Mistra
Environmental
NanoSafety
Phase II

ANNUAL REPORT 2021

Content

1. Message from the Chair

Nanotechnology is often presented as the technology of the future. It has the potential to revolutionise the electronics industry, energy supply, healthcare, fashion, our leisure activities and the environmental work. In many ways it is true. Nanotechnology offers many new opportunities in all these areas. Increased efficiency of next-generation solar panels, strong lightweight materials for building taller wind turbines, climate-smart houses, nanoparticles in soil remediation, light and energy-efficient computers, smart clothing, and targeted medicine delivery. Nanotechnology provides us with many benefits and can play a major role in solving several of our major challenges. Therefore, it is important that we ensure continued and innovative and safe development and use of nanoparticles. This is the mission of the Mistra Environmental Nanosafety programme.

Small size gives nanoparticles new characteristics

It is the small size that gives nano-sized material new characteristics and thereby the nanotechnology new opportunities. However, the small size and the new characteristics also change how the material interacts with the surroundings. It will spread, dust, bind, penetrate, dissolve, oxidise, and aggregate differently compared with larger pieces of the same material. This means that when a nanomaterial is produced, used by consumers, and in the end discarded as waste it will act with a degree of unpredictability. It is even more complicated as also the ageing of the material and its interactions with natural and unnatural matter will affect the impact on producers, consumers, and the environment. The second phase of the programme focuses on these dynamic features that arise once the nanomaterial reaches the consumers and nature.

Man-made nano-sized particles are not only created and exposed to nature by intention. Other products and human activities as the fragmentation of rubbers and plastics, combustion of oil and waste are sources for nanoparticles. Although these are unintentionally made, the evaluation of their potentially negative impact on the environment has largely the same complexity. The industrial producers of these materials are not necessarily involved themselves in nanotechnology, but their own and their consumers concerns of how the products impact on people's health and on the environment is closely related to the nanotechnology industry. This aspect of the nanosafety area increases the number of companies and products interested in the field and often involves products produced and consumed in very large quantities. We have during the third year of the programme enjoyed an increased interest from companies that have joined as associate members.

Several aspects of nanotechnology and nanomaterials are important

To ensure an innovative and safe development of the nanotechnology several aspects must be taken into account. The most obvious, from a safety aspect, is the need for knowledge about how nanomaterials behave and affect humans and the environment. This may, at first, seem straightforward but as explained above, the complexity is high and there is a great need for deeper understanding. This lack of knowledge leads to other potential challenges. The regulatory requirements concerning nanomaterials have increased in recent years. Today, companies producing and using nanomaterials, are obliged to report, in detail, the environmental impact of the material. A task that to some extent is very challenging if not impossible. Furthermore, a safe working environment must be ensured which requires reliable measurements and measures, which is difficult if fundamental methods for certification re missing.

Lack of knowledge about how safe nanotechnology is

The lack of knowledge of how safe nanotechnology is may also leads to exaggerated concerns and an unwillingness to engage in the field. This does not only apply to researchers and nanotechnology companies but also to the public. There are indications that the public opinion about nanotechnology is balancing between good and bad. The benefits with the new technology are great and obvious while the disadvantages are more obscure and maybe even scary. This division is perhaps best reflected in the results of a small study by researchers in Lund a few years ago. It revealed that nanotechnology was perceived as good whereas nanoparticles were perceived as bad. The proposed explanation is that when the benefits are described in media, there is often in parallel news about negative environmental effects from the use of nanoparticles. Therefore, communication strategy is another area identified as important to ensure an innovative and safe development. Not the least, as there is a growing concern that the lack of knowledge will push the public opinion in a negative direction before the science is in place. Therefore, despite the corona epidemic, the programme has engaged in outreach activities aimed at the general public and school children.

The Mistra Environmental Nanosafety Programme tackles crucial aspects

Phase two of the Mistra Environmental Nanosafety programme tackles the described environmental challenges by first in detail characterise the chemical ageing and biological weathering of nanoparticles in simulated natural aquatic environment. Then, the environmental fate of the transformed nanoparticles is determined in a unique wet land model system in which nanoparticles can be test-ed in parallel. The toxicity is tested at low concentrations on aquatic organisms and on fish and human cells with the aim to link weathering of the nanoparticles with changes in toxicity. The possibility to detect nanoparticles in the re-cycling process of products with embedded nanoparticles are explored. The participants in the programme aim to work with the same material to ensure that the results from each level can be coupled to each other to build a deeper understanding on how the weathering of nanoparticles affects their environmental fate and impact. The results from the chemical and biological tests are used to suggest methods and ways to fulfil the regulatory demands. The programme is focusing on the life cycle aspects which are probably the most challenging parts of the regulation. The self-imposed mission is not limited to simply try to fulfill the regulatory demands but aim to suggest improvements and, when needed, simplifications of the regulations. This work has been intensified using new data produced in the programme and we believe that it will help already established companies to register their products and make it easier for new companies to enter the nanotechnology field. To further ensure innovative and safe development of nanotechnology the programme are mapping all involved stakeholders, documenting their interests and needs, and create functional networks. In these two aspects not only scientists are involved, but also partner companies and a growing number of associated companies and industrial organisations.

The second phase continues to produce good results

The first three years of the second phase of the Mistra Environmental Nanosafety programme have been buzzing with activities. Research has been performed and published. Regular meetings, workshops and programme conferences have strengthened the internal and external cooperation and communication. New associated companies have been recruited. The corona pandemic situation has influenced all activities as all meetings have been digital and lab spaces closed or have had limited access during longer and shorter periods. In spite of these challenges, the main activities has been carried out. The activities and accomplishments and how they align with the programme's goals are described in the annual report.

PHOTO: KENNET RUONA

Rolf Annerberg
Chair of the programme board

2. Message from Management

In the annual report 2020 we described the challenges of working during a worldwide pandemic. Once again, we had a year affected by the corona virus and spread of covid-19. However, the programme continued and managed to be very active. The performance of high-quality research has not been disturbed by the corona situation, except for a few delays in some work packages. We have published several papers in high impact journals within the relevant topics.

Unfortunately, interactions between our members, who are located throughout the country, have not been able to take place in person as much as we wanted. Zoom and other digital platforms can only replace some of the exchange and relation building needed to interact. The meetings by the coffee machine can´t really be replaced online. All the same, we have organised a number of seminars, meetings and workshops online and they were successful in their own merit.

Our mentorship programme started in the fall 2021 and will continue during the spring of 2022. You can read two interviews with participants in this report. The mentorship program aims to help and coach the mentees further on in their professional life, not only nor just specifically as Nano scientists. The mentors are from both academia, industry, and various organisations. One mentor is even located in the Netherlands, which was only made possible by Zoom, so digital platforms are not always the second-best option.
Due to new ownership, new business focus and restructuring factors, the programme unfortunately lost the core partners Nouryon and Höganäs. It also became evident that the personal relationship with specific key persons individuals often play a huge part in maintain good collaborations with companies, both small and large. Therefor we decided to actively try to expand the numbers of associated partners. Recently added partners are Alfa Laval and Pronano.

