Atlantic Oceans where plastic debris accumulates in regions dubbed, "garbage patches". Her current research interests focus on the sources of plastic to the marine environment, understanding how ocean physics determines the distribution of plastic and other marine debris, and the degradation and ultimate fate of different plastic materials in the ocean.

Dr Cristóbal Galbán, GEMA Center, Universidad Mayor, Chile

Dr Cristóbal Galbán's primary research topic is focused on the Biogeochemical implications on the Persistent Organic Pollutants Cycling in the Oceans with special interest in the upper water column and the influence of phytoplankton and zooplankton.

Dr Chihhao Fan, NT University, Chinese Taipei

Dr Chihhao Fan is a professor of the Department of BioEnvironmental Systems Engineering, National Taiwan University (NTU). He received his PhD in Civil Engineering from Purdue University in 1997. He was hired as a postdoctoral fellow at the Hydrotech Research Institute of NTU immediately after receiving his PhD degree. After one year with NTU, he decided to work with the Environmental Protection Administration as an environmental engineer. In 2000, Dr Fan joined Ming Chi University of Technology, Chinese Taipei as a faculty member, and transferred to NTU in 2015. Dr Fan's main research areas include environmental chemistry and applications, watershed management, water/wastewater treatment, and water resource management. Recently, Prof. Fan is involved in projects funded by the Ministry of Science and Technology, Chinese Taipei, focusing on the assessment of microplastic in the aquatic environment. He conducted more than 60 projects in the areas related to the environment, and currently, he has been serving as a board member of several government committees as well as the managing editor of Paddy and Water Environment.

[31] Pre-recorded session presentations can be viewed here: https://youtu.be/MJ8jLB6qPNE

Dr Jennifer Provencher, Environment and Climate Change Canada, Canadian Wildlife Service, Canada

Dr Jennifer Provencher is the Head of the Wildlife Health Unit at the Canadian Wildlife Service in Environment and Climate Change Canada. Her research examines issues affecting the conservation of wildlife species with partners, including plastic pollution both as a physical and a chemical contaminant in the environment. She has published numerous peer-reviewed papers on plastic pollution interactions with wildlife in the Pacific, Atlantic and Arctic oceans. Her main research programs are in Nunavut, Canada where she first became involved in Arctic research during the 2007-2008 International Polar Year. Her work is focused primarily on Arctic ecosystems where she works with Indigenous communities to develop and implement harmonized monitoring programs to track and understand plastic pollution in the environment. She is the co-chair for newly formed Litter and Microplastic Expert Group under the Arctic Council's Arctic Monitoring and Assessment Program (AMAP), and is a member and chairs a number of domestic and international working groups and committees focused on plastic pollution.

Dr Brett Howard, American Chemistry Council, US

Adept technical professional with comprehensive training in federal chemical regulations, sustainability, law, and organic chemistry. Extensive project management skill set that includes conception, technical design, implementation, advocacy, and budget supervision.

Britta Denise Hardesty, Commonwealth Scientific and Industrial Research Organisation, Australia

Britta Denise Hardesty has been leading a portfolio of plastics related projects for the past 15+ years, focusing on sources, movement, impacts and policy responses of plastics of all sizes. She works with governments, international bodies, and local community members. She is a senior principal research scientist for Commonwealth Scientific and Industrial Research Organisation (CSIRO) the federal research institution of Australia.

Dr Winnie Lau, The Pew Charitable Trusts, US

Winnie Lau is a project director with Pew's preventing ocean plastics project, which aims to propose strategies to reduce the global ocean plastic pollution problem. She has also worked on Pew's international conservation unit, developing new projects, and partnerships in Asia. Before joining Pew, she was the climate change science and technology adviser with the US Agency for International Development's mission to Sri Lanka and the Maldives. She also managed the Marine Ecosystem Services Program at Forest Trends and was a science and technology policy fellow for the American Association for the Advancement of Science at the US State Department. Lau holds a bachelor's degree in integrative biology and environmental sciences from the University of California, Berkeley and a doctorate in oceanography from the University of Washington.

Discussion Session 1[32]

Dr Olga Pantos, Institute of Environmental Science and Research, New Zealand
Dr Olga Pantos is a senior research scientist in ESR's Water and Biowaste group. Her research background is in the impact of anthropogenic stressors such as climate change and eutrophication on marine ecosystems. At the centre of her current research she is the co-lead of a domestic research programme looking at the levels, potential impacts and solutions of microplastic contamination in New Zealand's freshwater, marine and terrestrial environments. The project team is made up of researchers from other New Zealand research institutes and universities, with expertise in a broad range of disciplines, from marine biology and microbiology to polymer chemistry and social science. Dr Pantos is also co-lead of range of other plastic projects, including dietary exposure to microplastics in New Zealand and the risks posed to humans and the environment from the use and post-life of synthetic clothing.

Dr Shuhei Tanaka, Kyoto University, Japan
Dr Shuhei Tanaka works in the field of environmentally friendly industries for sustainable development. In the Kyoto University laboratory, we conduct basic and applied research contributing to real-world environmental policies, and foster environmental leaders who will have the ability to solve environmental problems. Conservation and management of aquatic environments, improvement of water infrastructure, promotion of resource recycling, development of energy saving industries, and analysis of solutions to water sanitation issues in Japan and abroad are all topics being studied using various tools, such as water quality analysis, micro-pollutant analysis, and water and micropollutant treatment technologies and mathematical modelling.

Dr Qinmei Li, Institute of Analysis and Testing, Beijing Academy of Science and Technology (Beijing Center for Physical and Chemical Analysis), China
Dr Qinmei Li is Associate Professor at Beijing Academy of Science and Technology. Dr Li's research focusses on methods for analysis of microplastics and the degradation process of plastics.

