Mistra TerraClean
Annual Report 2022

MISTRA
TERRACLEAN

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LETTER FROM THE BOARD CHAIR

Phase II of the Mistra TerraClean program has started in excellence and the board is very pleased with the progress in the program. The devoted team has continued to work through a multidisciplinary approach also taken on new partners to enable the programme to continue to address the sustainable challenges of today. The programme has accomplished many tasks during this year, and I would like to thank everyone involved for the great work that you have done. The program has carried on the challenge of developing smart materials and sensors for elimination of contaminations from water and air. All this could not have been achieved without the devoted team that is involved in Mistra TerraClean and I am very impressed by your work.

I would also like to give recognition to the all the members of the board and the contribution that you all give. This past year, due to that the pandemic has been less influencing on the daily work, the board have had the opportunity to have some of the board meetings at program partners which has been very rewarding. I can see that this “new normal” also have had a positive effect on the work in the program.

Thank you to all participating scientists and experts, research institutions, universities, board members and partners who have contributed the past year, you have all contributed to the excellent results of Mistra TerraClean.

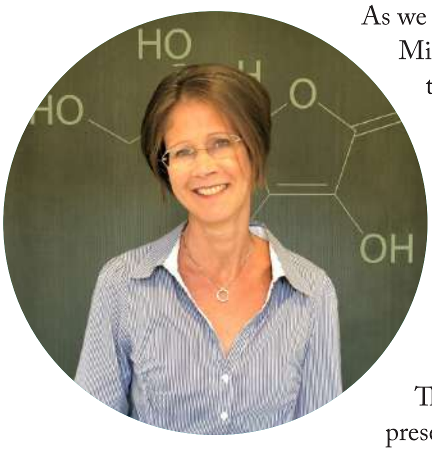
I very much look forward to continuing the work in this important and very relevant program.

Katja Pettersson Sjöström
Chair of Mistra TerraClean Board
March 2023

LIST OF ABBREVIATIONS

ACC	Activated carbon cloth
AFM	Atomic force microscopy
AOP	Advanced oxidation process
API	Active pharmaceutical ingredient
BET	Brunauer–Emmett–Teller gas adsorption
CDI	Capacitive deionization
CFU	Colony Forming Unit
COD	Chemical oxygen demand
CSP	Case Study Package
DOM	Dissolved organic matters
FPT	Fibre and Polymer Technology
FTIR	Fourier-transform infrared spectroscopy
6:2 FTS	6:2 Fluorotelomer Sulfonate
GAC	Granular activated carbon
GC/MS	Gas chromatography/mass spectrometry
IKEM	Innovations- och Kemiindustrierna i Sverige
ICP-OES	Inductively coupled plasma-Optical emission spectroscopy
LC/MS	Liquid chromatography/mass spectrometry
LCA	Life cycle assessment
LCBRM	Life cycle based risk mapping
LCC	Life cycle cost analysis
LCIA	Life cycle impact assessment
MAC	Magnetic activated carbon
MNF	Material and nanophysics
MOF	Metal-organic framework
NMR	Nuclear magnetic resonance
PFAS	Per- and polyfluoroalkyl substances
PCR	Polymerase Chain Reaction
PEX	Cross-linked polyethylene
PFHxS	Perfluorohexanesulfonic acid
PFOA	Perfluorooctanesulfonic acid
PFOS	Perfluorooctane sulfonate
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene fluoride
PoC	Proof-of-Concept
PoP	Persistent organic pollutant
RT-PCR	Reverse Transcriptase Polymerase Chain Reaction
REE	Rare Earth Elements
RMP	Risk Mitigation Plan
SEM	Scanning electron microscopy
SME	Small-medium enterprise
SGU	Statens Geologiska Undersökning
TEM	Transmission electron microscopy
TRL	Technology readiness level
UF	Ultrafiltration
VFE	Viral Filtration Efficiency
VOC	Volatile organic compounds
WP	Work Package
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction

A MISTRA TERRACLEAN PERSPECTIVE ON 2022



As we close 2022, we also close the first full year of phase II in Mistra TerraClean – a productive one for our research project thanks in large part to the valuable collaborations we have formed with academic, research institute, and industry partners. The established partnerships enable us to access cutting-edge research and resources, as well as provide us with valuable insights into real-world applications of our research. These partnerships have also allowed us to test and validate our findings in practical settings and have opened up opportunities for optimization and integration of components into more sophisticated systems. These partnerships have led to several joint publications and presentations and have allowed us to expand the scope of our project to include new and exciting research ideas.

The overarching goal of this programme, smart materials for clean air and water, felt ever as timely and important during the past year. The contaminants that we address are of increasing concern and significant material and sensor technologies will be needed to adequately deal with remediation, not the least PFAS substances, volatile organic compounds, and heavy metals. In light of the recent pandemic, we see an increasing interest in air quality issues and indoor air purification, as well as the need for further developments in anti-fouling materials. The research conducted within Mistra TerraClean addresses these issues and many more.

The many highlights of 2022 include:

- The continuous development of materials with fine-tuned chemical and morphological structures for efficient removal of impurities from water and air, risk mitigation plans for user cases to accelerate the safety of materials,
- An ambitious take on sensors to accelerate the smartness of materials. Designing a sensor that can accurately and reliably measure the desired parameter in complex systems is challenging and this is where the interdisciplinary collaborations and competence within Mistra TerraClean is a true asset,

- The first Ph.D. student within the programme graduated,
- The establishment by RISE of a bioreactor-based test system for testing material/chemistry solutions in air-borne biofouling,
- A standardized system for assessing viral contamination of air filtration material,
- Completed lab-scale trials of purification of PFAS from partly spiked water and partly polluted water with good results in terms of capture and capacity,
- Risk Mitigation Plans to identify relevant risks for human health and the environment, how these are potentially mitigated and what environmental and health assessment methods that are suitable for each user case,
- We have brought on several new team members who have brought fresh perspectives and ideas to the project.

Just like everyone else, our team was set back by the pandemic and the concomitant disturbance of our in-person meetings and research activities. The past year was a gradual return to normalcy. Long-awaited field trips, site visits, workshops, and an in-real-life full-scale consortium meeting were finally realized, propelling, and inspiring our future work.

I want to express my sincere gratitude to our board and Mistra for their invaluable support and guidance. I also extend a heartfelt thank you to all the partners and supporters of Mistra TerraClean for their contributions, including their expertise, funding, dedication, and collaborative spirit. This has allowed for co-creation between and beyond the boundaries of our disciplines. We look forward to continuing to work together in the coming year and making further contributions to the field.

Ulrica Edlund
Director of Mistra TerraClean
February 2023

INTRODUCTION

Phase II of Mistra TerraClean runs from 2021 to 2025, with an ambition to level up the materials and technologies developed in phase I to industrial applications. The working structure (Figure 1) addresses current and future needs for clean water and clean air. With the know-how and attention developed in phase I, Mistra TerraClean has attracted attention from many new partners.

Six areas, CSPs, have been selected where Mistra TerraClean expertise could meet the needs. They include several activities on different TRL levels, where materials and devices are evaluated and developed in collaboration with stakeholders for specific contaminants.

The case topics are well motivated and responds to the needs of today while being pro-active for those of tomorrow. Mistra TerraClean phase I has surveyed the area, built a firm foundation and implemented an interdisciplinary competence hub.

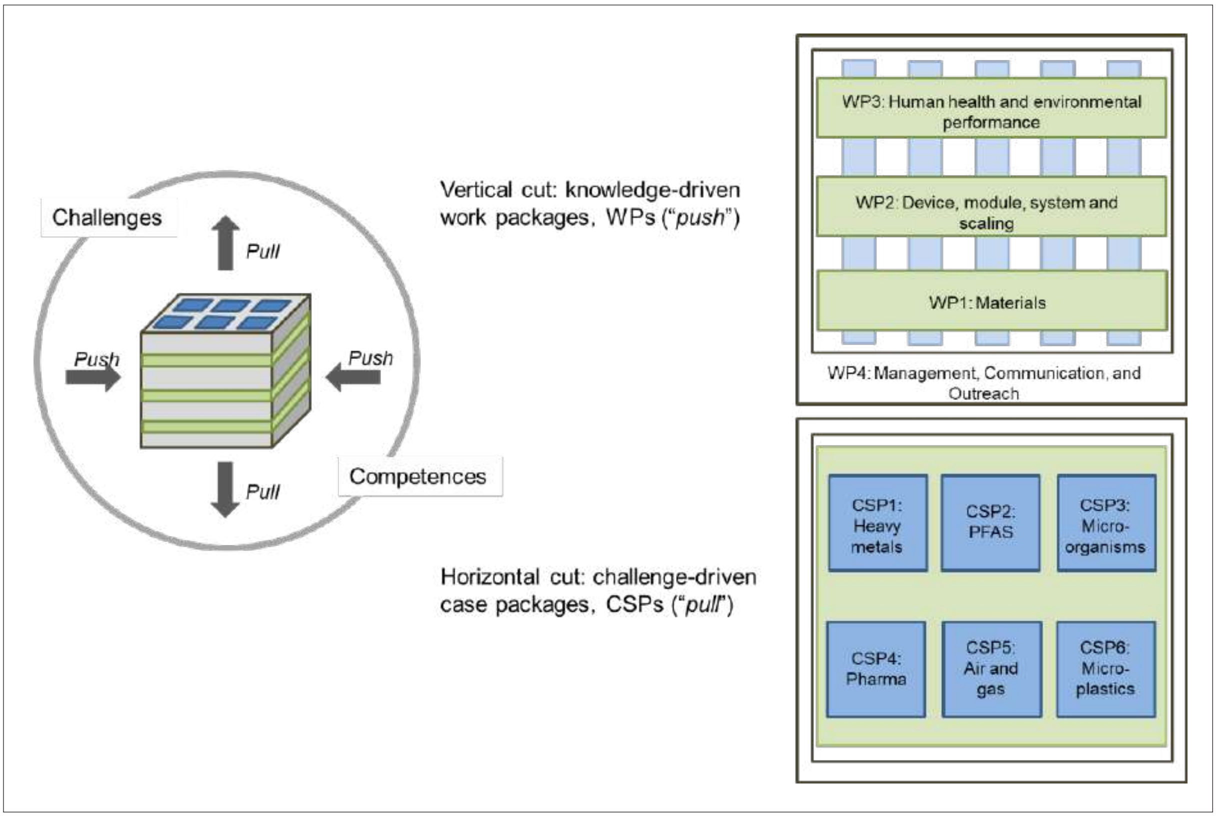


FIGURE 1.