In the end of the year, we were finally able to meet in person for our annual MISTRA NanoSafety get-together at Långholmen in Stockholm. The meeting can be summarized in one sentence "it only took about an hour or so before the members of the program started to feel like a team again both on a scientific and personal level".

We also encouraged the various work packages to initiate new collaborations within the Mistra program although the fact that the groups of various work packages are spread out at different universities provides a challenge. In Lund we got a positive confirmation of our work. Due to the fact that Lund is heading the Mistra Environmental Nano safety phase II, the Lund University management awarded us a crossdisciplinarity thematic collaboration grant for the next three years.

PHOTO: SHUTTERSTOCK

3. About the Mistra Programme

The interdisciplinary research programme, Mistra Environmental Nanosafety, aims to develop research, knowledge and best practice on risks associated with nanomaterials and their impact on our environment. This includes focused research on transformed nanoparticles, which have been altered by natural ecosystems, and on developing policies and risk assessments to ensure a safe and innovative development of nanotechnology in Sweden and internationally.

The programme also works with the question of how a pioneering research and development environment can be maintained. The first phase of the programme ended in 2018 and the research that was identified as most interesting is further developed in phase two of Mistra Environmental Nanosafety 2019–2023.

PHOTO: SHUTTERSTOCK

Work Packages

SCALING UP: ASSESSING STRUCTURAL CHANGE AND FATE OF NANOPARTICLES WHEN ENTERING NATURAL ECOSYSTEMS

- **WP1** examines how different nanoparticles' fate and characteristics are changed by the natural environment. It will scale up the studies of nanoparticles performed in work packages 2 and 3 (toxicity and weathering) in order to make recommendations to regulators, industry actors and wider society on which nanoparticles should be either avoided or used with caution.

CHEMICAL WEATHERING AND BIOCORONA FORMATION ON NANOPARTICLES

- **WP2** focuses on generating a mechanistic understanding of what happens to nanoparticles if dispersed and weathered at natural environmental conditions, for instance how such transformation influences their particle composition/characteristics, dissolution pattern, colloidal stability, fate and toxic potency? It focuses mainly on interactions with different kind of natural organic matter and its specific biomolecular constituents (for instance secreted biomolecules). Special attention is given to materials that undergo specific transformations that change their toxic effects (investigated in work package 3). These aspects are, despite many efforts, relatively poorly understood in the context of nanoparticles transformations and toxicity.

TRANSFORMED NANOPARTICLES ON AQUATIC FOOD CHAINS AND CELL MODELS

- **WP3** examines the effects of transformed nanoparticles on aquatic organisms, food chains and models. Nanoparticles may enter the environment through intentional releases (e.g., environmental remediation and pesticide use) as well as through unintentional releases from nanoparticles utilisation, atmospheric emissions and solid or liquid waste streams from production facilities. Once introduced to the aquatic environment, nanoparticles will undergo a multitude of transformation via a number of processes including dissolution, aggregation/agglomeration and subsequent sedimentation, as well as interactions with abiotic and biotic components present in the aquatic system. Agglomeration followed by sedimentation of nanoparticles may lead to deposition on the sediment surface where benthic organisms may be particularly at risk of exposure.

PROACTIVE RISK ASSESSMENT, REGULATION AND CREATION OF STAKEHOLDER LEARNING ALLIANCES

- **WP4** works with proactive risk assessment, regulation and the creation of stakeholder learning alliances. Of importance is to modify nanosafety regulation to reflect real risks by for example include the consideration of corona formation in risk assessments. Furthermore, this work package aims to support the effective flow and use of information between experimentalists, regulators, and industry, and to help mobilise stakeholders to engage in responsible innovation and risk governance.

SAFE HANDLING OF NANOMATERIALS AFTER PRODUCT END-OF LIFE

- **WP5** focuses on researching and developing appropriate strategies for the end-of-life management for products containing nanomaterials. This research is critical to minimise human and/or environmental exposure. Risks include both immediate exposure of humans and a long-term exposure of the ecosystem, including humans, due to leaching and accumulation. More knowledge is needed in the area of waste management and recycling, and of risks related to handling nanomaterials, in order to develop appropriate strategies, which both foster development and minimise risks.

MANAGEMENT, COMMUNICATION, ECONOMY AND STAKEHOLDER RELATIONS

- **WP 6** focuses on ensuring the smooth facilitation of the programme in phase two. It focuses on supporting a steady progression of the other work packages: internal and external communication, including societal impact. Another aim is to build networks, support platform building and manage industrial, scientific, authority and other stakeholder interaction.

4. Selected Highlights 2021

NANOMATERIAL REGULATION – A DRIVER OR BARRIER FOR NANOTECHNOLOGY INNOVATION

The new EU regulation concerning nanomaterials was the focus for this webinar, as manufacturers and importers of nanomaterials or products containing nanomaterials as of 2021 needed to comply with several information requirements, although some of them were challenging to fulfill. The online panel discussion included researchers, companies, and representation from the European Commission on the potential and limitations of current nanomaterial regulation.

NEW COLLABORATION INITIATIVE BETWEEN RESEARCH AND INDUSTRY: NANOSAFE4ALL

A collaboration initiative hosted by Lund University was formed to ensure that products based on nanotechnology can be developed and handled in a safe way. Nanotechnology has the potential to revolutionize energy supply, material consumption and precision medicine but nanosized materials can also be harmful to our environment. The aim of the initiative is to help companies to develop efficient and safe materials in a way that does not harm humans or nature. Nanosafe4all wants to provide conditions for good environmental protection, waste management and safe development of nanotechnology from a life cycle perspective.

RESEARCH PAPER ON NANOMATERIALS IN THE EUROPEAN CHEMICALS LEGISLATION

In 2021, researchers within the programme published a paper in Environmental Science, covering the methodological challenges for registration and environmental safety assessment. The research paper focuses on the revised annexes of the EU chemical legislation (REACH) which came into effect 1st January 2020. Manufacturers and importers of nanomaterials or products containing nanomaterials need to comply with several technical information requirements regarding registration and chemical safety assessments of nanoparticles.

The analysis showed a list of methodological challenges, and a need for more targeted efforts to develop test methods pertaining to areas such as nanoparticle adsorption, degradation, and exposure scenarios. The results can function as a departure for discussion for both regulators and industry in terms of ensuring both safe use and innovation of nanomaterials.

RESPONSIBLE INNOVATION IN NANOTECH: A MISTRA NANOSAFETY WEBINAR

The webinar raised the questions of the approach "responsible research and innovation", RRI, that has gained prominence to governing the future course of emerging technologies. The concept emerged to a certain extent as a response to public concerns about the safety of nanotechnology. Representatives from Chalmers, Tetra Pak and SwedNanoTech highlighted key questions and research frontiers related to responsible innovation.