Dr Jennifer Lynch, National Institute of Standards and Technology, Hawaii Pacific University Center for Marine Debris Research, US
Dr Jennifer M. (Keller) Lynch's research interests are to improve the quality of measurements in the field of marine environmental toxicology and chemistry. She has performed organic analytical chemistry research for the National Institute of Standards and Technology since 2003. In 2019 she became the Co-Director of the Hawaii Pacific University (HPU) Center for Marine Debris Research (CMDR). The CMDR was established in 2019 in Hawaii, which is one of Earth's most plastic polluted regions. Dr Lynch's current research focuses heavily on quantifying and chemically characterizing plastic marine debris to optimize methods to help

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[32] Pre-recorded session presentations can be viewed here: https://youtu.be/yJ9l-lnU_ZU

answer questions about plastic debris quantities, sources, fate, transport, effects, and reuse. She also leads the Biological and Environmental Monitoring and Archival of Sea Turtle tissues (BEMAST) project, as part of the NIST Biorepository. The BEMAST collection currently holds over 3,000 sea turtle tissue samples from across the Pacific Ocean for health and contaminant research, including ingested plastic debris, archived in liquid nitrogen vapor temperatures. She has published extensively on the measurement and effects of persistent organic pollutants, including legacy organochlorines, flame retardants, and perfluoroalkyl acids, in reference materials, sea turtles and other organisms. She has authored 61 peer-reviewed publications and four book chapters, served on the thesis committees of 21 graduate students, and holds affiliate positions at Hawaii Pacific University and University of Hawaii. Dr Lynch is motivated to study pollution exposure and effects in the ocean and educate others through technology transfer to perform quality science that can inform policy and improve environmental measurement. Her research is part of NIST's Circular Economy program, which supports the nation’s need to transition away from a model in which materials are extracted from the environment, manufactured into products, used, then discarded (a so called “linear economy”) toward one in which the atoms and molecules that make up those products repeatedly cycle within the economy and retain their value.

Dr Anna Posaka, Ocean Diagnostics, Canada

Dr Anna Posaka is an ocean scientist and plastic pollution expert who provides scientific leadership and strategic direction and drives collaborative partnerships to better understand the sources, transport and fate of plastic pollution. She is Chief Scientic Officer at Ocena Diagnotics. Her work has been supported by the Canadian government, featured in major Canadian news outlets and the prestigious Nature Communications journal, and influenced Canadian policy. She currently serves on the Expert Advisory Committee providing recommendations to address microfiber pollution to the US Congress. She previously headed research at the Plastics Lab of Ocean Wise - a non-profit ocean conservation organization. She conducted applied studies to identify and characterize sources, transport and fate of microplastics in the ocean. Her past research includes studies on oceanic trace metal biogeochemical cycles and microbial metal nutrition (PhD, Earth & Ocea Sciences, UBC, Vancouver, Canada), and degradation of pharmaceuticals in the aquatic environment (MSc, Plymouth University).

Dr Tatiana Lastovina, Southern Scientific Center of Russian Academy of Sciences, Russia

Dr Tatiana Lastovina is Senior Scientist and head of the laboratory. Tatiana's research has looked at methods for extraction, removal and stimulated degradation of microplastics. Her work has also covered concentrations, risks and methods for analysis of microplastic pollution.

Discussion - Session 2: Environment and human exposure; potential effects; mixtures toxicology[33]

Dr Eddy Zeng, Jinan University, China

Dr Eddy Y. Zeng is currently a professor and the dean of the School of Environment at Jinan University, Guangzhou, China. He obtained his BSc from the University of Science and Technology of China, MSc from Sun Yat-sen University (China) and PhD from the University of Southern California (US). He has been conducting research in the field of environmental geochemistry, focusing mainly on the environmental occurrence and fate of persistent organic pollutants. He has authored more than 170 peer-reviewed scientific articles and several book chapters.

Dr Sarva Mangala Praveena, Universiti Putra Malaysia, Malaysia

Dr Sarva Mangala Praveena is currently working as an Associate Professor at University Putra Malaysia, Malaysia. She obtained her PhD and Master degrees in Environmental Science from University Malaysia Sabah, Malaysia. Praveena's expertise is in environmental pollution analysis. She is experienced in analyzing common and emerging pollutants as well as estimating the environmental and health risks associated with these pollutants. Praveena has been involved in understanding the microplastics sources and occurrence in the environmental matrixes especially from residential areas. She is also involved in Working Group of Malaysia's Plastics Sustainability Roadmap for Microplastics.

Dr Qing-Xiang "Amy" Sang, Florida State University, Department of Chemistry & Biochemistry, US

Dr Sang's laboratory deciphers the biochemical mechanisms of human breast, prostate, and brain cancer initiation, progression, metabolism, angiogenesis, and invasion for cancer biomarker and drug discovery. Protein biochemistry and genomics studies are combined with molecular cell biology, medicinal chemistry, biostatistics and bioinformatics, and biomedical engineering. Novel metalloproteinases such as human cancer-derived endometase/matrilysin-2 (MMP-26) and adamalysin 19 (ADAM19) were discovered. Pro-enzyme activation, substrate specificities, the inhibition kinetics, and the structure-function relationships of the proteinases and their inhibitors were investigated. The Sang group decoded the driven gene mutations and oncogenic pathways of brain cancer medulloblastoma. Human childhood brain malignant rhabdoid tumor is modeled using induced pluripotent stem cell-derived brain organoids. The gene editing and stem cell technologies are utilized to generate this novel cancer model for drug evaluation for the effective treatment of pediatric brain cancer. Environmental toxins are also evaluated using human cell lines and brain organoids.

Prof. Jesus Olivero-Verbel, University of Cartagena, Cartagena, Colombia

Prof. Jesus Olivero-Verbel is Director of the program in Environmental Toxicology, and part of

[33] Pre-recorded session presentations can be viewed here: https://youtu.be/FPUxJewdv8w

the Environmental and Computational Chemistry Group at the University of Cartagena, Cartagena, Colombia. He gained his PhD at the University of Cartagena, Cartagena, Colombia. Today he has involvement in over 250 research items, and over 6000 citations. His work has included looking at emerging contaminants and priority substances in marine sediments.

Greg Zarus, Agency for Toxic Substances & Disease Registry, US

Greg is the Office Director of the Agency for Toxic Substances & Disease Registry's Office of Innovation & Analytics. His office is home to the agency's namesake programs: it develops the toxic substance profiles and manages the disease registry. This provides additional tools and analytic consultation to the agency programs that evaluate population exposures and risks, including geospatial research and computational toxicology. His Office Purpose: To use best practices to collect, analyze, and interpret data and disseminate scientific information to enable internal and external partners to make actionable decisions regarding exposure to hazardous substances. The office provides analytic and modeling expertise; develops new analytical tools, tox profiles, and repository of data; integrates the use of geospatial science in public health activities; conducts synthesis of research, and surveillance and registry programs; evaluates methodological and programmatic best practices internally and externally.