The push-pull driven structure of Mistra TerraClean II.

WORK PACKAGE 1
MATERIALS

WP1 Leader: Niklas Hedin, Stockholm University

Key questions and scope

In this WP, materials are developed and functionalized, and they are further studied in the CSPs and their targeted applications. The four tasks of the WP have a focus on developing materials with specific functions for the removal of heavy metals, pharmaceuticals and related molecules, and PFAS from water, in addition to the reduction of microorganisms and fouling in water and gas tubes, and the removal microplastics, and for gas purification in relation to, for example, the removal of VOC and CO_2. The tasks involve efforts to make the materials adaptive, responsive, or interactive, preparing them for integration in devices in WP2 and in the CSPs.

Tasks	Partners
1.1 Carbonates, hydroxides, and related compounds	UU; RISE
1.2 Carbon-based smart materials	SU; RISE; BrightDay Graphene
1.3 Lignocellulosic materials	KTH; SU; RISE; MoRe
1.4 Chemically modified materials	KTH; SU; UU; RISE; Alfa Laval
1.5 Characterization platform	RISE; KTH; SU; UU

TABLE 1. Overview of WP1, tasks and involved partners.

Progress and achievements during 2022

Task 1.1 Carbonates, hydroxides, and related compounds

This task explores the compositions and applications of carbonates and hydroxide materials, and how existing materials such as Upsalite can be improved and optimized for use for pollutant removal. Additionally, we are exploring high temperature regeneration of heat-resistive mineral materials will be evaluated in CSP2 and CSP4.

Zirconium and hafnium-based inorganic oxides (related to carbonates and hydroxides) have been synthesized and optimized for high temperature CO_2 sorptions. Primary studies are completed, and manuscripts are being prepared for publication.

The work of developing a detailed model of the surface-adsorbate interaction on carbonates/hydroxides has begun. It will continue as follow up studies, after the publications of manuscripts mentioned above.

Task 1.2 Carbon-based smart materials

In this task we focus on the development of magnetic activated carbons from biomass, 3D arrangement of graphene, and the modification of activated carbon cloth to create smart, multifunctional electrochemical electrodes. These materials are explored in a variety of applications such as the removal of short-chained PFAS molecules, air and gas purification, and the removal of metal ions and pharmaceutical intermediates/residues.

Activated carbons for the removal of VOC, such as isopropanol and acetone, have been prepared and studied, as well as activated carbons modified with FeS and FeSe for the removal of Cd^{2+} and Pb^{2+}. The work on a detailed understanding of the carbon-adsorbate interaction and its kinetics is ongoing.

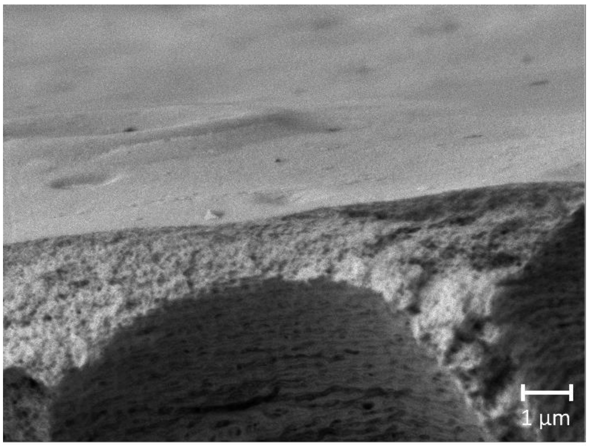


FIGURE 2. Cellulose acetate membranes functionalised with cellulose nanocrystals prepared by phase inversion method (SU-Alfa Laval collaboration).

Task 1.3 Lignocellulosic materials

In Task 1.3 we focus on the synthesis and preparation of hybrids and composites using cellulose, hemicellulose, and lignin, three components that make up a large portion of the biomass on Earth. These materials are relevant for the carrier of inorganic components, support for membranes/filters, and the functional materials for selective capture/rejection of water and air pollutants.

Three different approaches are in progress where nanocellulose is used as the template or functional entity to develop materials for water treatment and CO_2 capture.

Cellulose nanofibers functionalized with metal-organic frameworks were made into flat sheets and used as adsorbents for metal ions and dyes. The flat sheets also showed electrochemical sensing capability which was selective towards Pb.

Phase inversion membranes of cellulose acetate with cellulose nanocrystals and nanofibers as the functional entity to increase the hydrophilicity and antifouling properties were developed in collaboration with Alfa Laval AB (Figure 2). The doctor blading method was used to prepare micrometer thick layer on a porous substrate and was regenerated in a non-solvent to process anisotropic membranes.

We also developed 3D printed filters based on bio-nanocomposites where nanocellulose is used as functional entity. The removal of metal ions and microplastics was evaluated. This approach provides possibilities for adsorption and size exclusion at high flux, as well as multiple use of the filters.

Two papers have been published reporting the adsorption capacity and selectivity towards charged pollutants. Characterization of nanocellulose-based membranes and filters with and without metal organic frame works is ongoing.

A database for adsorption of molecules and ions of lignocellulosic materials is in the process. Two reviews on the use of materials based on lignocellulose for water treatment by adsorption and size exclusion have been published.

Task 1.4 Chemically modified materials

To gain the intended functionality, materials sometimes need to be chemically modified. With so called molecular layer-by-layer assembly, intended functionalities for the surface are provided. In relation to functional materials, amine modification is used for enhancing CO_2 affinities. We are also exploring surface chemistry modification to achieve low-fouling membranes.

Different coating techniques are explored for a potential scale-up, such as roll, dip- and spray-coating, and aerosol-based techniques. Moreover, we investigate the preparation of green composite aerogels and foams of cellulose and protein nanofibrils like amyloid nanofibrils. These protein fibrils can be easily prepared from whey, the byproduct of dairy industries. The aerogels are prepared via freeze-linking and the foams are prepared via oven drying. This eliminates the need for freeze-drying or other highly energy-consuming methods.

The SU team has successfully developed hybrids of cellulose and metal organic frameworks and used it in membrane and filter processing. Membranes were prepared by a vacuum filtration method that produced Cello-MOF paper, which showed multiple functionality towards adsorption of metal ions and dyes, electrochemical sensing of Pb^{2+} as well as CO_2 capture. These materials also showed recyclability and possibility for multiple use.

Filters were prepared from these materials via 3D printing which resulted in 3D filters which showed adsorption of metal ions and CO_2. Both these methods are scalable and selective towards multiple charged pollutants in water medium.

Work is performed on relating adsorption and conductivity in the domain of electro-adsorption, which is of importance in the understanding of capacitive deionization technologies.

Task 1.5 Characterization platform

The focus here is on documenting the characterization and validation of the sorbent materials developed for the project. This involves the documentation of the variety of surface characterization techniques such as XPS, SEM, TEM, XRD, IR, ICP-OES and solid-state NMR spectroscopy.

The knowledge transfer approach about current and future capacities for cutting-edge techniques for characterization is getting analyzed.

The approach for collecting and sharing protocols for advanced analyses proceeds continuously throughout the programme lifetime.

FIGURE 3. Dimitrios Georgouvelas became the programme's first PhD student to graduate. The picture is taken at his dissertation.

WORK PACKAGE 2
SMART FILTER DESIGN AND VALIDATION

WP2 Leader: Mats Sandberg, RISE

Key questions and scope

WP2 connects materials at the molecular level with the device level by creating devices with connected materials. At the organizational level in the project, WP2 is to provide early feedback from techno-economical evaluation of materials developed in WP1 and connects to LCA work in WP3.

Tasks	Partners
2.1 Connected Filter Devices and Integration	RISE; KTH
2.2 Sensors and Sensor Materials	RISE; SU
2.3 Scaling and Techno-economy	RISE; IVL; SU; Alfa Laval

TABLE 2. Overview of WP2, tasks and involved partners.