Highlights articles: Mentor programme launched

The Mistra Environmental Nanosafety mentor programme provides an opportunity for PhD students, post-docs and early career researchers with an interest in nano safety to be mentored by representatives from partner organisations or senior researchers.

The purposes of the programme are to:

- Support PhD students in their self-awareness and personal development
- Strengthen the PhD students' relational and communication skills
- Improve PhD students' career planning and knowledge about career prospects within and outside of academia
- Enlarge the network within and among academia, industry and different government authorities.

Launched in October 2021, the one-year programme will run until September 2022. Six modules will immerse into issues such as Sustainable Self leadership, Career tips, Trust and Collaborations as well as Mastering suppression techniques. To promote knowledge exchange and mutual learning, the networking is not only between disciplines but also age, gender, scientific fields and experiences. The mentors and mentees meet in person approximately eight times during the year.

Some students with a nano research interest in the MISTRA STEPS programme, focusing on sustainable plastics and pathways for transformation, have also been invited to join the programme. In all, nine PhD-students and post docs participate from Lund University, University of Gothenburg, Chalmers, Karolinska and Technical University of Denmark.

Throughout the Mentor programme, the programme leader and certified psychologist **Katarina Billing** from INDEA provides guidance for how to make the most out of the mentee-mentor relationship:

- Being a great mentee means being dedicated to learning and practicing new skills. Being a great mentor entails caring about developing the mentee as a person. Some overall advice I give is that both parties try to keep communications open, define expectations, stay honest, reliable, and consistent but also try to be innovative and creative.

- The programme rests on the foundation of research that shows that future leaders within academia needs to be visionary, results and change oriented, good communicators with great perseverance and strong self-esteem.

Mentee interviews:

Egle Kelpsiene, PhD Biochemistry, Lund University (WP2)

– I enrolled for the mentorship programme with the expectation to define my goals and way towards realizing them since I believe that if you have clear goals, you can also get clear results. During this learning journey I hope to develop both professional and personal skills and approaches.

Egle feels there are many interesting aspects such as expanding her network of contacts, to get better at communication and helpful tips for planning a career.

– Having a mentor, although maybe not in the same field is valuable both for sharing experiences but also as we are from different cultures and ages, our exchange opens up for new thoughts and perspectives. It is a continuous cycle of trying, learning and growing.

The corona pandemic has been challenging in many ways and this online program has helped her.

– However, I do look forward to meeting both the mentor and my fellow mentees in real life. How to communicate with other people and make yourself understood is a general challenge but during the pandemic I think cultural understanding between people has been even more important.

Egle is originally from Lithuania and has lived in Lund for almost five years now. She has a bachelor's degree in biology and master's degree in parasitology, and is currently a PhD student in Biochemistry. For the Mistra Environmental Nanosafety programme she works in Tommy Cedervalls group, where she focuses on nanoplastic's effects to aquatic organisms *(D. magna)*, as well as yttria nanoparticle-protein interaction.

Alexander Khort, PhD Chemistry, KTH Royal Institute of Technology (WP2)

– This is a good programme for future leaders. I want to work on defining a vision and see how I can take on more responsibilities. My ambition is to create this kind of leadership mindset and understand my capabilities.

Alexander Khort thinks that communication is an important part, also learning about communicating one's research to the society, which all researchers need to pay more attention to. One of the seminars given in the programme is called "Pitching my research" and aims at developing the young researchers' ability to spread their research to the larger society.

– Every step of the process is interesting. I got some inspiring ideas and have been doing some rethinking. There is more work to elaborate, and I especially look forward to the part about trust and collaboration.

– Although the programme is designed to be online it was nice to meet several others in the Mentorship programme at the conference at Långholmen in Stockholm in November 2021. It was good to have a physical get-together and get to know also other mentees.

Alexander Khort is a Ph.D researcher, currently at the division of Surface Chemistry and Corrosion Science at KTH, Royal Institute of Technology in the group of Professor Inger Odnevall. He came to Sweden from Belarus two and a half years ago and altered his research focus from new methods of synthesis and application of metallic, oxide and oxygen-free nanomaterials to studying their environmental transformation and degradation.

Circularity and regulation that reduces risk but stimulates innovation

The topic of the spring programme meeting for MISTRA Environmental Nanosafety 2021 was Circular Economy – how circular processes, solutions and regulations of nano particles fit in a future, more systematic circular system. Not all materials can be fully reused or recycled but the use of harmful substances can be reduced.

Some of the wicked problems were presented by Josefin Ahlqvist from LUBRIC, Lund University Biobased Industry Research Centre, that connects researchers from various faculties with external partners on the topics of circular and biobased economy:

– Is it environmentally and economically beneficial to use more material on a product that will have an improved lifetime and reusability? Is it beneficial to use a process design that give more leakage of something less valuable and hazardous than something that gives less leakage, though is more hazardous?

More and new knowledge is needed on various technical materials and processes, the toxicity, the impact on ecosystems, humans, and animals but also on societal issues such as risk management, policies and business models.

– We ask how we can save energy, money and the environment in the best way and how we can prevent leakage in the circular system, explains Josefin Ahlqvist.

More knowledge needed

The Swedish EPA presented their new assignment by the Swedish government to produce a report on nanoparticles in waste and opened for dialogue on these issues. Input from all the researchers from the many disciplines represented in the Mistra Environmental Nanosafety programme was welcome. Johanna Farelius, Deputy Head of Sustainable Society Department & Coordinator of Environmental Economy, reflected on the topics covered in the presentations, panel and workshop:

– We had more questions then usual as this is an area where we have not defined where it should be handled in our organisation or how we should address it in recommendations and guidance to industry and other stakeholders.

What happens with different types of nanoparticles in different types of environments? Which types and sizes of nanoparticles will likely harm organisms and ecosystem functions? What can be done upstream to prolong product life for certain materials?

– When you lack knowledge, it is easy to apply the precautionary principle and propose to ban the use of potentially harmful materials but based on experience we know that it may prevent innovation or good use of new materials.

Lessons learnt from new regulation

An analysis and overview of present legislation and regulation regarding nano materials was then provided by Steffen Foss Hansen from WP 4 in the programme. The group has studied new EU policies such as the EU action plan for Circular Economy sets some principles and the Chemicals Strategy for Sustainability that further addresses the interface between chemicals, products and waste legislation and strengthen synergies with the circular economy such as "Safe and Sustainable by Design" and "One substance, one assessment".

They stated that the regulatory tools need to be exploited to drive and reward the production and use of safe and sustainable chemicals and that innovation for the green transition of the chemical industry and its value chain must be stepped up.