Dr Moiz Mumtaz, Agency for Toxic Substances and Disease Registry (ATSDR)/Centers for Disease Control and Prevention (CDC), US

Dr Mumtaz's longtime research interests include the development of toxicity and risk assessment methods for environmental chemicals/pollutants and their mixtures. Dr Mumtaz obtained his BSc (Osmania University, India), MSc (Oregon State University), and PhD (University of Maryland). He did his post-doctoral research in occupational health and joined USEPA Office of Research and Development in 1987. He has been working as a Toxicologist at the Agency for Toxic Substances and Disease Registry (ATSDR)/Centers for Disease Control and Prevention (CDC), Atlanta, GA since 1992. He is the principal representative of the Agency for Toxic Substances and Disease Registry (ATSDR/CDC) on the Department of Health and Human Services (DHHS) Interagency Coordinating committee on the validation of alternative methods (ICCVAM). A member of SOT and the past - president of Mixtures Specialty Section (MixSS). In 2013, he was elected a Fellow of the Academy of Toxicological Sciences (FATS) and won the SOT Lehman award for major contributions to risk assessment and the regulation of chemical agents.

Dr Suresh Valiyaveettil, National University of Singapore, Singapore

Suresh Valiyaveettil is an Associate Professor at the National University of Singapore. He received his PhD degree from University of Victoria, BC, Canada. Before joining the National University of Singapore, he was at the Max-Planck Institute for Polymer Research, Germany and Cornell University, NY, US. His current research interests are in multifunctional polymers, biomaterials, nanomaterials, nanotoxicology, developing frugal engineering methods for water purification and improving chemical safety in academic institutions. Some of his recent awards include, Outstanding Scientist Award, Faculty of Science, National University of Singapore and Erudite Professorship at School of Chemistry, MG University, Kerala. He is a member of the editorial board of 13 international journals. He has published more than 240 refereed papers in international journals, given 120 invited talks and has an H-index of 46 with more than 9000 citations.

Plenary Day Two discussion panel - Regulatory and regional perspectives[34]

Dr Prashiela Manga, US Food and Drug Administration, US

Prashiela Manga is the Deputy Director, Office of Cosmetics and Colors at the US Food and Drug Administration. She has been Research Associate Professor, New York University Langone Medical Center since 2014. She has 73 publications in the focus areas of Melanocytes, Vitiligo, Melanoma, Monophenol Monooxygenase and Albinism, Oculocutaneous.

Dr Kathryn Beers, National Institute of Standards and Technology (NIST), US

Dr Kathryn Beers is a Senior Research Scientist, and Leader of the Circular Economy Program at US NIST. From 2013 to 2021, Beers served as Group Leader of the Polymers and Complex Fluids group in the Materials Science and Engineering Division at NIST. Beers has researched advances in polymer synthesis and reaction monitoring, macromolecular separations, integrated and high throughput measurements of polymeric materials, microreactors and microfluidics, degradable and renewable polymeric materials, and sustainable materials. In 2005, Beers was awarded the Department of Commerce Silver Medal. She was a 2006 Department of Commerce Science and Technology Policy (ComSci) fellow. In 2007, she received the Presidential Early Career Award for Scientists and Engineers. She is a fellow of the American Chemical Society, and has served on numerous scientific and technical advisory boards for academic centers, professional societies, government agencies and technical journals.

Dr Wonjoon Shim, Korea Institute of Ocean Science and Technology, Korea

Dr Wonjoon Shim is a principal research scientist of Korea Institute of Ocean Science and Technology (KIOST) and a professor of Department of Marine Sciences at Korea University of Science and Technology. He serves as the Director General of South Research Institute of KIOST. His scientific background is environmental chemistry. He has studied on persistent organic pollutants in marine environments including analysis, monitoring and fate study, since his MSc. and Ph.D works. His recent research focuses include development of analytical methods of nano - and microplastics, assessment and characterization of microplastic pollution, and weathering process of producing micro- and nano-size particles. He is a member of multiple international expert working groups such as GESAMP WG40, SCOR WG153, PICES WG42, and IOC/WESTPAC for micro- and macro-plastic debris pollution issues.

Dr Scott Coffin, California State Water Resources Control Board, US

Scott Coffin is a Research Scientist at the California State Water Resources Control Board,

[34] Pre-recorded session presentations can be viewed here: https://youtu.be/XXFr0nN1jU4

where he focuses on microplastics and constituents of emerging concern in drinking water such as PFAS. Scott completed his PhD in Environmental Toxicology at the University of California, Riverside. His graduate work focused on endocrine-disrupting chemicals and eco-toxicological effects of plastic. Scott's expertise are in analytical chemistry and bioanalytical screening, and he is experienced with fish bioassays, molecular biology, bioaccumulation modeling and human health risk assessments. His specialism is on the development of regulations for microplastics in drinking water.

Dr Birgit Sokull-Kluettgen, European Commission, Joint Research Centre, Italy
Birgit Sokull-Klüttgen, who has a PhD in Natural Sciences (Biology), is the Deputy Head of the Consumer Products Safety Unit of the European Commission's Joint Research Centre (JRC) in Ispra (Italy). Joining the European Commission in 1995, Birgit worked for many years on the scientific/technical support to the conception, development, implementation and monitoring of EU legislation on chemicals. For a long time Birgit has been involved in research and policy support projects on safety assessment of nanomaterials. Furthermore, she coordinates the JRC work on the impact and sustainability of plastics. She is particularly interested in linking science to policy needs in order to provide circumspect opinions for a better regulation to the European Commission and to EU Agencies.

Discussion - Session 3: Terminology, nomenclature and harmonizing methods: efforts towards consensus[35]

Dr Dingyi Yu, National Centre for Food Science, Singapore Food Agency, Singapore
Dr Yu obtained his PhD in Organic Chemistry & Material Science from Jilin University, China, in 2008, He later joined Harvard University in US as a Postdoctoral Research Associate (2008-2010). In 2010, he joined the Institute of Bioengineering and nanotechnology (IBN) in Singapore as a Research Scientist & Project Leader (2010-2016) leading a research group to develop new organo/organometallic synergy catalytic systems for Green Synthesis and Biomass Conversion. Dr Yu is currently the Chemical Specialist Team Lead (2019-present) in Singapore Food Agency (SFA). The applied research strategies include forecasting food safety risks through early detection of food safety concerns and exploration of new technologies to advance in-lab and on-site rapid testing capabilities. His research interests cover 1) Non-targeted Analysis for early food safety alert, 2) Nanomaterial detection, characterization and monitoring in food and food Contact Materials and 3) Micro- and Nanoplastics detection and identification in food and water systems. He is a member of SCC Technical Committee and Working Group – ISO/TC/229/JWG2 and JWG3 and a member of Working Group of Singapore Biochar Standard development.