In exploration of suitable working and meeting modes, bimonthly meetings were held during the spring, where the meetings were themed on CSPs. Orientation on each CSP, progress, needs for evaluation of materials, devices, sensors were discussed, as well the prospects for commercialization and scaling of the technology. A common view was that the work in most CSPs were not mature enough for an evaluation of commercialization plans. For this reason, the meeting mode was changed to workshops in the fall.

Two workshops were held, presenting the benchmark systems and new materials for clean water, and clean air, respectively. The workshops included a lecture on materials and devices (filters and sensors), describing the compatibility issues, and a demonstration of materials developed in WP1 for the purpose. The goal for the workshops was to present the benchmark systems currently in use and describe their bottlenecks. The benchmark systems should act as template for new setup and evaluation. Another goal was to present a proposed decision process for upscaling.

The workshops were appreciated and acted as push and pull to assist faster implementation of materials in the different cases.

Progress and achievements during 2022

Task 2.1 Connected filter devices and integration

This task is to build on the sensor-absorbent concept developed in task 2.2 and has not produced results under 2022. The development of the optical sensing methods, UV fluorescence, to detect presence of biofilms is reported in CSP3.

Task 2.2 Sensors and sensor materials

In this task, the original focus has been more specified to develop PFAS sensors based on metal-organic frameworks (MOF). Further, the target to develop sensors for perfluorinated pollutants has been changed to include devices for detection of PFAS-substances by low-cost dose-exposure indicators. This change and specification in ambition is motivated by the abundance of reports on selective accumulator materials that can work as responsive materials or together with sensors at concentrations that are in the range of regulatory concentrations. On the other hand, we have not found reports on sensors with a reversible and dynamic response in the concentration ranges of relevance for health effects and regulatory concentration limits. Dose indicators operating by exposing an accumulator or accumulator-responsive material for a specific time or water volume exposure can potentially solve problems for field studies, provided the product is low cost.

A new method to functionalize porous absorbents such as carbons was developed. This method employs works by impregnating the porous material with polymerizable compound to afford stable immobilized functions at the surface by polymerization. The method starts from bio-based phenols to produce benzoxazines and phenols polymerized with the benzoxazines and produces immobilized functions, stable to extreme pH, chemicals and high temperature, to a low cost of materials and processes. Here, we have employed the chelating and redox functionalities of the polymerized materials onto porous carbons to afford sensor-absorbent materials.

The SU team developed cellulose-metal organic framework hybrid paper which acts as adsorbents and sensing material simultaneously. A scalable water-mediated processing of nanocellulose - Zeolitic Imidazolate framework hybrid paper was developed. The produced papers, i.e. CelloZIFPaper, were applied as adsorbents for the removal of the heavy metals from water, with adsorption capacities of 66.2–354.0 mg/g. CelloZIFPaper can also be used as a 'self-standing' working electrode for the selective sensing of toxic heavy metals, i. e. lead ions (Pb^{2+}), using electrochemical-based methods with a detection limit of 8 µM (Figure 4). The electrochemical measurements may advance 'Lab-on-CelloZIFPaper' technologies for label-free detection of Pb^{2+}.

Another track of this task develops low-cost tools for robotized analysis of absorbents and sensor materials. The objective here is to aid the development of electrochemical sensor-absorbents for water pollutants using robotized dispensing of test solution and electrode preparation and enable software supported tools for materials development. This methodology development is needed to generate the large number of analytical data needed to establish sensor and absorption parameters for all materials under development and for all relevant water matrices. The concept is tested on a new class of sensor absorbents developed in this task and in phase one of this programme, and that is immobilization of chelating and redox functions on porous electrode materials using coupling polymerization of bio-derived benzoxazines. The function of a sample of this materials class is shown below (Figure 5).

A pre-study report on possible approaches for PFAS sensor development was delivered, presented, and up-loaded in connection with the consortium meeting in October 2022.

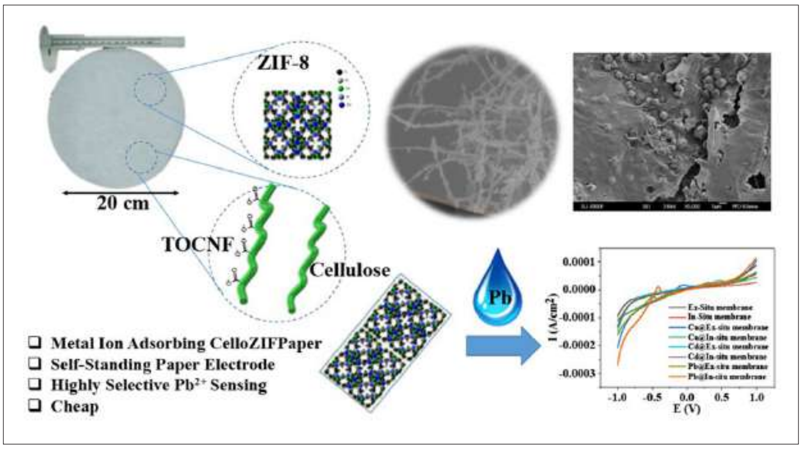


FIGURE 4. CelloZIFPaper combines absorbent- and sensor functions to form a "smart Mistra TerraClean filter material" for water contaminated by heavy metal ions.

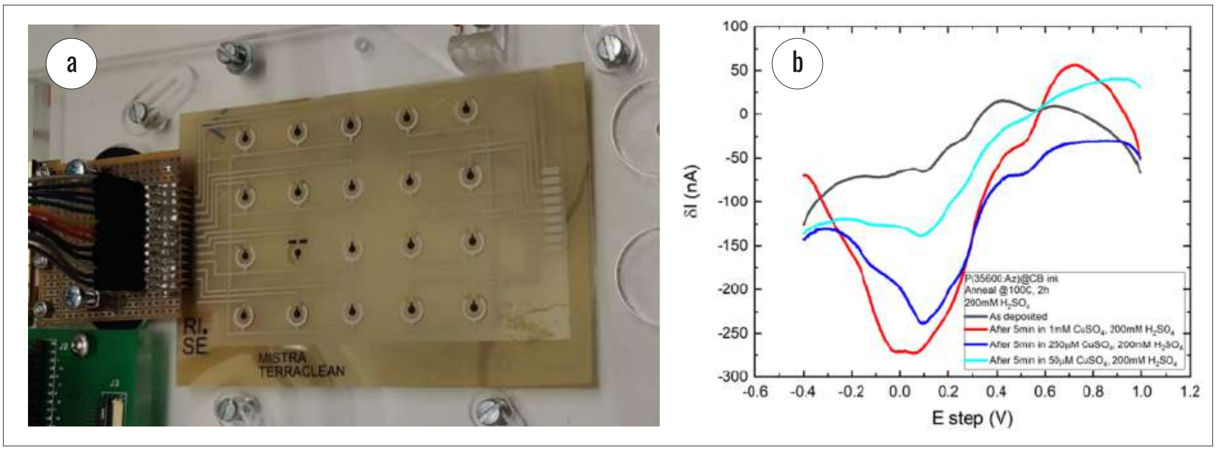


FIGURE 5. a) A printed array of electrochemical cells, an enabler for robotized characterization of sensor absorbents. b) A sensor-absorbent electrode material, functionalized porous carbon, analyzed for the ability to capture and respond to metal ions.

Task 2.3 Scaling and techno-economy

To organize and keep track of development and evaluation of materials being developed, two actions were taken in this task. First, a list of materials ready for techno-economical evaluation was established, and second a procedure on how the evaluation of materials should be processed within WP2 was proposed, where the latter was one of the deliverables during 2022. The aim of the evaluation decision process is to provide early feedback to material developers and to keep track of material cases under development in the process.

A proposed formalized decision process for selecting upscaling cases was presented and up-loaded in connection with a workshop in October.

A list of material candidates, regarding scalability, techno-economical, and performance evaluation of materials developed in WP1, and devices can be found in a continuously updated document. It is considered the rolling report of this delivery.

WORK PACKAGE 3
ENVIRONMENTAL AND HUMAN HEALTH ASSESSMENT

WP3 Leader: Maja Halling, IVL Swedish Environmental Research Institute

Key questions and scope

The aim is to provide input regarding human health and environmental impacts to the various CSPs involved in phase II for developing smart, flexible and effective materials. WP3 will utilize several tools for reaching valuable input to the CSPs: Life cycle-based risk mappings (LCBRM), Life cycle assessment (LCA), Life cycle costing (LCC), and Safety assessment and ecotoxicological tests.

Tasks	Partners
3.1 Appraisal process development and risk mitigation plans	IVL; RISE; SLU
3.2 Tier 1: Toxicological appraisal of the material and identification of most important environmental and human health aspects of material production, application, post- consumer fate and management	IVL; RISE; SLU
3.3 Tier 2: Environmental (LCA) and economic (LCC + external costs) performance of material and devices in individual case studies. Applied toxicological testing of filter treatments in individual case studies with focus on ecotoxicity.	IVL; RISE; SLU

TABLE 3. Overview of WP3, tasks and involved partners.