Lessons learnt on how environmental regulation can stimulate innovation were summarised as:

- Environmental regulation should set the frame for innovation
- Transition period is vital for industry to adapt and find innovative solutions
- Clear and concise regulations
- Flexible regulation and compliance deadlines
- Economic incentives and other benefits for (doing more than) complying
- Inclusive regulatory process
- More robust evaluation of the effects on innovation
- Secure support and capacity building
- Multiple regulatory measures are needed

An online workshop on the topic "Nanomaterial regulation as a driver or barrier for Nanotechnology Innovation" was organised in April 2021 with policy officer Andrej Kobe from the European Commission as a key speaker and presentations and reflections from Maria Bille Nielen, DTU (work package 4) and Anna Stenstam, CEO of CR Competence, industrial partner to MISTRA Environmental Nanosafety. The workshop attracted many participants from both academia and industry.

A serious game on regulation

The Mistra Environmental Nanosafety programme meeting in November 2021 was a long-awaited opportunity to meet again in person and exchange results and reflections across the work package teams. At the former prison on the island Långholmen in Stockholm the speakers kept the audience captive and an interactive workshop captured insights of the gathered cross-competences in an innovative way.

"It only took about an hour or so before the members of the program started to feel like a team again both on a scientific and social level"

Steffen Foss Hansen and the colleagues in work package four prepared an exercise in the format of a game board spread out on the floor in the conference room. Twelve tiles, with guiding documents from the European Chemical Agency (ECHA), with relevance to nano safety, formed the game plan. The way to move from the start to the end was by mapping as many articles from the phase I and II of the programme, 46 articles in all, with corresponding regulatory texts.

In three groups with participants from as many work packages as possible, the teams set out to speed read articles and get a general overview of the "regulation tiles". The algorithm for success was the most tiles covered and the highest number of placed articles on the game plan. The three hours were intense and the outcomes impressive.

Targeting potential influence on policies

The second day concluded with a debrief of the workshop from the first day. The ambitions of the organisers were to both identify where Mistra Environmental Nanosafety can influence policy and to set a collective writing project in motion.

Influencing policy is a matter of timing and many policies are to be reviewed in a near future. The tiles or policies that got the highest number of mentions were identified, as well as the ones that are most likely not going to be reviewed or possible to influence. Other take-aways were discussed in the respective work package teams to see how this joint effort can be taken further.

A challenge to map all articles published in phase I and II with ECHA's guidance documents of relevance to nanosafety.

5. A chat with our researchers

I. Christophe Langhammer: Can one tell us more than many?

Christophe Langhammer
Professor Chemical Physics, Chalmers University of Technology

As a physicist and a material science researcher, Christoph Langhammer brings another set of perspectives to the Mistra Environmental Nanosafety programme, complementing those who are more specialised in environmental nanosafety. In his research group, they are particularly interested in nanomaterials and nanoparticles to be used in sensors of various kinds and their catalytic qualities. To study them, they continuously develop experimental methods and although they first create platforms for a certain purpose, they eventually strive for using them also in new contexts.

"We can look at how different geometrical shape or chemical composition affect catalytic characteristics of nanoparticles. For the research questions that we address in MISTRA Environmental Nanosafety, we can instead investigate how these nanoparticle characteristics in the end may influence their toxicology. By using optical microscopy, we can study single nanoparticles when they interact with their surroundings, maybe in a gas or in an aquatic environment".

No nanoparticles are alike
A key moment for Christoph occurred in the end of the first phase of the Mistra Environmental Nanosafety programme when he realized that researchers from other disciplines often visualised nanoparticles as something spherical. However, in reality, they mostly have more complex shapes, that are dictated by their size, what kind of atoms they are comprised of, and which environment they reside in.

"No particle is identical to another, and they are very seldomly 100 percent pure. This means that if we want to understand if a certain size is the most toxic, it is challenging because in a sample that contains billions of particles there will always be a wide variety and distribution of particle types. Maybe not all particles of the same size are equally toxic, since they may vary in terms of other factors as well, such as their shape or composition at the atomic level".

This is why the study of single nanoparticles, and many of them at the same time, is essential to find out just how, or if, it is individual characteristics that matter most.

Inter-disciplinary research comparing data
A big challenge in 2021 was that Ishara Fernando, a post doc from Singapore, joined the research group during the pandemic when no one could meet in person. In addition, her tasks were to work on developing a totally new methodology for nanosafety studies, which would have been a challenge even in normal circumstances. Therefore, it was rewarding that she could attend the programme days in Stockholm in November 2021, present her findings and get a lot of positive feedback on her work. Christoph Langhammer on the next steps:

"Our question now is how we can translate our results obtained in controlled environments to natural conditions, and in which way they can be relevant to, for example understand what happens when nanoparticles in water streams end up in fish and other organisms?"

Ahead, more experiments and collaborations, especially with Inger Odnevall at KTH and her research group, will continue. They have studied the same type of particles but in solution and seen similar behavior. This confirms that the experimental approach of studying single nanoparticles on surfaces, as we do, makes a good model for particles in the environment. It will, however, also be of interest to analyse what is not seen in the different sets of data.

"I really enjoy when you have to face new challenges, when you do not know what to find and you have to learn and thereby grow, says Christoph Langhammer enthusiastically. Something new evolves and in the end, you have learnt other things than you initially thought that you would. I think that our project has the potential to shed light on a new aspect of nanosafety that hopefully will prove important also beyond the current Mistra Environmental Nanosafety programme."

II. Lauge Peter Westergaard Clausen – Regulation research is very rewarding

Lauge Peter Westergaard Clausen
PhD Environmental Engineering, in 2021 Post doctoral fellow at Technical University of Denmark and guest researcher at Lund University

In 2021, commuting between Copenhagen and Lund was enjoyable as there were not so many people and plenty of space to sit and work on the train. This is not usually the case in rush hour traffic. For Lauge Clausen it also gave interesting comparisons and reflections on culture and formal regulations during the pandemic. In Denmark everyone had a face mask, in Sweden hardly anyone.

In the MISTRA programme, regulations related to Environmental Nanosafety is the research focus for Lauge Clausen. Recently, he has studied Partner expert groups, or PEGS, and the new nano specific regulatory obligations introduced in the European Commission's registration, evaluation, authorisation and restriction of chemicals legislation abbreviated REACH.

Who influences chemical regulation and how?
The formal procedure for selecting members of the PEGs is based on a list of accredited stakeholders by ECHA, The European Chemicals Agency. Experts or organisations need to fulfill certain criteria and apply to be on the list. Members of the accredited stakeholder list are invited to participate in the PEGs and can choose to engage.

"We posed some questions such as: who are represented in these groups, which institutions do they represent, and how do the PEGS differ from the ordinary expert groups? We thought it is interesting to see who the ECHA engaged with since those included in the process have a lot of influence on the REACH legislation, explains Lauge Clausen. "We looked at all the comments that were provided by the PEGs. How many comments did each stakeholder provide and which comments where accommodated or so to say, approved by ECHA? We see this data as a sort of proxy measure of their influence."