Dr Susanne Belz, European Commission Joint Research Centre, Italy
Susanne Belz is an analytical chemist by training and has experience in multiple scientific fields

[35] Pre-recorded session presentations can be viewed here: https://youtu.be/WaZ_BDDdMOg

from environmental and food chemistry to toxicology and pharmaceutical quality. After 10 years in research, she worked for a short period in a contract laboratory and subsequently in a regulatory agency, before joining, in 2011, the Joint Research Centre of the European Commission. Since 2019, she is providing scientific and technical support on EU policies on microplastics, including liaison with standardization bodies.

Dr Nanna B. Hartmann, Technical University of Denmark, DTU Environment, Denmark
Nanna B. Hartmann is a senior researcher in environmental fate, ecotoxicological effects and risk assessment of nanomaterials and microplastics. She has an MSc in environmental engineering (civil , 2007) and holds a PhD in ecotoxicology of nanomaterials (2011) . Her research interests include test method development, science communication and the link between science and regulation. She has been involved in the development of OECD test methods and guidelines for ecotoxicological testing of nanomaterials. Through her current research she seeks mechanistic understandings of the fate, degradation, transport and effects of nano- and microplastics in the environment and in technical systems, thereby feeding into technical process optimization. Co-founder of the DTU network 'Women in Engineering Science' and former member of the DTU Steering Group on Equality and Diversity (2015-2018).

Nikolai Kozlovskii, Pacific Geographical Institute FEB RAS, Russia
Nikolai Kozlovskii received his postgraduate qualification in geoecology from the Pacific Geographical Institute (PGI) of the Far Eastern Branch of the Russian Academy of Sciences. He is currently a researcher and staff member at the Pollution Monitoring Regional Activity Center of North West Pacific Action Plan (NOWPAP POMRAC) at PGI in Vladivostok, Russian Federation. POMRAC is responsible for cooperative measures related to atmospheric deposition of contaminants and direct inputs of contaminants to the marine and coastal environment with river discharge. POMRAC activities are addressing marine litter issues, including the assessment of microplastics inputs with river discharge in the NOWPAP region. Mr Kozlovskii co-authored the report "Guidelines for Harmonizing Ocean Surface Microplastic Monitoring Methods" and has involvement in North Pacific Marine Science Organization Working Group 42 - on indicators of marine plastic pollution.

Dr Mark Anthony Browne, University of New South Wales, Australia
Dr Mark Anthony Browne works on conserving biodiversity by understanding the impacts of human activities (priority pollutants, plastic debris, urbanization) on biodiversity and rehabilitating affected habitats (ecological engineering). He collaborates closely with colleagues at a wide range of domestic and international institutions, enabling a strong multi-disciplinary approach. He is particularly interested in the scientific basis for biological conservation through managing environmental problems and advises the United Nations, European Union and governments (Australia, UK, US.) on this. He has lectured (>120 contact-hours), prepared teaching materials, supervised post- and under-graduate students, and has secured >$1.245M in research funding.

Dr Claus-Gerhard Bannick, Umweltbundesamt (German Environment Agency), Germany
Dr Claus G. Bannick currently works as Head of Unit "Wastewater Technology Research; Waste Water Disposal, Umweltbundesamt, Germany. Claus does research in Waste Water Quality and Processes, Environmental Science and in the field of micro plastic. Claus is involved in several microplastic research projects founded by the German Research Ministry (MIWA, ENSURE, RUSEKU, SUBµTRACK). Claus is convener of two ISO committees (WG4 in SC 14/ ISO TC 61 Plastics - Characterization of plastics leaked into the environment (including microplastics) and quality control criteria of respective methods and Joint Working Group 1 Plastics (including microplastics) in waters and related matrices in SC 2 / TC 147 Water Quality) an involved in various standardization works at ISO and CEN Level (ISO TC 38 Textiles, CEN TC 248 Textiles and CEN TC 249 Plastics).

Dr Denis Koltsov, BREC Solutions Limited, UK
Dr Denis Koltsov is a Nanotechnology consulting professional with background in Physics and Engineering specializing in innovation, research, technology scouting, market research, standardization and nanotechnology-related regulation. He is one of the few experts following all nanotechnology standardization groups. He provides information on existing standards and actively develop new ones. He is an expert at BSI NTI/1, BSI LBI/37, BSI LBI/50, CEN TC352, ISO TC24/SC4, ISO TC281 and ISO TC229. He has already drafted, managed and published a number of standards under ISO and CEN. He is currently the Chairman of ISO TC229 (Nanotechnologies). He provides consulting services on all aspects of nanotechnology standardization, regulations, nanomaterial notification, market evaluation, technology scouting and funding brokerage. Besides this he also gets involved in hands on research and development at BREC Solutions (Nanotechnology consulting firm). Research interests are in nanomaterials characterization, dispersion stability, fine bubbles technology, novel applications and product development, process optimization and strategy for innovation. He also provides bespoke intelligence reports, independent technology evaluations and market surveys in the area of nanotechnology or nanomaterials.

Discussion - Session 4: Strategies for micro- and nanoplastics mitigation, remediation, and recycling[36]

Dr Chelsea Rochman, University of Toronto, Canada
Dr Chelsea Rochman is an Assistant Professor in Ecology at the University of Toronto, a scientific advisor to the Ocean Conservancy, and a co-founder and director of the UofT Trash Team. Chelsea holds a BSc in Biology from University of California, San Diego and a PhD in Marine Ecology from University of California, Davis and San Diego State University. Chelsea has been researching the sources, sinks and ecological implications of plastic debris in marine and freshwater habitats for the past decade. She currently runs a research program of more than 30 people researching plastic pollution, with microplastics being a major focus. She has

[36] Pre-recorded session presentations can be viewed here: https://youtu.be/4JsRJ6RYWNs

published dozens of scientific papers in respected journals and has led international working groups about plastic pollution. In addition to her research, Chelsea works to translate her science beyond academia. For example, her research group runs an outreach program in the community and Chelsea regularly presents their work to and/or provides advice for policy makers and managers in Canada, the US, the EU and the UNE.