Progress and achievements during 2022

Risk mitigation plan

The work has been focused on developing a Risk mitigation plan (RMP) for each CSP to identify relevant risks for human health and the environment, how these are potentially mitigated and what environmental and health assessment methods that are suitable for each case. The goal was to introduce environmental and health aspects early in the technology development phase, as a criterion for decision making moving forward. The RMPs lay the foundation for identifying which case studies and technologies to focus on during the upcoming years regarding the application of the human health and environmental assessments planned for WP3. To further utilize the RMPs for identifying such technologies, a RMP matrix was set up to identify where there are synergies between different CSPs and how the WP3 assessments can be planned in a time efficient way.

During the year, RMPs have been developed for each CSP and shared with the CSP leaders, respectively.

Appraisal process

An appraisal process was developed aiming at providing a strategy for the work that will be performed by WP3 during year 2-4 in the programme. The document includes a strategy for prioritization between the different materials and technologies developed in the programme as well as initial project plans describing data collection, a basic time plan and a workplan within WP3. It further presents a series of suggested topics for training sessions that are planned for 2023–2024.

Workshop

In June, an internal workshop was held at the IVL Swedish Environmental Research Institute in Stockholm. All partners in the programme were welcome to join and everyone who planned to be involved in WP3 at that point participated actively. The purpose of the workshop was to identify the toolbox of environmental and human health assessments available in the WP, and to identify the persons with the competence to participate in each assessment.

Life cycle-based risk mapping (LCBRM)

The work with LCBRMs started during the autumn with focus on defining a methodological approach to use, as no straightforward methodology exists for performing a LCBRM scientifically. LCBRM intends to streamline the initial process of identifying hot spots along the entire life cycle for a wide range of materials and devices, usually based on existing publications for comparable items. There are several options available, and therefore it was considered important to define what a LCBRM within phase II should include. A report template was created as an output of this work.

In total, five LCBRMs will be performed. Two LCBRM were initiated during 2022, one focussing on the magnetic activated carbon (MAC) used in CSP 2 and CSP4, and the other on ferrous sulphate activated carbon used in CSP1. A project leader within WP3 has been assigned for the assessments and contact with involved partners has been established.

Complementary LCA

Representatives from WP3 attended a study visit at the AstraZeneca facility in Södertälje in May. During the autumn, data sharing has been initiated to perform a complementary LCA, benefitting from previously performed carbon footprint LCA for AstraZeneca's wastewater treatment plant and data from LCA on CDI performed in phase I.

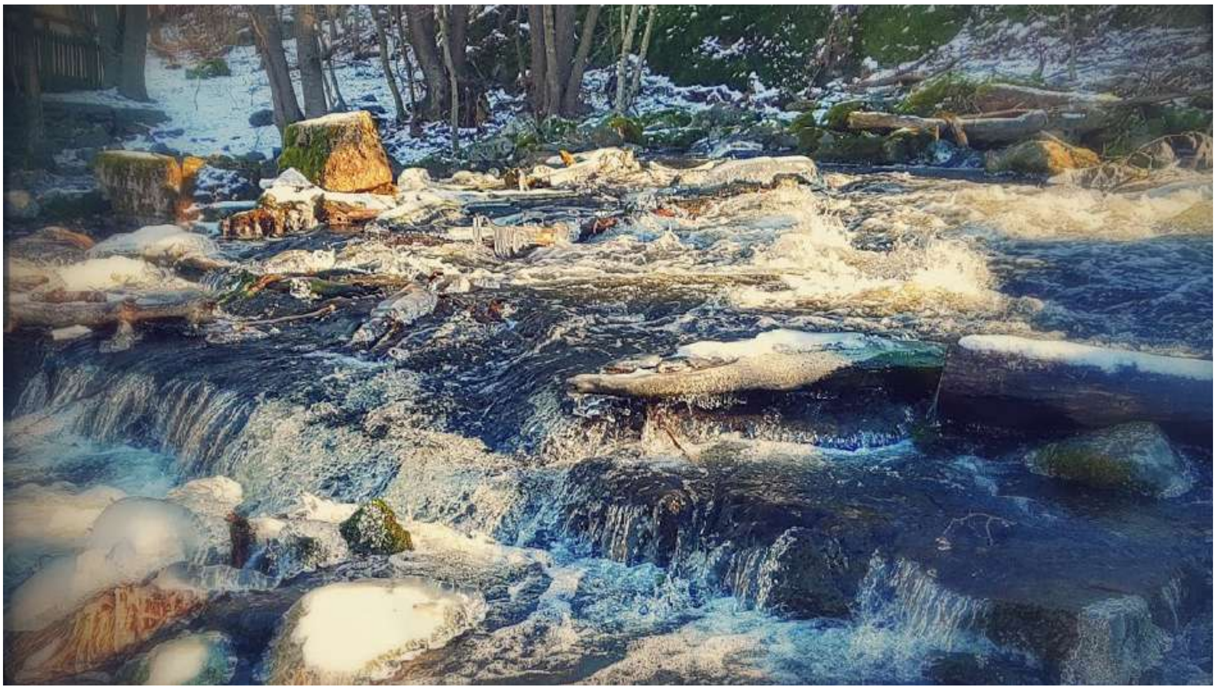


FIGURE 6. When introducing environmental and health aspects early in the technology development phase, a risk mitigation plan can serve as a criterion for decision making.

WORK PACKAGE 4
MANAGEMENT, COMMUNICATION, AND OUTREACH

WP4 Leader: KTH, Communication leader: IKEM

Key questions and scope

WP4 is responsible for administrative and financial management, assuring that deliverables, prototypes and demonstrations are on time within the given budget. Key questions are the following: *Programme management plan, Programme organization, Communication within programme, Materials and results flow within the programme, IPR agreements between partners and securing base for further commercialization in Sweden of the programme results, Communication to stakeholders, Dissemination to public, society, and policy makers, and To facilitate an effective cooperation and communication between the different WPs.*

Tasks	Partners
4.1 Administrative and financial management	KTH
4.2 Programme monitoring, quality control and risk management	KTH
4.3 Case-oriented outreach activities	IKEM
4.4 Connect to relevant policy instruments	IKEM
4.5 Ongoing communication and reporting	KTH; IKEM

TABLE 4. Overview of WP4, tasks and involved partners.

Progress and achievements during 2022

One year into phase II, WP4 regularly arrange steering group meetings, board meetings, facilitate knowledge transfer and outreach, and maintain control of programme finances and resources on a regular reporting period basis.

In 2022, we organized site visits in connection with board meetings (Figure 7) to facilitate knowledge transfer and and insights in programme activities.

Outreach to Policy Instruments

The dissemination channels, mainly LinkedIn and the web site, have been redesigned and updated. During the year focus has been to reach out from Mistra TerraClean towards EU Industrial Emissions Directive, IED. The IED is the European common regulation on emissions from industrial process and are under negotiation in the European Union. Mistra TerraClean has been in contact with the Swedish Environmental Protection Agency, and the Swedish Government and is planning a joint seminar 2023.

Another focus area has been the European Chemical Strategy, with upcoming revisions on chemical legislation in the EU. The planning for a seminar together with the programme Mistra SafeChem and the Swedish Chemicals Agency started during the autumn.

FIGURE 7. Mistra TerraClean Board visiting RISE facilities in Stockholm.

Consortium meeting

Following several years of meetings and travel restrictions, we were thrilled to once again arrange a full-scale annual consortium meeting. Meeting was held in Norrköping on October 3-4, joining partners from near and far together – academia, institutes, authorities, organizations, and industry (Figure 8). The site for the consortium meeting was chosen with care. Norrköping is the home for RISE Printed Electronics Arena, Sweden´s main site for printed electronics research, where several of the consortium's researchers work. The scientific field is multi-disciplinary, at the intersection of electronics design, chemistry, and physics, and ranges from fundamental research in polymers (materials science) to applied research with confidential applications in a multitude of market segments, like humidity sensors, batteries for power supply, printed solar cells on paper or plastic and wireless "labels" for network connection. A site visit to RISE was an obvious part of the meeting agenda.

The first day included discussions and group workshops on the smartness of filter materials, in the exiting venue of Visualization center. What is really a smart material, what benefits can smartness bring, and what are the weak points with the concept? How do we make new smart innovative solutions competitive with existing technology? Scaling and market readiness level? Smart materials solutions may seem expensive. But it could in the end be costlier to not embrace innovations.

The second day was a day rich in insights and inspiration. We enjoyed a tour around the facilities of Freudenberg Home and Cleaning Solutions in Norrköping to learn more about the products and process from a chemical and manufacturing perspective. Here, more than 6 million m^2 of the well-known Wettex cloth is produced annually. The Wettex cloth, invented in 1949, is an ingenious example of a bio-based all-cellulose wet-stable and high absorptive material and of high relevance for Mistra TerraClean.

FIGURE 8. Snapshots from the annual consortium meeting in Norrköping.

CASE STUDY PACKAGE 1: HEAVY METALS

CSP1 Leader: Johan Strandberg, IVL Swedish Environmental Research Institute

Involved partners: IVL; KTH; Stockholm Water Technology; SU; RISE; SGU; Lovisagruvan; Boliden; Nordic Water (Sulzer).

Key questions and scope

CSP1 addresses the treatment and separation of heavy metals from water streams in active and closed mining operations. The applied methods may also be applicable for treating other waters contaminated by heavy metals, e. g. leachate water or contaminated stormwater.

The scope of this case package is to find new methods with higher efficiency, less waste and lower cost than the methods available today.