There are of course different kinds of comment, some are editorial, and others are highly technical. However, in guidance documents the content is primarily technical and thus the approach was deemed relevant. This study was published in the fall of 2021 and the work was very rewarding to Lauge Clausen and his colleagues at DTU:

"Then we looked into regulation more broadly to figure out how we should design regulation so it can spark innovation? We boiled it down to ten lessons learnt and looked at three recent environmental regulations by EC. How does these new regulations support the identified ten lessons learnt?

Regulation should facilitate further innovation
One important aspect of this investigation is that regulation should do more than just assure compliance. Otherwise all innovation stops once the targets are met. The ambition is that regulation should facilitate and drive continuous development and innovation. None of the new regulations support this according to the studies carried out by Lauge and his fellows.

"I think this is because nobody thought about it in that way. If you look at the history of environmental regulation the tradition is to protect the environment and you rely on risk assessment and the goal is to reach below a certain threshold concentration of substances. When companies have reached this level there is no drive to go further. This is a study that we expect to publish in 2022. Maybe it will trigger some change, says Lauge Clausen hopefully.

As a regulatory scientist he often looks at the Chemical Watch site that provides the latest news and insights for professionals managing chemicals. Recently, Lauge was interviewed by Andrew Turley from Chemical Watch about this recent study and he hopes that it will reach a broad audience in industry and among regulators. He stresses that it will be interesting to get feedback on their findings.

Nano – when less is more: A Citizen Science project

Another idea that developed in 2021 was a continuation of the outreach activities from 2020 with the theatre group Sagohuset. Lauge started to commute to Lund for this work together with Tommy Cedervall, Martin Lundqvist and Mikael Ekvall in forming a citizen science project engaging school pupils aged 12–14.

The project is called **Nano – when less is more,** or **Nano – när mindre blir mer,** says Lauge in broken Swedish and explains what it entails:

"We have produced teaching material, telling the story about nano. What do we mean by nano, how big or rather, how small is it? And why is nano interesting at all? We address the properties of nano and what it can be used for. We also raise the issue of whether nanomaterials might have any negative impacts. Are we sure we have thought of everything"?

Both pupils and researchers learn from the activities

The "nanotest kit" also offers some fun-to-do exercises and experiments for the classroom. One proposes to take a rope, cut it in half and do the same thing thirty times to get pieces in nano scale. It becomes evident for the children that doing this even ten times is an effort and that nano particles are really, really, tiny.

"Nano – When less is more! is accompanied by a questionnaire that the pupils fill in before and after their learning activity. It gives us indications on how their perceptions of "nano" changes during the project and how knowledgeable they become by doing these exercises."

Another layer is the citizen science part where the children map what nano materials are present in their homes, in various consumer products. To simplify the identification of obvious nano products, three guidelines are provided – look for nano in the product name, is nano part of the branding and finally is nano mentioned in the ingredient list.

"We ask them to report all products and provide the product names and producer names. These data will then be fed into a the Nano database, an online inventory, hosted by DTU Environment and led by Steffen Foss Hansen."

At DTU researchers will screen the products and guarantee the quality assurance.

"The nice feedback loop for the pupils is that they will be able to see when "their" products pop up in the database. They will also see that their effort actually matters, and the inventory will enable all kinds of analysis, says Lauge with great enthusiasm."

An amazing chance to have a large societal impact

The big launch will take place in 2022. Tests had to be postponed due to the pandemic but when these are resumed, funding is approved or collaborations are settled, the project is ready to go.

"We have the possibility to get a lot of data, and it will also be interesting to see what the children will find - or not find! I think we have an amazing chance to make societal impact with this project. We can both publish papers about the findings, but this is so much more. If we can scale this, we can educate all the kids in Sweden - and their parents! This is really rewarding, concludes Lauge Clausen."

PHOTO: SHUTTERSTOCK

6. Communication and Impact Work

Communication, collaboration, and impact are key features of the Mistra Environmental Nanosafety programme. In 2021, several strategic communication activities were organised to increase knowledge and understanding of nano safety, and the research within the programme.

Many of the activities had to still be carried out online due to the continued covid-19 pandemic. Events with a limited number of participants and outdoor activities where possible for a period when restrictions were lifted due to massive vaccination and a decrease in the spread of the virus.

Some key communication highlights include a workshop with the Swedish Environmental Agency which was highly valued for the input provided by the programme for further regulatory work within the authority. Furthermore, we held outreach activities during Sustainability week in Lund, for high school students in the Botanical Garden and public lectures in the City Library during Future Week at Lund University.

Scientific conferences and seminars

Fadeel B., Karolinska Institutet: Keynote Lecture, 10th International Nanotoxicology Conference [virtual meeting], April 22–25, 2021: "Unmasking the surface effect: a superficial view of nanotoxicology".

Gupta G: poster presentation at 10th International Nanotoxicology Conference: "Copper nanoparticles trigger lysosome-dependent, non-apoptotic cell death in murine macrophages: evidence for cell death by cuproptosis".

Hansson L-A et al. *Fate and effects of nano-plastics in freshwater ecosystems – or rather: Will plastic nanoparticles be a major future environmental problem?* Dep. Biology LU Jan 2022

Hansson, L-A *Environmental effects of nanoparticles when flushed into aquatic ecosystems.* Lecture Nano-Lund PhD course on Nanosafety 2021

Stábile, F et al. *Threats to freshwater systems: assessing Nanomaterials as novel environmental stressors.* Shallow Lakes conference 2021 (digital)

Odnevall I., Presentation in Swedish: Korrosion och ytkemi-studier av metalliska material kopplat till hälso och miljöeffekter – ett axplock av pågående tvärvetenskapliga aktiviteter. I. Odnevall, Occupational and Environmental Medicine, Linköping University Hospital, 4 mars, 2021 (KTH)

Odnevall I., The interplay between bacteria, biomolecules and metallic surfaces, Inger Odnevall invited speaker, NanoMed North Focus Seminar, June 10, 2021 (KTH)

Rissler J. 4th Annual Research Network Workshop: Measurability of Nanoparticles in Occupational Environments. What do we know and what do we need?, National Nanosafety platform, SweNanoSafe & Swedish Work Environment Authority, 9 November 2021, "Occupational nanomaterial exposure – From production to waste"

Rissler J. Metal Beams seminar, 30 Nov 2021, "Characterization of chemical forms of metals in residual products using XAS"

Other public outreach / dissemination activities:

Engagement in the national nanosafety platform SweNanoSafe, commissioned by the Swedish Ministry of Environment. Bengt Fadeel, chair of the scientific panel and member of the steering group of SweNanoSafe.

Outdoor workshops about nanoplastics with students from Engelska Skolan, Lund (Tommy Cedervall)

Theatrical lecture and workshops in high school classes in for example Halmstad, Falkenberg, Helsingborg, Klippan and for the NanoLund staff at Fysicum Lund University. (Tommy Cedervall)

Popular Science lecture at the City Library in Lund. (Tommy Cedervall)

Nano – When less is more! A combined outreach and citizen science initiative targeting approximately 30 classes from 6th to 8th grade in Sweden (Lund, Göteborg, Sjöbo and Simrishamn). The project entails development of teaching material and a citizen science part where the students help mapping consumer products containing nanomaterials in their homes.