Dr Hatim Albasri, Center for Fisheries Research, Ministry of Marine Affairs and Fisheries, Indonesia

Hatim Albasri received the M.A. degree in geography from the University of Hawaii at Manoa, Honolulu, HI, US, in 2009, and the PhD degree in geography from the University of New South Wales, Sydney, NSW, Australia, in 2019. He started his career as a Researcher at the Center for Fisheries Research, Indonesian Ministry of Marine Affairs and Fisheries, in 2003. His research interests include policy analysis, site selection carrying capacity, spatial modeling and optimization, and environmental impact assessment related to aquaculture. Mr Albasri is a member of the Global Research Team of OCEAN2050. He received several awards and honors, including Ford Foundation Fellowships, Australian Award Fellowships, and Nuffic Neso. He is currently the Indonesian Principal Investigator of SATREPS Mariculture funded by JICA, JST, and MMAF, the Project Overseer of an APEC-OFWG funded project, and a Co-Domestic Project Coordinator of IAEA-RCA RAS7037. He is an Associate Editor of the Indonesian Aquaculture Journal and two other nationally recognized journals in Indonesia. He also serves as a Reviewer for several international journals.

Rachael Zoe Miller, Rozalia Project for a Clean Ocean and Cora Ball, US

Rachael Zoe Miller is an expedition scientist, entrepreneur, inventor and National Geographic Explorer working to protect the ocean. She is the Founder of Rozalia Project for a Clean Ocean, a nonprofit working on the problem of marine debris and co-inventor of the Cora Ball, the world’s first microfiber-catching laundry ball. Rachael leads teams on expeditions whose scientific results are published in peer-reviewed journals and education programs that inspire thousands of people of all ages. She’s presented at venues worldwide including on the TedX stage and at The Explorer’s Club. Rachael captains the 60’ sailing research vessel, American Promise, certified hundreds of people to be sailing instructors, trained Navy SEALS to find unexploded mines using underwear robots, pitched to audiences at Our Ocean and Plastics Europe and mentors young scientists at the New York Harbor School.

Mr Jean-David, Lantagne, Hoola One technology, Canada

Jean-David is in charge of Hoola One's technological development. He is mainly involved in the development of the product, but also in R&D and strategic positioning of Hoola One’s future products in relation to the problems of plastic in our environment.

Associate Professor Bronwyn Laycock, The University of Queensland, Australia

Dr Bronwyn Laycock has a diverse background in translational research, working not only in academia but also in industry and as a consulting chemist, as well as at CSIRO. Her research activities have ranged from bio/degradable polymers, composites, organic and organometallic synthesis, waste conversion technologies, and pulp and paper chemistry, to general polymer chemistry. She is currently working across a range of projects with a focus on materials for circular economy applications and management of the transition to the new plastics economy. The application areas in her research program include biopolymers (particularly polyhydroxyalkanoates), polymer lifetime estimation and end-of-life management/conversion technologies, biocomposites, controlled release matrixes for pesticide and fertiliser applications, polyurethane chemistry, polymer foams, biodegradable packaging, carbon nanofibre production and peptide based conducting nanowires. As a Project Leader and Deputy Program Leader within the CRC for Polymers, she also managed a project that delivered an oxodegradable thin film polyethylene that was commercially licenced by Integrated Packaging. This work earned the team a Joint Chairman’s Award for research/commercialization (CRC for Polymers) and an Excellence in Innovation Award (CRC Association).

Professor Veena, Sahajwalla, The University of New South Wales, Australia
Veena Sahajwalla is an inventor and Scientia Professor of Materials Science in the Faculty of Science at UNSW Australia. She is the Director of the UNSW SM@RT Centre for Sustainable Materials Research and Technology and an Australian Research Council Laureate Fellow. Sahajwalla is known for her role as a councillor on the independent Australian Climate Council and as a judge on the ABC television show The New Inventors. Sahajwalla also served as a commissioner on the now defunct Australian Climate Commission. Sahajwalla is known internationally as the Inventor of 'Green Steel'. Sahajwalla's research is recognised for changing the way the properties of carbon-bearing materials are understood, including coals, cokes, graphites, plastics and rubber. Sahajwalla's work has had significant impact on the theory and practices that form the basis of operations of the Iron-making, Steel-making and Ceramics industries. Of particular importance is her demonstration that waste plastics and waste rubber can be partial replacements for coal and coke in steel-making. Sahajwalla's unique focus on the evolution of carbon properties in high-temperature conditions has not only advanced scientific understanding of materials processing, but has provided cost-effective opportunities for industries to move towards sustainable and environmentally friendly production methods. In 2013, Sahajwalla was awarded the AIST Howe Memorial Lecture award. In 2012, Sahajwalla was awarded the Banksia Environmental Foundation GE Innovation Award. In 2012, Sahajwalla won the Australian Innovation Challenge in recognition of her revolutionary work turning recycled rubber tires into steel. In 2011, Sahajwalla was awarded the Nokia Business Innovation Award, presented at the Telstra Business Women's Awards. In 2008 Sahajwalla was named NSW Scientist of the Year for Engineering Sciences by the NSW Government Office of the Chief Scientist.

Discussion - Session 5: Current and proposed regulations on intentionally used plastics[37]

Dr Rachel Meidl, Baker Institute for Public Policy, Rice University, US

Rachel A. Meidl, LP.D., CHMM, is the fellow in energy and environment at Rice University's Baker Institute for Public Policy, Center for Energy Studies. She was previously appointed deputy associate administrator for the Pipeline and Hazardous Materials Safety Administration, an agency of the US Dept. of Transportation. Her research focuses on sustainability; the circular economy; environmental justice, domestic and international policy and law as it relates to life cycle management of hazardous wastes; safety and environmental regulations of the treatment, storage, disposal, and transportation of chemicals within and outside the US; assessing plastics, plastic recycling technologies, advanced electronics, and alternative energy applications from a sustainability and life cycle perspective to understand the environmental, economic, and social impacts across the supply chain; and resiliency of the energy industry. Prior to her public service, Meidl was the director of regulatory and technical affairs at the American Chemistry Council in Washington, D.C., where she advanced a broad range of regulatory and policy issues, including reforming the Toxic Substances and Control Act, hazardous waste management and emergency response, and addressing contaminated site issues. She has more than 25 years of experience in industry, academia, government, politics and international relations, managing the entire life cycle of hazardous waste operations and emergency response to chemical, explosive, radioactive and biohazardous materials. Meidl holds a doctorate in law and public policy from Northeastern University, a master's in environmental policy and management with a concentration in environmental chemistry and international law from the University of Denver, a master's in applied science and technology from National University, bachelor's degrees in conservation biology and zoology & animal physiology from the University of Wisconsin–Madison and is a Certified Hazardous Materials Manager. Dr Meidl is also a strategist and advisor for Morgan Stanly Capital International on circular economy.