Description of cases within the package

Lovisagruvan

Since 2004, Lovisagruvan (Figure 9) has been running an underground mine in Bergslagen, just north of Lindesberg, with high concentrations of zinc, lead, and minor silver. The continued decrease of the release of zinc and lead to the surrounding environment is the aim target in this case for Mistra TerraClean. In addition, a nearby closed cobalt mine (Håkanboda) is also owned by the Lovisagruvan company. This mine and its leachate, which is not governed actively, might contain rare earth elements, REE.

Svärtträsk

The Geological Survey of Sweden is the governmental authority responsible for acting as the operator in cases where contaminated areas lack an owner. Svärtträsk is such a case, where a rock landfill of mining residues has been constructed in a former open pit mine. Acidic water runs from the landfill through ditches in the area, directed to a water treatment station. The performance of this treatment with respect to passive operation and low running costs are the challenges for the researchers in the program.

FIGURE 9. Basin for infiltrating groundwater in Lovisagruvan.

Boliden mines

Boliden operates several mines in Sweden and abroad. Many of them are based on sulphide-rich ores containing, for example, copper, zinc, gold, silver and lead. The residues are reactive in an aerobic environment, creating an acidic leachate that contains dissolved metals. Hence, Boliden's water treatment requirements are both in the active and closed phases of a mine. The specific challenge to be addressed by the program has not been defined but is more general.

Progress and achievements during 2022

The CSP aims to find feasible options for use in the cases presented by the industry to the group of researchers (Figure 10). If this occurs, the applications and cases may be subjected to additional research within the program or as a result of collaboration between companies and industry, depending on where the IP of the chosen solution resides.

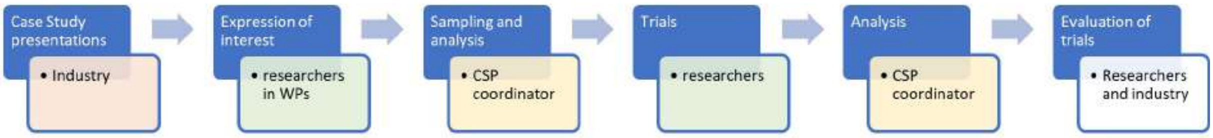


FIGURE 10. Process description for the stepwise engagement of mine operators and scientists in CSP1.

Case Study presentations

Industry representatives from Lovisagruvan and Svartträsk presented their cases to a group of researchers from the WPs and companies in June 2022. From the presentations and the following discussions, it was evident that the needs of Svärtträsk were going to be difficult to meet using the materials and processes in the project. Lovisagruvan's case attracted interest from four research groups and three companies within the program.

Sampling and analysis of real water

Water from Lovisagruvan was collected at different points, as per below, to allow researchers to try sorbents and processes on a lab scale on actual water:

1. Untreated water from Lovisagruvan at 235 m depth, expected to contain high concentrations of Pb and Zn.
2. Treated water (NaOH and $FeSO_4$) from Lovisagruvan.
3. Treated water (NaOH, $FeSO_4$ and peat filter) from Lovisagruvan
4. Untreated water from Håkanboda open pit mine (Figure 11), expected to contain As, Cu, Pb, Co and possibly rare earth elements (REE)
5. Untreated leachate from slagpiles in Håkanboda

Trials

Separation of metals and REE were tested on the following materials from the program with the following methods:

- Electroflotation
- Magnetic activated carbon
- Coagulation, Chromafora
- Metal-organic frameworks
- Polymeric filters based on lignocellulose
- Standard $FeSO_4$ precipitation (benchmark)

FIGURE 11. Water sampling from Håkanboda open pit mine.

CASE STUDY PACKAGE 2: PFAS AND INDUSTRIAL WATER

CSP2 Leader: Johanna Snellström, RISE

Involved parners: RISE; KTH; SU; IVL; Alfa Laval; SAAB; Stockholm Water Technology; Radma Carbon

Key questions and scope

The aim of CSP2 is to test the practical application of materials and devices partly developed within the project for removal of persistent organic pollutants from water of two test sites – PFAS polluted ground and surface water from SAAB's airport in Linköping and polluted slope water from SKF's industrial process. Due to acquisition of the SKF branch by another company, the experiments at the SKF's site were cancelled. The case study will further focus only on the SAAB site.

Progress and achievements during 2022

Three areas have been in focus for research and application. Firstly, the application of microfiltration membranes for pretreatment of PFAS-rich water was studied using tap water spiked with PFAS. Secondly, the application of capacitive deionization (CDI) for removal of PFAS from polluted water from SAAB was studied in lab-scale trials at KTH in cooperation with Stockholm Water Technology (SWT), IVL and RISE. Thirdly, initial trials on application of magnetic activated carbon (MAC) were performed with the same water as in the CDI experiments.

During the year, we have been in contact with different companies interested in joining the project. Two of them presented their techniques in project-wide seminars. There have been regular internal meetings within CSP2 and interactions with WP2 on sensors and WP3 on risk mitigation plans.

Microfiltration with membranes from Alfa Laval

It has previously been shown that a short chain PFAS adsorbs to a PTFE membrane and diffuse into the bulk polymer[1]. Since the membrane used in this case was coated with an active layer of PVDF, chemically similar to PTFE, it was assumed that it may cause adsorption or sorption of PFAS while filtering out particles from the water.

The tests were performed using tap water, spiked with a known concentration of five different PFAS, both short- and long-chain (Figure 12). The water was circulated through the membrane and the PFAS concentrations were followed. The results show that some PFAS (e.g. PFOS and PFHxS) were removed from the filtered water by as much as 74 %. However, the removal was due to sorption to the membrane, and not to rejection. Moreover, the perfluoro carboxylic acids (e.g. PFOA) was not removed.

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[1] (Chenn et. al. Direct contact membrane distillation for effective concentration of perfluoroalkyl substances – Impact of surface fouling and material stability, Water research, 2020, 116010)

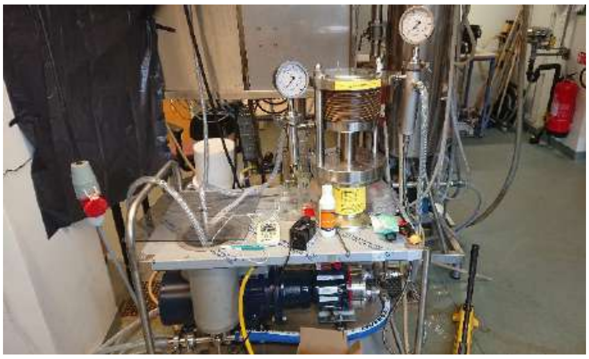

FIGURE 12. The Alfa Laval test unit used for microfiltration.

Since only some PFAS substances are removed by microfiltration, it is not useful to utilize the sorption phenomenon for practical application since most polluted waters contain a mix of PFAS substances.

An unexpected observation was made, namely that the concentration of 6:2 FTS was very high in all the samples even though the substance was not added to the tap water. These results were confirmed by both IVL and RISE analytical lab. Several hypotheses explaining the phenomenon were proposed, including presence as impurity in other PFAS standards, leaching from the pilot unit and leaching from membrane.

The experiments were conducted by IVL in cooperation with RISE and Alfa Laval. Even though no additional experiments with the membrane are planned within the CSP2, Alfa Laval will use the results for further product development outside the project.

Application of CDI

Performance of the CDI process when treating PFAS polluted water from SAAB was studied in two sets of experiments (Figure 13). In the first set, industrial scale electrodes were used.

A voltage of 2V and 4V respectively was applied during the electrosorption/destruction phase. After the sorption phase, the polarity was reversed for a short period followed by a longer period of short-circuiting the electrodes. The run was ended by circulating isopropanol solution to wash out the PFAS sorbed but not electrochemically released.

It was expected that during the first phase when the electrosorption or destruction of PFAS occurs, the concentration of PFAS in water should decrease. During the regeneration phase, the PFAS which was electrosorbed but not destructed would be released, leading to increase of the PFAS concentration. A third run (0 V) was also performed for reference.

The results showed very little difference between the three runs (Figure 14). The removal efficiency towards PFAS was 96-99 %, with no release of PFAS during the regeneration phase. Since the same performance was observed in the reference run, it indicates that the main mechanism of PFAS removal was physical sorption of PFAS. Moreover, it shows that isopropanol is not effective for chemical regeneration of electrodes.