Who are engaging in the nano-specific partner expert groups? An analysis of partner expert groups vs. expert groups. Lauge P W Clausen interviewed by Andrew Turley from **Chemical Watch** about a recent Mistra publication (Clausen L.P.W., Nielsen M.B., Hansen S.F. (2021) Expected to be published as a news article at Chemical Watch.

Publications

Long-term exposure to nanoplastics reduces lifetime in *Daphnia magna* Kelpsiene, E., Torstensson, O., Ekvall, M. T., Hansson, L-A. & Cedervall, T., 2020. **Scientific Reports** 10 (1) 5979.

Influence of natural organic matter on the transformation/dissolution of metal and metal oxide nanoparticles and their ecotoxic potency on a piscine cell line at simulated freshwater conditions – a short-term laboratory study. A. Khort, M. Brookman-Amissah, J. Hedberg, T. Chang, N. Mei, A. Lundberg, J. Sturve, E. Blomberg, I. Odnevall, Nanoimpact, 25, 100386, https://doi.org/10.1016/j.impact.2022.100386 (2022)

Transfer of Cobalt Nanoparticles in a Simplified Food Web: From Algae to Zooplankton to Fish. Mei N., Hedberg J., Ekvall M. T., Kelpsiene, E., Hansson L.-A., Cedervall T., Blomberg E., and Odnevall I. 2021. In: Applied Nano 2(3), 184-205,
https://doi.org/10.3390/applnano2030014

Adsorption of bio organic eco corona molecules reduces the toxic response to metallic nanoparticles in Daphnia magna Ekvall, MT., Hedberg, J., Odnevall Wallinder, I., Malmendal, A., Hansson, L-A., Cedervall, T. 2021., Scientific Reports 11:10784
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Development of microfluidic, serum-free bronchial epithelial cells-on-a-chip to facilitate a more realistic *in vitro* testing of nanoplastics. Gupta G, Vallabani S, Bordes R, Bhattacharya K, Fadeel B. Front. Toxicol. 2021. Oct 6.
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Novel multimethod approach for the determination of the colloidal stability of nanomaterials in complex environmental mixtures using a global stability index: TiO2 as case study. Badetti, E. Brunelli, A., Basei, G., Gallego-Urrea, J.A., Stoll, S. ,Walch, H., Praetorius, A., von der Kammer, F., Marcomini, A.. 2021. In:Science of the Total Environment.
https://doi.org/10.1016/j.scitotenv.2021.149607

Corrosion and Transformation of Solution Combustion Synthesized Co, Ni and CoNi Nanoparticles in Synthetic Freshwater with and without Natural Organic Matter. A. Khort, J. Hedberg, N. Mei, V. Romanovski, E. Blomberg, I. Odnevall Wallinder. 2021. In: Scientific Reports.
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Release of carbon nanotubes during combustion of polymer nanocomposites in a pilot-scale facility for waste incineration. Janhäll, S., Petersson M,, Davidsson K., Öman,T., Sommertune,J., Kåredal,M., Messing,M.E., Rissler,J. 2021. In: NanoImpact.
https://doi.org/10.1016/j.impact.2021.100357

Nanomaterials in the European chemicals legislation – methodological challenges for registration and environmental safety assessment. Nielsen, M.B., Baun, A., Mackevica, A. Thit, A., Odnevall Wallinder, I., Alberto Gallego, J., Westergaard Clausen, L.P., Rissler, J., Skjolding, L., Castro Nilsson, A. Cedervall, T. and Foss Hansen, S.
https://d 23A

SUBMITTED MANUSCRIPTS:

Copper oxide nanoparticles trigger macrophage cell death with misfolding of Cu/Zn superoxide dismutase 1 (SOD1). Gupta G, Cappellini F, Farcal L, Gornati R, Bernardini G, Fadeel B. Part Fibre Toxicol. 2021. [in revision].

Lipid peroxidation drives silica nanoparticle-induced pro-inflammatory cell death (lipoptosis) in monocytes. [submitted]. Gupta G, Bhattacharya K, Gazzi A, Furesi G, Rauner M, Fuoco C, Orecchioni M, Delogu L, Haag L, Stehr JE, Thomen A, Bordes R, Malmberg P, Seisenbaeva G, Kessler V, Persson M, Fadeel B.

Annex 1. Progress Report for the Mistra Environmental Nanosafety Work Packages 2021

SCALING UP: ASSESSING STRUCTURAL CHANGE AND FATE OF NANOPARTICLES WHEN ENTERING NATURAL ECOSYSTEMS

WP1 examines how different nanoparticles' fate and characteristics are changed by the natural environment. It will scale up the studies of nanoparticles performed in work packages 2 and 3 (toxicity and weathering) in order to make recommendations to regulators, industry actors and wider society on which nanoparticles should be either avoided or used with caution.

During 2021 we finalised the construction of the large-scale wetland infrastructure including 12 replicated wetlands. We also performed the first long-term experiment (10 weeks) using gold-cored polystyrene nanoparticles (NP). The gold core made it possible to follow the plastic NP´s and assess their fate when entering a (semi) natural wetland. The experiment was a success, showing that most biota, including phytoplankton, invertebrates and plants take up NP´s entering natural systems and that some, such as phytoplankton show reduced growth.

Moreover, we detected a tendency for zooplankton to change their behavior when exposed to NP´s. The data is now analysed, and several potential publications are in preparation. The next step, beginning in spring 2022, will be to perform a similar study on NP´s emitted from recycling of instruments, such as mobile phones and computers, i.e., to prepare companies, as well as society, to handle potential environmental problems with recycling.

CHEMICAL WEATHERING AND BIOCORONA FORMATION ON NANOPARTICLES

WP2 focuses on generating a mechanistic understanding of what happens to metal and metal oxide nanoparticles (NPs) if dispersed into freshwater conditions, and specifically how they interact with biomolecules and naturally weather and transform upon contact with natural organic matter of different kinds in terms of changes in surface characteristics/composition, metal release/dissolution, colloidal stability and (eco)toxic potency.

These fundamental studies are performed at simulated in vitro conditions and conducted on both assemblies of particles (powder) and single NPs using a multitude of different spectroscopic, diffraction, electrochemical and chemical tools. The ultimate goals are to elucidate how and if adsorption of biomolecules (i.e., formation of a bio corona) and environmental biotransformation /dissolution characteristics of metal and metal oxide NPs can explain and/or be linked to potential adverse toxic effects on, for instance, aquatic organisms at in-vitro conditions (WP3) and in vivo at wetland conditions (WP1, WP5).

Another objective is to generate improved and novel scientific knowledge on how to improve regulatory (REACH) guidance documents for how to test and regulate nanomaterials (WP4).