Dr Andrew Bartholomaeus, University of Queensland, Daimantina Institute, Australia

Dr Andrew Bartholomaeus, B.Pharm, PhD, Cert Ag (III), obtained a bachelors degree in pharmacy from the University of Sydney and following professional practice in pharmaceutical manufacturing, hospital and military pharmacy completed a PhD in toxicology at RMIT University in Melbourne. Over the past 30 years Prof. Bartholomaeus has worked as a toxicologist across a broad range of chemical regulatory areas including agricultural, veterinary and industrial chemicals, complementary medicines, gene technology products and food. Prior to June 2008 he held the position of Chief Toxicologist with the Prescription Medicines area of the Therapeutic Goods Administration in Australia with responsibilities in the area of preclinical assessment and in leading the TGAs response to the Australian National Nanotechnology Strategy. Prof. Bartholomaeus subsequently took up the position of General Manager of the

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[37] Pre-recorded session presentations can be viewed here: https://youtu.be/54d6NOzHNIo

Risk Assessment Branch at Food Standards Australia New Zealand. Prof. Bartholomaeus retired from FSANZ in 2012 to establish his own consultancy and to devote more time to research and teaching. He currently holds extramural appointments with FSANZ as a science fellow, the University of Queensland Medical School as an Adjunct Professor, the University of Canberra as an Adjunct Professor of Toxicology and Pharmacy, has previously been an expert advisor to the FAO/WHO and was a member of the ILSI IFBiC Steering Group. In June 2009 Dr Bartholomaeus chaired the FAO/WHO Expert consultation on the Application of Nanotechnologies in the Food and Agriculture Sectors: Potential Food Safety Implications. Prof. Bartholomaeus is a member of the Society of Toxicology and ACTRA.

Dr Ben Maurer, National Renewable Energy Laboratory, US

Dr Maurer is the Sustainable Oceans Lead at the US Department of Energy's National Renewable Energy Laboratory, where he serves as the principal investigator (PI) for the Waterborne Plastics Assessment and Collection Technologies (WaterPACT) project. As PI, Ben leads a cross-disciplinary team at two domestic laboratories characterizing the broad spectrum of plastics in US waterways and developing technology solutions in sensing, collection, conversion, and redesign to reclaim plastic debris for the circular economy and remediate waterways pollution. In his over twenty years in ocean science research, Dr Maurer has held positions at NREL, the University of Washington, the University of Cambridge, and UC San Diego, and directly supported US DOE and NOAA's NMFS (National Oceanic and Atmospheric Administration - National Marine Fisheries Service). Ben earned his doctorate in oceanography at Scripps Institution of Oceanography and his masters in engineering sciences at UC San Diego.

Dr Barbara Martinez, Conservation X Labs, US

Dr Barbara Martinez is the Open Innovation Director for Conservation X Labs. She leads open innovation prize-based Challenges and Make for the Planet competitions, including the Artisanal Mining Grand Challenge and the Microfiber Innovation Challenge. She was previously a science policy fellow in the Office of the Science Advisor and the Office of Research and Development at the US Environmental Protection Agency, where she worked with multiple teams including with the Scientific Integrity Official and the Innovation Team. Barbara also has spent time in laboratories and remote field sites studying endocrine disruption in prairie voles, seed dispersal by lemurs, seed dispersal by hornbills and monkeys, and songbird behavior. She has her PhD in Conservation Biology from the University of Minnesota with a minor in Development Studies and Social Change and a BS in Wildlife Ecology from the University of Wisconsin - Madison.

Declan Mc Adams, Pinovo AS, Norway

Mr Mc Adams is chairman of Pinovo, a Norwegian ocean impact company whose patented technology and equipment recover paint residuals, rust and blasting material during surface treatment, effectively stopping Ocean Paint Microplastic Emissions at source. Waste is then safely disposed of and Pinovo aims to incorporate a recycling solution as their technology develops. Pinovo have been working closely with UpLink/WEF, Solar Impulse Foundation, and

Ocean Conservancy to put the issue of Ocean Paint Microplastic Leakage “on the agenda” in an effort to drive regulatory change on this matter.

Discussion - Session 6: Approaches for Nanoplastics[38]

Dr Ludovic Hermabessiere, University of Toronto, Canada

Dr Ludovic Hermabessiere has an interest in microplastic pollution and he recently complete a PhD. This work allowed him to quantify microplastic pollution in fish and shellfish species. To do so he developed methods to extract and characterize microplastic. He is also interested in plastic additive and their potential effects on marine organisms. He is currently working at the University of Toronto as a Post-Doc fellow. During his previous experiences he was working on the accumulation of paralytic toxins in oyster after a natural bloom of toxic microalgae and on the assessment of trophic resources of the american oyster in Florida.

Dr Andrea Valsesia, European Commission Joint Research Centre, Ispra, Italy

Dr Andrea Valsesia holds a PhD in physics on Nanofabrication of surfaces for biological application obtained at the University of Pavia (Italy). He joined the European Commission Joint Research Centre (JRC) in 2003 and he worked there as researcher in the development of nanostructured surfaces for biosensing devices. After 5 years’ experience in the private sector, he went back to JRC working on novel methods for the detection and characterization of nanomaterials. Recently his research focuses on the development of methods for the characterization, identification and quantification of nanoplastics in complex matrices. In 2019 he was visiting scientist at the National Institute of Standards and Technology (NIST) in Gaithersburg (US) working in the field on nanoplastics.