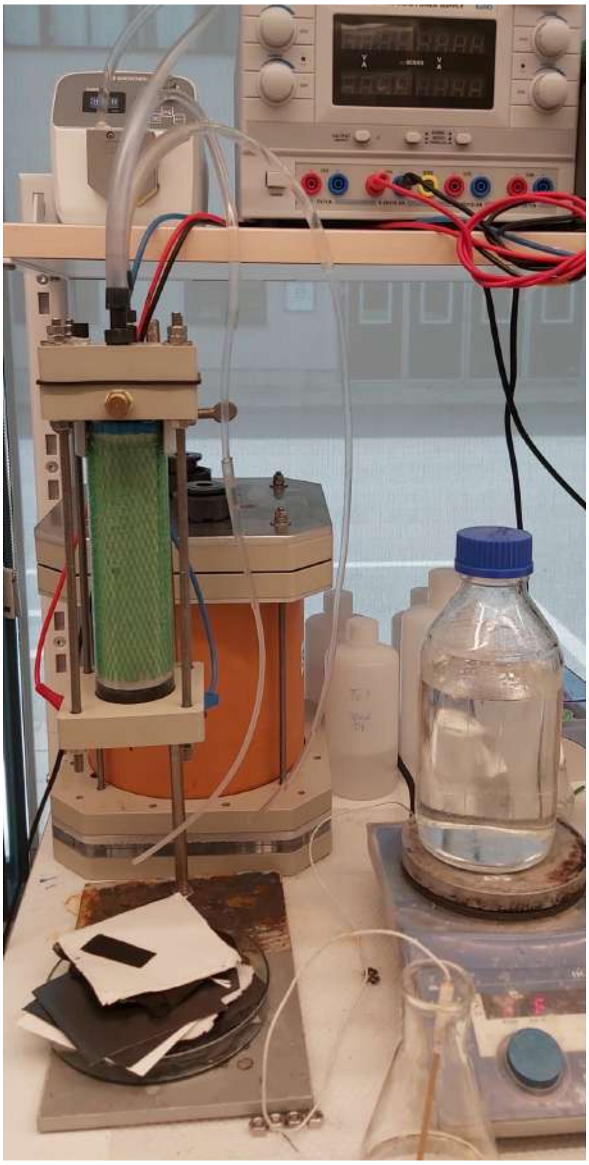

FIGURE 13. The CDI cell, cylindrical disposition, connected to a power supply. Two electrodes (450 cm^2 each) separated by cellulosic paper are inside the device.

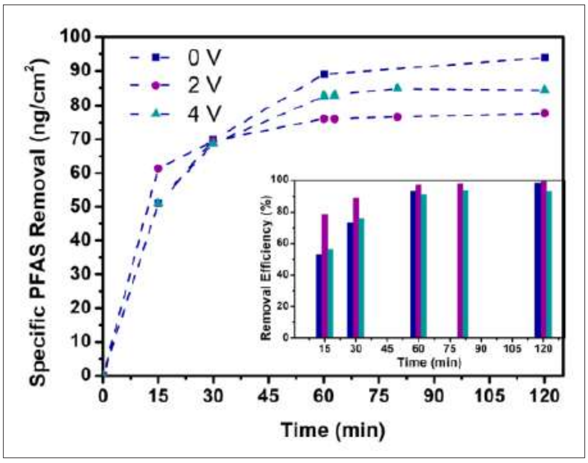

FIGURE 14. Removal of PFAS in the first run of experiments with CDI.

In the second test, the strategy was to fully saturate the electrodes with PFAS before the actual voltage application, to observe the effect of the electrochemical processes.

The electrode was saturated in two consequent runs of physical sorption (A-1 and A-2 in Figure 15). Deionized water was circulated through the cell to break down or regenerate the sorbed PFAS. The test was then repeated to show if the sorption capacity of the electrode was regenerated. Further, another trial of electro-regeneration was performed using a saline solution followed by a final sorption trial.

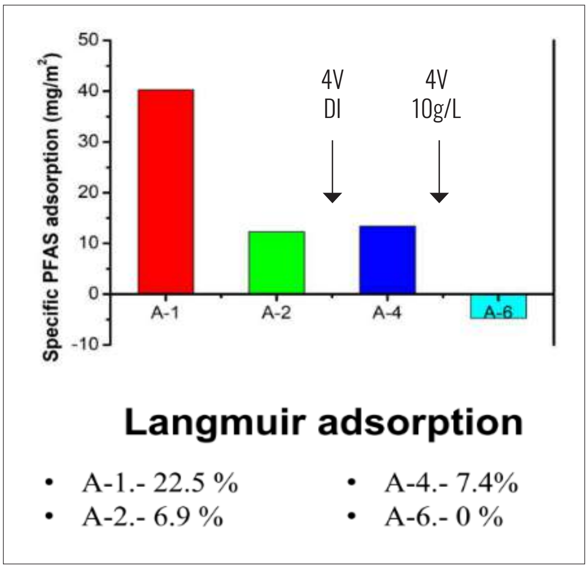

FIGURE 15. Removal of PFAS in the second run of experiments with CDI.

The conclusion was that the electro-regeneration with deionized water was effective. Conversely, regeneration with salt solution does not seem to be effective since no net removal of PFAS in A-6 is observed.

It is noted that the efficiency of PFAS removal was negligible, probably due to an overload of PFAS on the electrodes. The uncertainty of the analysis does therefore not allow any definitive conclusion.

Application of MAC

Initial testing of the MAC was performed. Different MAC doses were tested (Figure 16) and compared to the same doses of polycyclic aromatic compounds, PAC. It was found that at different concentrations of MAC, (200–500 mg/L), the removal of PFAS exceeds 80 %. The comparison with commercial PAC showed however that application of as low as 100 mg/L of PAC gives the same performance as the application of 500 mg/L of MAC.

It is therefore crucial that the MAC can be reused and regenerated effectively for the technology to be competitive with PAC.

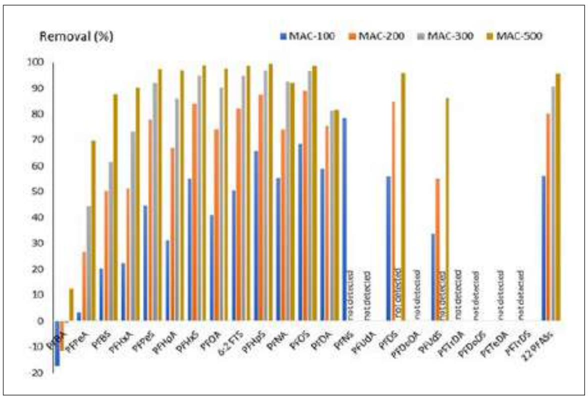

FIGURE 16. Removal of PFAS with different MAC doses.

CASE STUDY PACKAGE 3: MICROORGANISMS AND FOULING

CSP3 Leader: Ian Cotgreave, RISE

Involved partners: RISE; KTH; SU; Uponor; Camfil; Alfa Laval; Stockholm Water Technology

Key questions and scope

The case study focuses on the use of advanced chemical/material/sensing techniques in preventing biofouling from water- and air-borne sources. The work was divided up into two sections at the onset of 2022 and will be reported according to this.

Progress and achievements during 2022

Water-borne biofouling

An important part of the case study is establishing the bioreactor structure and function, for the material testing to be performed within (Figure 17). RISE has now established a parallel biofilm reactor system which includes a heat disinfection unit.

The instrument has then been used to establish biofilm generation on the surfaces of various PEX plastic samples delivered from Uponor. Total bacterial colony forming unit (CFU, a standard growth-based method) was used as a measure of bacterial contamination. A stable biofilm is achieved after 14 days of incubation, using a rotor speed of 120 rpm.

Several different PEX surfaces have been tested and all perform equivalently in the bioreactor.

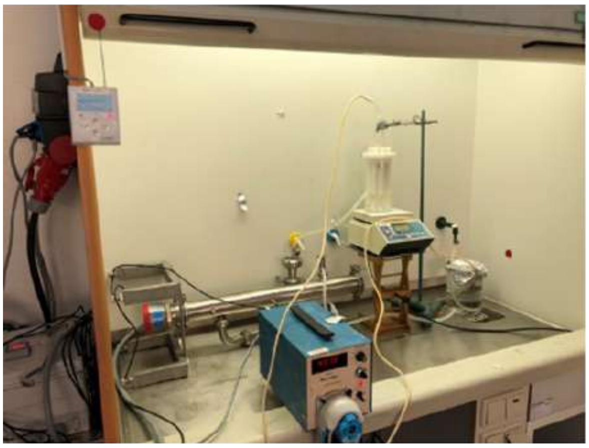

FIGURE 17. Setup of biofilm reactors to analyze parallel surfaces. The setup consists of three parallel reactors, where the rotor speed can be differentiated, and a unit for decontamination of water, if pathogens are present.

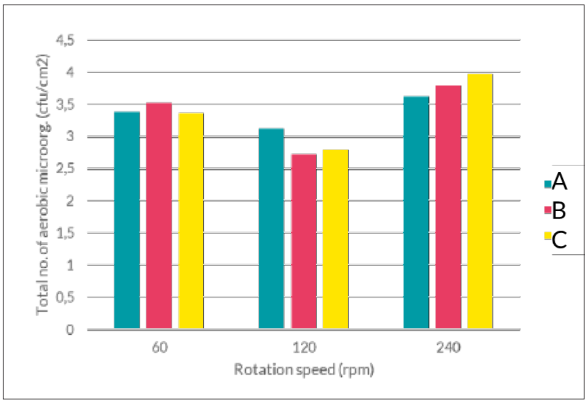

FIGURE 18. Comparison of different PEX sources.

This included "old" PEX from Uponor, and new PEX from two commercial sources.

PEX from different sources and ages perform equivalently in allowing biofilm accumulation in the RISE bioreactor set-up (Figure 18).

In a parallel track, attempts to utilize fluorescence detection in quantification of biofilm on the PEX surfaces have been made by RISE. Initial work focussed on potential background interference from intrinsic fluorescence of the PEX polymer.