The main research questions of 2021 have aimed to answer whether the adsorption of natural organic matter (NOM) or excreted biomolecules from *Daphnia* (surface weathering) mitigates or promotes the environmental transformation/dissolution of a range of different metals (metal core with surface oxide) and metal oxide NPs in FW, and whether information on their environmental transformation potential and polarizing capacity could be used for grouping, read across, modelling and risk assessment.

Another research question relates to assessing if the adsorption of NOM forming a "bio corona" to metallic NPs influences their short-term environmental transformation and dissolution properties in synthetic freshwater and their ecotoxic potency on aquatic organisms. The studies have comprised both less investigated metallic NPs (Sb-, Sn-, Co-, Ni-, Mn-containing and Y_2O_3) and more extensively studied metal oxide NPs (ZnO and CeO_2). Parallel ecotoxicological studies have been performed in collaboration with Gothenburg University (WP3) on selected metal NPs (e.g. Mn, Sn, and Ni), which in the presence of NOM showed no effect, increased release or reduced dissolution. The dissolution rate of the NPs in the presence of NOM was shown to correlate with the strength of interactions between the carboxylate group of NOM and the particle surface, and resulted in either no (Mn, Sb, ZnO NPs), increased (Co, Sn NPs) and decreased (Ni, NiO,

Sb2O3, Y2O3 NPs) levels of dissolution. The presence of NOM generally reduced the intracellular ROS generation by 20–40% for the investigated NPs. The results are published in Nanoimpact (Khort et al., 2022), and another manuscript is in preparation.

Transformation/dissolution studies of Co and Ni NPs and their binary combinations (Co_3Ni, CoNi, and $CoNi_3$) in synthetic freshwater with and without NOM or eco-corona biomolecules (excreted organic matter from Daphnia) were completed during 2021. Aspects that were addressed included particle stability and mobility as well as the importance of NP synthesis method, microstructure, phase composition, crystalline structure and corrosion properties and kinetic adsorption effects on the NP biotransformation/dissolution characteristics. The results showed that in contrast to findings for the pure metal NPs, the presence of NOM increased the release of Co and Ni from the bimetallic NPs in freshwater compared to freshwater only, even though its presence reduced the corrosion rate (current density). It was shown that the properties of the bimetallic nanomaterials were influenced by multiple factors such as their composition, including carbon shell, type of surface oxides, and the entropy of mixing. The results are published in Scientific Reports (Khort et al., 2021)

The interdisciplinary studies conducted during 2020–2021 in collaboration with Lund University (WP3) to assess the effects of hetero-agglomeration between Co NPs and algae and on the transformation/dissolution and toxic effects in the food web, including *Daphnia* and fish. The results are published in AppliedNano (Mei et al., 2021) and presented in a video on YouTube. The results elucidate that Co NPs gain different properties upon trophic transfer in the food web, which imply that risk assessments should be conducted on transformed and weathered NPs rather than on pristine particles.

Transformation/dissolution and toxicity studies of selected NPs (Y_2O_3, CeO_2, Sb_3O_4, Co) were initiated during 2021 and are on-going in collaboration with Lund University (Co), Gothenburg University and Karolinska Institutet (Y_2O_3, CeO_2, Sb_3O_4). Interdisciplinary studies are also on-going on 2D-materials (MXenes) in collaboration with DTU and Karolinska Institutet (WP3, WP4) and on collected electronic waste particles (WEEE) in collaboration with Lund University and Gothenburg University (WP1, WP3, WP5).

Initial tests of the optical response of nanofabricated arrays of Ag, Cu, Ni and Co NPs have been conducted in four different aquatic environments, i.e., Milli Q water, Freshwater, Freshwater + Suwanee River NOM and Freshwater + Eco Corona solution. Key results are that each type of metal NP behaves differently in the different solutions and that the optical response is correlated to postmortem SEM images of the nanoparticle structure. Based on the proof of principle from the initial tests, investigations have during 2021 been conducted on the same four metals at the single-particle level using electron-beam lithography fabricated arrays of 89 NPs of each size, with sizes ranging from 60–220 nm. Key results are that the response of single NPs can be resolved in situ in different aquatic environments and that they behave very differently at the level of the different metals. The results reveal size- and microstructure related effects for each metal, such as increased dissolution rates of copper for larger particles. Other findings elucidate that NPs that are less polycrystalline dissolve or oxidize at a significantly slower rate than highly polycrystalline particles. A manuscript is currently drafted.

To address the impact of these structural differences in detail, a sample holder was constructed during 2021, which allows single-particle optical measurements on samples and is compatible with transmission electron microscopy. This set-up enables in-depth assessments of changes on how crystallinity, shape and surface coatings will affect morphological changes of NPs when exposed to different aquatic environments.

Initial experiments were further conducted during 2021 to assess the role of the size of single NPs on NOM interactions. This work is on-going.

TRANSFORMED NANOPARTICLES ON AQUATIC FOOD CHAINS AND CELL MODELS

WP3 examines the effects of transformed nanoparticles on aquatic organisms, food chains and models. Nanoparticles may enter the environment through intentional releases (e.g., environmental remediation and pesticide use) as well as through unintentional releases from nanoparticles utilisation, atmospheric emissions and solid or liquid waste streams from production facilities.

Once introduced to the aquatic environment, nanoparticles will undergo a multitude of transformations via a number of processes including dissolution, aggregation/agglomeration and subsequent sedimentation, as well as interactions with abiotic and biotic components present in the aquatic system. Agglomeration followed by sedimentation of nanoparticles may lead to deposition on the sediment surface where benthic organisms may be particularly at risk of exposure. WP3 also studies the potential impact of nanoparticles on human health using *in vitro* models of the lungs (inhalation) and the gut (ingestion).

The overall work carried out in 2021 in WP3 includes screening of selected nanoparticles including nano plastics, and studies were carried out on polystyrene (PS) nanoparticles. Screening for cytotoxicity and other sublethal endpoints (reactive oxygen species production, and CYP450 enzyme activation) induced by PS nanoparticles of different sizes (25, 100 and 2000 nm) after short term exposure (24 h) using rainbow trout gill and liver monolayer cell lines. The same set of PS particles were tested on a variety of human cell lines derived from the gastrointestinal tract and the liver and we did not observe any cytotoxicity.

Moreover, a study was conducted to evaluate the uptake of fluorescent-labeled PS particles and silica particles using conventional (static) cell cultures *versus* a microfluidics-based system with continuous flow of cell medium. The results showed that the low-density PS particles were taken up by human lung cells under flow conditions but not in standard cell cultures whereas the high-density silica particles were equally internalized by the cells in both settings. The results have been published in the open access journal *Frontiers in Toxicology* (2021).

Additionally, WP3 finalised and submitted a study of a panel of amorphous silica particles prepared by our partners at Nouryon. This work has shown that small, amorphous silica particles elicit pro-inflammatory effects while silane modification of the particle surface serves to mitigate these effects.