Dr Nathalie Tufenkji, McGill University, Canada

Dr Nathalie Tufenkji received her Bachelor’s degree in Chemical Engineering from McGill University in 1999 and went on to Yale University, where she earned the MSc and PhD degrees in Chemical and Environmental Engineering. Nathalie’s graduate research at Yale focused on contaminant transport and filtration in groundwater and riverbank environments. She received the American Water Works Association Academic Achievement Award for best doctoral dissertation in the field (2006), as well as the Becton Prize for Best PhD dissertation in the Faculty of Engineering & Applied Science at Yale (2005). Dr Tufenkji returned to her alma mater as Assistant Professor in 2005 and is presently Professor in the Department of Chemical Engineering at McGill University where she holds the Tier I Canada Research Chair in Biocolloids and Surfaces. Dr Tufenkji leads a research group working in the area of (bio)colloid-surface interactions with applications in protection of water resources, engineering of biosensors and antimicrobial materials, and development of safe nanotechnology. Professor Tufenkji was awarded the Early Career Research Excellence Award by the Faculty of Engineering at McGill University (2010), a Fulbright Scholar Award for tenure at Harvard

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[38] Pre-recorded session presentations can be viewed here: https://youtu.be/rsifWG11oh0

University (2012), an Excellence in Review Award from the journal Environmental Science and Technology (2012), and the YWCA Woman of Distinction Award in Science and Technology (2014). She was elected to the College of New Scholars, Artists and Scientists of the Royal Society of Canada in 2016. In 2020, she received a Killam Research Fellowship and the Environment Division Research and Development Dima Award from the Chemical Institute of Canada. The same year, Dr Tufenkji was elected to the Canadian Academy of Engineering and received the Award for the Support of Women in the Engineering Profession by Engineers Canada.

Dr Shreyas Patankar, Ocean Wise Conservation Association, Canada
Dr Shreyas Patankar is a Research Scientist at the Ocean Wise Conservation Association, based in Vancouver, Canada. Shreyas specializes in analytical techniques to identify sources, transport, and fate of microplastics in the ocean, and to evaluate solutions to combat plastic pollution. He holds a PhD in Physics from the University of California, Berkeley where he researched optical properties of quantum materials. Prior to joining Ocean Wise, Shreyas was a postdoctoral fellow at the University of British Columbia, and has research experience in nanotechnology, materials science, energy and environmental policy.

Dr Parisa Ariya, McGill University, Canada
Professor Ariya is James McGill Chair in Chemistry and Atmospheric and Oceanic Sciences. Her labs' research is at the intersection of analytical chemistry and physical chemistry. Her lab explores particles, bridging chemical, physical and biological processes, in air, and interfaces with water/snow, soil, and built surfaces. This lab currently designs novel analytical chemistry technologies to enable tracking individual single and/or cluster of particles, including airborne virus droplets and aerosols, in milliseconds. They also develop ultra-trace chemical detection capabilities and remote sensed with artificial intelligence, recyclable nano-sensors, while deciphering feedback mechanisms between atmospheric, biogeochemical, and microphysical processes. This lab is contributing to solve the pollution enigma by developing sustainable remediation-recycling methods and technologies for pollutants (gaseous and particles, including bioaerosols such as airborne viruses, and emerging contaminants), with zero-net energy. Dr Ariya has published >145 internationally peer-reviewed publications, 4 patents, a book, > 300 proceedings, and presented >145 invited lectures in four continents. She has been recipient of numerous awards and distinctions in Canada, US, and EU, including the highest awards in Chemistry in Canada in the fields of Analytical, environmental/physical chemistry and the highest award done by a woman chemist. She has served in several leadership positions, e.g., the principal investigator of major grant applications, leading or serving as a member of grant agencies in Canada, U.S., EU, etc., notably serving as the chairperson of the Joint European Union Panel on Arctic Climate Change. She has served as an Editor, and on the Editorial Boards of several international journals, including Analytical Chemistry (ACS), Cambridge Press and Royal Society for Chemistry (UK). Dr Ariya has also served as the chairperson of McGill's Department of Atmospheric and Oceanic Sciences. Professor Ariya has served as the lead author of two United Nations Environmental Protection chapters on metal transformation in the environment. In addition, she has contributed to policy-related scientific reports namely on toxic contaminants, the Canadian Environmental Protection act, Clean Air

Regulatory Agenda, Arctic assessment reports, and advisor to Canadian Minamata delegates. Her numerous interviews have been distributed through major international mainstream and web-based media, from Spiegel and Times to Huffington Post and Vice.

Dr Samuel M. Stavis, National Institute of Standards and Technology (NIST), US

Dr Samuel M. Stavis is the Leader of the Nanostructure Fabrication and Measurement Group at the National Institute of Standards and Technology (NIST). He received a BSE in Engineering Physics from the University of Michigan and a MSc and PhD in Applied Physics from Cornell University, where he was also a Postdoctoral Research Associate in Biological and Environmental Engineering. At Cornell, he performed early research in measuring fluorescence from single molecules in nanofluidic devices. Sam joined the NIST staff through a Research Council Postdoctoral Research Associateship award. At NIST, he has advanced what is possible to make and measure at small scales. By developing and combining fabrication processes, device technologies, and microscopy methods, he has established new ways and limits of controlling and quantifying nanoscale systems. His research has diverse applications in manufacturing, healthcare, and the environment. Sam was an Editor of the Journal of Research of NIST. He has received a Bronze Medal award, two Innovations in Measurement Science awards, a Strategic Emerging Research Initiative award, and an Outstanding Authorship award from NIST.

Session Chairs

Dr Anil K. Patri, Nanocore Director, US Food and Drug Administration, US (Plenary One, Concluding Plenary)

Dr Anil Patri is the director of the Nanotechnology Core Facility (NanoCore) and was appointed Chair of the Nanotechnology Task Force in the US FDA's Office of the Commissioner. He serves on the National Nanotechnology Initiative's (NNI) Nanoscale Science, Engineering, and Technology Subcommittee and the Nanotechnology Environmental and Health Implications (NEHI) Interagency Working Group of the NNI. Dr Patri also serves as the co-chair of the US-EU Communities of Research on Characterization. He has co-authored more than 65 publications, book chapters, and reviews. Dr Patri's group conducts regulatory-science research with a focus on nanomaterial characterization, structure activity, and stability studies that help to determine the nanomaterial's impact on safety and efficacy. Dr Patri and his laboratory members are pursuing collaborative consensus standards development that can help regulatory agencies and industry.