Varied responses have been noted, but the pipe material tested so far seems to have a background fluorescence that may allow for biofilm detection. There are indications that the level of this potentially interfering background fluorescence may be dependent on the pipe production method. Current focus is on extending measurements to other materials, testing the approach for different cases, using known amounts of biofilms on neutral surfaces. An important area for development is also the design of the "in-pipe" device that might allow biomonitoring in real time *in situ*.

Air-borne biofouling

A pivotal achievement has been the establishment by RISE of a bioreactor-based test system for testing material/chemistry solutions in air-borne biofouling. Camfil collaborated with RISE to generate a standardized system for assessing viral contamination of air filtration material. Thirteen basic filter materials have so-far been tested.

The Viral Filtration Efficiency (VFE) method allows quantitation of viral particles recovered from filter material (Figure 19). The work has initially centered on the use of bacteriophage phi-X 174. Various "lifting" techniques have been tested and a bacterial (phage killing of bacteria) growth assay established as quantitative measure. Further experiments are ongoing to test if direct quantitation of live/dead phage can be achieved using quantitative RT-PCR.

Different buffers and methods have been tested, and a protocol for recovery of viable bacteriophages from filters has been developed. The next step has been to establish a live/dead test with a quantitative PCR method. The method has now been standardized according to ISO 18184 and is currently being extended beyond phage X-174 towards the use of other more pathogenic viruses, adenovirus and murine norovirus (Figure 20). The work is a result of collaboration with the Department of Infectious Diseases at Sahlgrenska Academy in Gothenburg and RISE Bioeconomy and Health.

In addition to assay establishment, work has begun on chemical modification of filter surfaces with ZnO. This has begun by establishing a risk assessment for its use at RISE. The coated filter materials are currently being created and will be tested using the phage-based assay initially. There are also plans to test both nano-carbon- and chitosan-based coatings.

FIGURE 19. Setup of the VFE assay.

FIGURE 20. The viruses tested in this work.

CASE STYDY PACKAGE 4: PHARMA

CSP4 Leader: Ian Cotgreave, RISE

Involved partners: RISE; KTH; AstraZeneca; Stockholm Water Technology, Radma Carbon

Key questions and scope

The case study centres on the use of variety of techniques and materials in the removal of highly potent active pharmaceutical ingredients (APIs) from wastewater streams at the AstraZeneca wastewater treatment plant in Gärtuna. The case study is divided into work performed with spiked solutions at laboratory scale and attempts to transfer to small pilot scale on-site. The experimental work also rests on the development of appropriate chemical analysis techniques for the APIs in various water-based matrices.

The capacitive deionisation technology from Stockholm Water Technology (SWT) is primarily in focus, but some work has been performed with the Axolot flocculation material, as well as the Radma Carbon material. These studies are at an early stage and will not be reported further here.

Progress and achievements during 2022

The AstraZeneca case

AstraZeneca has been very active in the collaboration, providing both API standards for analytical approaches, and providing spiked API samples for use by SWT/KTH and Axolot. The company has also hosted visits for KTH, SWT, IVL and RISE during the year, which is vital to cement ties and lay the ground for collaboration, particularly with respect to the need for establishing pilot studies on-site.

Development of analytical techniques

The analytical approaches have been developed by RISE and involve appropriate LC-MS/MS methods. Initial work successfully established quantitative analytical techniques for the 21 APIs identified by AstraZeneca as important.

The work was initially focused on three pure compounds for lab scale work, namely metoprolol, metformin (a substance difficult to remove with conventional approaches) and esomeprazole (a suspected chemically unstable substance) (Figure 21).

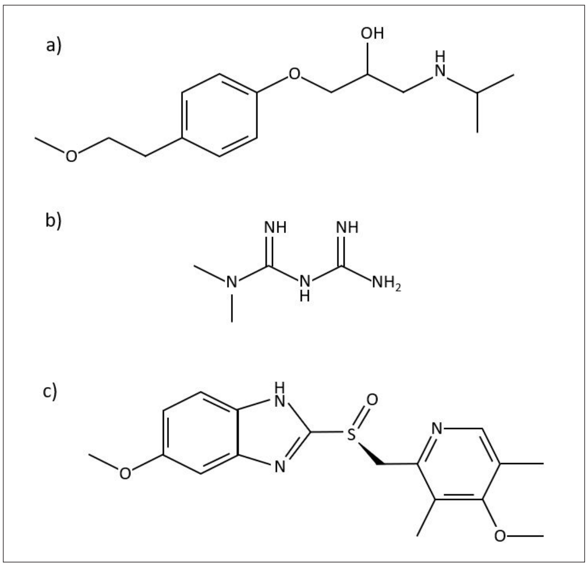

FIGURE 21. Molecular structure of a) metoprolol b) metformin and c) esomeprazole.

The methods have also been adapted to the analysis of APIs spiked into process water. Here process samples are filtered through a 0.22 µM PVDF membrane prior to further analysis by LC-MS.

A deeper investigation of the breakdown products emanating from esomeprazole was undertaken as initial experiments revealed instability under a variety of experimental conditions used in the lab-scale experiments. This also gained essential knowledge for interpretation of the experiment utilizing the CDI techniques on API spiked solutions. This work revealed a clear dependence on acidity for the breakdown process.

Application of the CDI technique to API remediation

Capacitive deionization (CDI) is an emerging technology that is showing considerable promises as a sustainable low energy process for purification of water from process and wastewater. It offers the possibility of both electrosorption/desorption as well as oxygen free-radical mediated degradation of bound molecules upon desorption (“catch and kill”). Its simplicity and cost-effective operation, together with potential energy recovery possibilities during its operation, makes it a promising technology to be implemented as part of treatment process of drinking water and industrial wastewater plants. The CDI technology has been described more fully in previous MTC reports.

Lab-scale phase

The lab-scale tests have been conducted at division of Functional Nanomaterials Group at KTH, whereas the analytical work was performed by researchers at RISE. The API spiked solutions used during the lab trials were provided by AstraZeneca. The solutions were immediately stored under freezing conditions until the experiments were performed. The lab-scale system comprised of a CDI flat cell of 5x5 cm, with a flow-through architecture (close to the SWT solution). The technicalities of the setup are out of scope for the report, but a schematic representation of the lab-scale rig is shown below (Figure 22).

Initial experiments revealed that metformin was not removed from water flow when only pure adsorption was applied, whereas metoprolol and esomeprazole were almost quantitatively removed after 120 minutes of circulation (Figure 23). Application of a between 2V and 5V potential did not greatly enhance the rate of removal of metoprolol and esomeprazole, but metformin was clearly more effectively adsorbed, indicating that metformin removal is mediated by electrosorption, whereas metoprolol and esomeprazole desorb rather poorly, reacting poorly to the reverse polarity. It may also be possible that degradation of the latter two APIs occurs on the electrodes, with release of by-products. This is the subject of further investigation, but esomeprazole is clearly subject to this (see above).

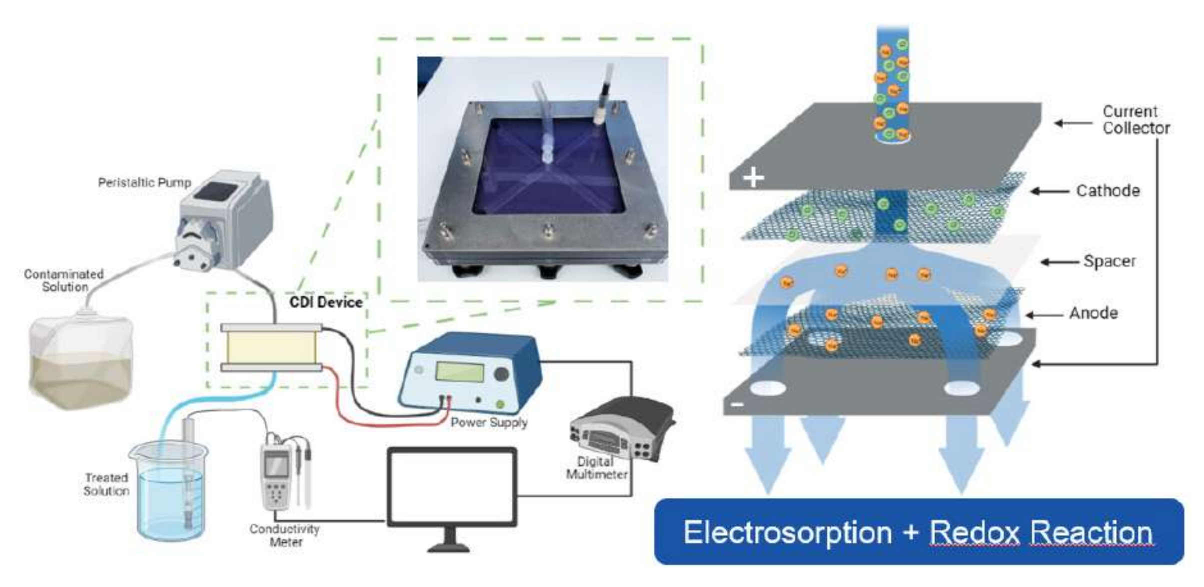

FIGURE 22. A schematic representation of the capacitive deionisation technique.

Latterly experiments are being performed focused on the use of the flat cell CDI architecture to investigate further aspects of the adsorption/desorption mode with respect to potential breakdown of the API. This is focused on a mass balance approach where either primary breakdown products are sought in the circulating solution and the API and potential breakdown products are retained on the electrode. The effects of pH and applied voltage are also included.