Ongoing work involve following long term metabolic changes in exposed *D. magna* by NMR based metabolomics and to link the binding of proteins in *D. magna* intestine to nanoparticle toxicity. In the collaboration with the Sph3roid project (Lead by Tobias Lammel) development of a standardised method of culturing 3D rainbow trout liver cells is ongoing for further *in vitro* screening and long-term studies. Plans are made to screen a number of rare earth metals nanoparticles using similar methods with and with the addition of eco-corona supplied by Lund University but is yet to be carried out.

Collaborations between the junior scientists involved in WP3 has resulted in the exchange of samples between LU and KI in order to evaluate whether nano plastics (i.e., polystyrene nanoparticles) can be detected *in situ* in daphnids by using Raman confocal microscopy-spectroscopy. The work is done in collaboration with RISE and our preliminary results have shown that label-free detection is feasible.

Prof. Bengt Fadeel (KI) served as chair of the scientific expert panel of the national nano safety platform, SweNanoSafe, at the Institute of Environmental Medicine at Karolinska Institutet, and Prof. Joachim Sturve (GU) is a member of the scientific expert panel. The platform is commissioned by the Ministry of Environment. The main objective is to provide science-based support to government agencies.

The collaboration between LU and KTH with Yttria particles has intensified exploring the effect of ecocorona and pre-filtration on the yttria nanoparticles and the toxicity toward D. magna.

PROACTIVE RISK ASSESSMENT, REGULATION AND CREATION OF STAKEHOLDER LEARNING ALLIANCES

WP4 works with proactive risk assessment, regulation and the creation of stakeholder learning alliances. Of importance is to modify nanosafety regulation to reflect real risks by for example include the consideration of corona formation in risk assessments. Furthermore, this work package aims to support the effective flow and use of information between experimentalists, regulators, and industry, and to help mobilise stakeholders to engage in responsible innovation and risk governance.

In 2021, the developed risk assessment framework developed in 2020 has been further tested, validated and calibrated in 2021 on additional nanomaterials as well as one example of a so-called advanced materials (MXenes). The results of the work have been accepted for publication in the ISI-journal NanoImpact. A project assistant has been hired that will work with screening environmental risk assessments of nanomaterials.

We continued to work on o analysing existing legislation on nanomaterials and making this information available to the public via nanodbregulaiton.dk. Our analysis of lesson learned about how environmental regulation can drive innovation has been completed and is currently undergoing review. The findings have and will continuously be integrated into the regulatory database just mentioned. Our exploration of possibilities to operationalise safety-by-design principles for NMs has focused in on how circular economy might influence the future development of nanomaterials and a paper has been published to Nature Nanotechnology describing our work. Specifically, we have investigated the state of the art within reuse, recycling, refurbishing, etc. of nanomaterials and nanoproducts and we find that there are several aspects that nanomaterial developers should take into consideration e.g., toxicity and persistency of nanomaterials in the products, during the use and waste phase. Finally, we have engaged with the European Environment Agency of the European Commission on the definition of principle of "necessity" and discussion about potential historical cases that can be used to derive the elements of such a regulatory environmental principle. One case includes the use of nano silver in sport textiles.

Our work discussing nanotechnology as a paradigmatic example of a new relationship between science, technology and the economy has been completed and accepted for publication. Pointing to the role of "responsible innovation" as a legitimation practice, we reviewed Habermas' classic 1973 book "Legitimation crisis" and suggest that it may contribute to contemporary debates. Following up on this work, we decided to study the concept of Responsible Research and Innovation (RRI) and critiques the current approach to responsibility within the European RRI discourse. We also studied the "hidden *values*" with respect to the recent carbon nanotube debate and identified different foundational values that underpin this debate, and concerns about nanomaterial regulation more broadly.

Besides engaging in inter-workpackage activities, WP 4 also assisted WP6 in organising several intra-project workshops and symposiums – a Mistra Nanosafaty Webinar on Responsible Innovation (March), a MISTRA Webinar on Nanomaterial regulation – a driver or barrier for nanotechnology innovation? (April) and a workshop with the Environmental Protection Agency in Sweden in May. WP4 furthermore, arranged an internal MISTRA workshop in November 2021 with the aim of understanding the regulatory relevance of the work done within the MISTRA programme. More specifically, this entailed identification of concrete recommendations for improvement of the guidance by the European Chemicals Agency on ecotoxicological endpoints for nanomaterials, based on the MISTRA publications from phase one and two.

SAFE HANDLING OF NANOMATERIALS AFTER PRODUCT END-OF LIFE

WP5 focuses on researching and developing appropriate strategies for the end-of-life management for products containing nanomaterials. This research is critical to minimise human and/or environmental exposure. Risks include both immediate exposure of humans and a long-term exposure of the ecosystem, including humans, due to emissions and accumulation. More knowledge is needed in the area of waste management and recycling of products containing nanomaterials, and of the risks related to handling nanomaterials, in order to develop appropriate strategies, which both foster development and minimize risks.

In 2021 the results from the exposure/emission measurements performed at facilities recycling electronic waste and metal scrap – two waste flows identified as likely to contain nanomaterials in the future – were analysed and is summarized in a manuscript. We plan to submit the manuscript in Q3 2022. In November 2021 we revisited one of the facilities to collect the PM1 fraction (dominated by the nano particles) of airborne particles using a high-volume sampler. At the visit, we also brought online instruments to perform a second emission study to be compared to the results from 2020. The main purpose of the collection of particles was to perform various eco toxicity tests. The eco-tox tests to be performed are those developed within the Mistra Nanosafety programme.

The earlier study on emissions from pilot scale combustion experiments of polymers with CNTs, under conditions resembling waste incineration (e.g. following the European directives for waste incineration) was accepted for publication in Nano Impact in spring 2021.

As a continuation of the test of recycling CNTs from polymers, we performed a full lab-scale recycling experiment in which we separated CNTs from the polymer by a thermochemical process and used the recycled CNTs as an additive in a new polymer. When analysing the performance of the polymer with respect to electric conductivity, comparing the polymers with new and recycled CNTs respectively, we could show that the performance of the polymer with recycled CNTs were actually better than the original material.

To further investigate emission from CNT containing concrete, we set-up a lab-method for dustiness testing based on a standard, e.g. the drop method. The work is presented in the diploma thesis "Dustiness Testing and Particle Characterization of CNT-enhanced Concretes", by Sara Marsh, 20211014. We plan to publish the results scientifically.

MANAGEMENT, COMMUNICATION, ECONOMY AND STAKEHOLDER RELATIONS

WP 6 focuses on ensuring the smooth facilitation of the programme in phase two. It focuses on supporting a steady progression of the other work packages: internal and external communication, including societal impact. Another aim is to build networks, support platform building and manage industrial, scientific, authority and other stakeholder interaction.

During 2021, the work package organised a number of programme meetings online due to the ongoing corona pandemic, as well as focused on planning and launching the mentorship programme for younger researchers. Effort was also put into assisting other work packages in organising targeted events, as well as on outreach events on nano plastics aimed at school pupils – "Nano less is more".

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MISTRA

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