Dr Kay Ho, US Environmental Protection Agency, US (Chair: Discussion Topic 1, Discussion Topic 6)

Dr Kay Ho is an Environmental Research Scientist at the US Environmental Protection Agency. She develops methods to assess coastal marine ecosystems. She is currently studying the effects of "emerging" contaminants - pharmaceutical, personal care products and nanomaterials - on marine ecosystems.

Gregory M. (Greg) Zarus, Agency for Toxic Substances & Disease Registry, US (Chair: Discussion Topic 2)

Greg is the Office Director of the Agency for Toxic Substances & Disease Registry's Office of Innovation & Analytics. His office is home to the agency's namesake programs: it develops the toxic substance profiles and manages the disease registry. This provides additional tools and analytic consultation to the agency programs that evaluate population exposures and risks, including geospatial research and computational toxicology. His Office Purpose: To use best practices to collect, analyze, and interpret data and disseminate scientific information to enable internal and external partners to make actionable decisions regarding exposure to hazardous substances. The office provides analytic and modeling expertise; develops new analytical tools, tox profiles, and repository of data; integrates the use of geospatial science in public health activities; conducts synthesis of research, and surveillance and registry programs; evaluates methodological and programmatic best practices internally and externally.

Dr Jennifer Lynch, National Institute of Standards and Technology, Hawaii Pacific University Center for Marine Debris Research, US (Chair: Virtual lab visit)

Dr Jennifer M. (Keller) Lynch's research interests are to improve the quality of measurements in the field of marine environmental toxicology and chemistry. She has performed organic analytical chemistry research for the National Institute of Standards and Technology since 2003. In 2019 she became the Co-Director of the Hawaii Pacific University (HPU) Center for Marine Debris Research (CMDR). The CMDR was established in 2019 in Hawaii, which is one of Earth's most plastic polluted regions. Dr Lynch's current research focuses heavily on quantifying and chemically characterizing plastic marine debris to optimize methods to help answer questions about plastic debris sources, fate, transport, and effects. She also leads the Biological and Environmental Monitoring and Archival of Sea Turtle tissues (BEMAST) project, as part of the NIST Biorepository. The BEMAST collection currently holds over 3,000 sea turtle tissue samples from across the Pacific Ocean for health and contaminant research, including ingested plastic debris, archived in liquid nitrogen vapor temperatures. She has published extensively on the measurement and effects of persistent organic pollutants, including legacy organochlorines, flame retardants, and perfluoroalkyl acids, in reference materials, sea turtles and other organisms. She has authored 53 peer-reviewed publications and three book chapters, served on the thesis committees of 21 graduate students, and holds affiliate positions at Hawaii Pacific University and University of Hawaii.

Dr Sarva Mangala Praveena, Universiti Putra Malaysia, Malaysia (Chair: Discussion Topic 2)

Dr Sarva Mangala Praveena is currently working as Senior Lecturer at University Putra Malaysia, Malaysia. She obtained her PhD and Master degree in Environmental Science from University Malaysia Sabah, Malaysia. She is also working as member of Malaysian Analytical Sciences Association, and International Water Association. In the past she worked as Demonstrator/ Past time Tutor/ Research Assistant/ and Post Doctoral Fellow at University Malaysia Sabah. She is also an Associate Editor of Journals. She is also serving as reviewer of several journals. Total numbers of publications in her credit are 73 out of which 42 are in citation-indexed journals and 7 in other refereed journals, 14 conference proceedings, 3 chapters in books, 5 abstracts and 5 in magazine/newsletter. Total citations are 180 out of which 9 in H-index (Scopus), 9 in H-index (Web of Science) and 12 in H-index (Google Scholar).

Matthew Kupchik, United States Agency for International Development, US (Chair: Plenary Two, Discussion Topic 5)
Matthew Kupchik is the Team Lead & Marine Natural Resources Advisor at United States Agency for International Development (USAID). He is experienced at providing and evaluating analyses and advice around science, diplomacy, and analytics to principals, international fora, and public private partnerships. He has a strong expertise in oceanography, fisheries, data analytics, visualization, program development and monitoring, project identification and capture, and strategy.

Dr Åsa Jämting, National Measurement Institute, Australia (Chair: Discussion Topic 3)
Dr Åsa Jämting is a senior scientist in the Nanometrology Section, National Measurement Institute, Lindfield, Sydney. She is the manager of the state-of-the-art nanoparticle characterisation facility, specialising in measurement and characterisation of a large number of different nanoparticle systems using a wide range of characterisation techniques. She is particularly interested in characterising nanoparticles in complex matrices, such as wastewater, food and sunscreen formulations. Her current research is focussed on various projects related to emerging measurement challenges for particulate materials, such as nanoparticles and microplastics in matrices of varying complexity.

Dr Christina Payne, National Science Foundation, US (Chair: Discussion Topic 4)
Dr Christina (Christy) M. Payne is a Program Director in the Engineering Directorate's Division of Chemical, Bioengineering, Environmental, and Transport Systems at the National Science Foundation. She manages the Interfacial Engineering program and several sustainability-related solicitations. Christy is also an adjunct associate professor in the Department of Chemical and Materials Engineering at the University of Kentucky. Christy received her BS and PhD in Chemical Engineering from Tennessee Technological University and Vanderbilt University, respectively. She subsequently joined URS as a chemical process engineer in the oil and gas and nuclear waste remediation industries, earning licensure as a professional engineer. Christy returned to academia holding positions as a postdoctoral researcher (2011) and staff scientist (2011-2012) at the National Renewable Energy Laboratory and assistant professor (2012-2017) at the University of Kentucky. She was also the August T. Larsson guest researcher at the Swedish University of Agricultural Science from 2013-2017. After earning tenure, Christy joined the National Science Foundation in 2017 to pursue a career in research administration. Her awards include the NSF CAREER award, the Presidential Early Career Award for Scientists and Engineers, the University of Kentucky's award for Excellence in Research, the Oak Ridge Associated Universities Ralph E. Powe Junior Faculty Award, and the August T. Larsson award. Her scientific contributions have been published in the Proceedings of the National Academy of Sciences, the Journal of the American Chemical Society, Chemical Reviews, and many other peer-reviewed journals.