Together these studies form the basis of an academic publication which is being developed.

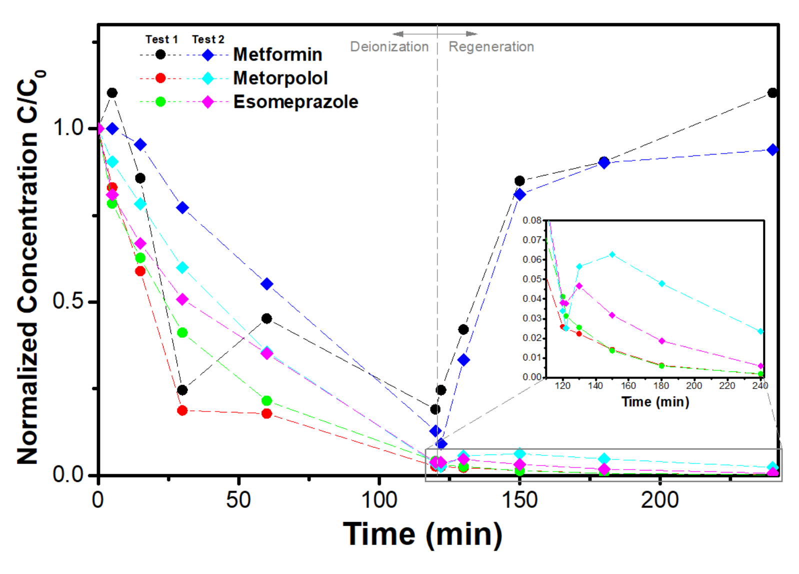

FIGURE 23. Normalized concentrations of esomeprazole, metformin and metoprolol in a spiked water mixture subjected to electrosorption at 2V.

CASE STUDY PACKAGE 5:
AIR AND GAS

CSP5 Leader: Hjalmar Granberg

Involved partners: RISE; SU; UU; KTH; IVL; Camfil; Svensk Ventilation; Humlegården; Avanzare; Bright. Day Graphene; Sally R; Insplorion

Key questions and scope

The principal purpose is to design and evaluate the sorbents used for removal of SOx and NOx in applications with low concentration for indoor air, as defined by the providers of ventilation solutions and users, typically in the ppb range up to 1 ppm.

For indoor air applications, removal of SOx, and NOx is challenging, as SO_2 influences the efficiency of the NOx removal. In, for example, an adsorbent media impregnated with a base, the presence of SO_2 would cause the premature desorption of NO_2 and NO. A system on which SOx and NOx are co-adsorbed is preferred.

Progress and achievements during 2022

There are ongoing trials regarding impregnation of filter paper substrates for the removal of SOx, impregnation of graphene aerogels for CO_2 removal, preparation of MOFs for CO_2 and SF_6 removal, preparation of activated carbons specifically tailored for VOC removal and CO_2 removal, and preparation of thin films of activated carbons targeting filters with a low pressure drop while maintaining a large gas removal.

A test chamber for gas adsorption evaluation has been set up. The work on thin film activated carbons show a very large surface area when bound together using a bio-based binder (Figure 24). The obtained surface (2000 m^2/g) of the film using 10 % binder was found to be the same as that of the pure activated carbon particles. Air simulation models indicate that gas flowing parallel to the surface of such films experience a low pressure drop. Low pressure drop is a performance criterium that is sought after in air filtering applications since it translates into low operating costs. The pressure drop and gas filtering properties are currently being investigated by comparing stacked films containing activated carbon with a loose fill media based on activated carbons having similar surface area.

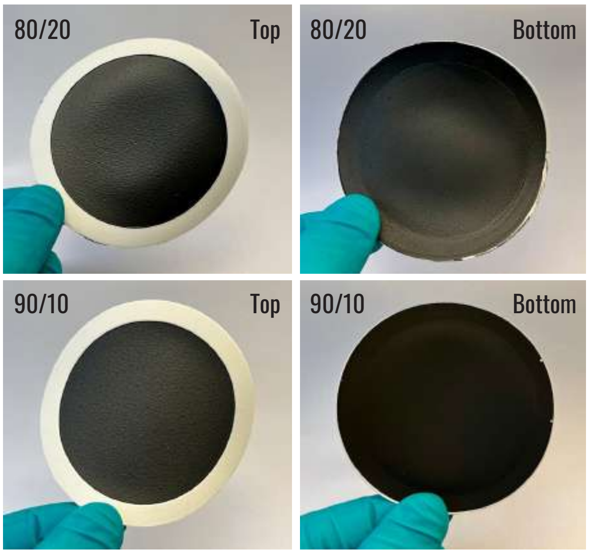

FIGURE 24. Top and bottom side of films based on activated carbon and 10 % or 20 % biobased binder.

During February 2022, CSP5 organised a number of online seminars and workshops on the topics of industry interests in air cleaning and the technical potential from the perspective of Mistra TerraClean on the following topics:

- Gas adsorption and related kinetics
- Gas adsorption in phase I and technical discussion
- Ventilation system requirements
- Graphene applications in Mistra TerraClean II
- Smartification of air filter solutions within Mistra TerraClean

This was followed by an online seminar in October, on Benchmark systems and new materials for clean air in collaboration with WP2.

FIGURE 25. Gauze impregnated with activated carbon and a biobased binder.

CASE STUDY PACKAGE 6: MICROPLASTICS

CSP6 Leader: Sven Norgren, RISE MoRe

Involved partners: SU; KTH; RISE; IVL; RISE MoRe; Mimbly

Key questions and scope

One identified source of microplastics in Sweden are particles generated in washing machine effluents. Early capture, and water-phase capture will lower the risk of particles becoming airborne and the risk of particle down-sizing.

CSP6 is addressing treatment of microplastic-containing water from household washing machines and laundries with biobased filters.

This case study engages Mimbly AB, as they want to contribute to microplastic-free laundry to the highest degree as possible.

FIGURE 26. The Mimbox reduces microplastic pollution from laundry.

Progress and achievements during 2022

In the autumn, the CSP6 participants made a study visit to Gothenburg and the Mimbly AB facility. The visit was important to understand the company's innovation, the Mimbox (Figure 26), which is an add-on device that connects to professional laundry.

The project group structured the future work regarding sampling and analysis. At this meeting two new postdocs and a researcher were introduced, as this CSP will have increasing workload during 2023 and 2024.

Initial work with material candidates has been done at SU and RISE MoRe. At SU, a 3D printed structure of a filter has been produced. RISE MoRe has tested wet strength in filter papers and has performed some data simulation of filter structure. Literature review has been done of several participants at SU, KTH and RISE MoRe.

At SU, fully biobased and biodegradable water purification filters were developed and processed by the means of three-dimensional (3D) printing, more specifically by fused deposition modelling. The polylactic acid (PLA) – based composites reinforced with chitin nanofibers were prepared. The monolithic, biocomposite filters were 3D printed in cylindrical as well as hourglass geometries with varying, multiscale pore architectures (Figure 27). The filters were designed to control the contact time between filter's active surfaces and contaminants, tailoring their permeance.

The adsorption of metal ions was attributed to electrostatic interactions between the NFs dispersed and PLA itself and copper ions, whereas the microplastics removal occurred primarily via size-exclusion enhanced by physical bonding of particles onto the filters' surface. The filters can be recycled, by initially being utilized for the adsorption of metal ions and then, after desorption and safe collection of metal ions, being reused multiple times for the removal of microplastics from contaminated laundry water.

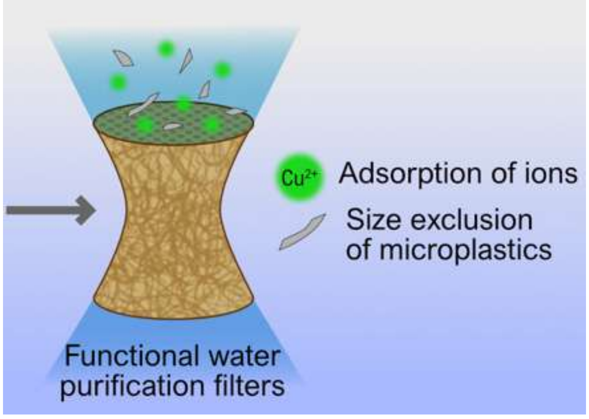

FIGURE 27. Schematic representation of 3D printed PLA nanocomposite filters that combines simultaneous removal of metal ions and microplastics.

FIGURE 28. Early capture of microplastics in washing machine effluents will contribute to microplastic-free laundry.

AN INDUSTRIAL PARTNER PERSPECTIVE ON MISTRA TERRACLEAN II

Why are you engaged in the Mistra TerraClean II?

– The programme's vision is to contribute towards clean soil, water and air by means of new technologies. This vision match with Radma's quest for efficient and affordable solutions for water remediation.

What are the benefits of joining a consortium for a company of your size and kind of business?

– Radma is a micro company and by participating in Mistra TerraClean II we get the opportunity to meet with experienced scientists and experts from academia and industry.

What do you expect from being a partner in Mistra TerraClean II?

– To evaluate and improve our magnetic carbon technology in real applications for water treatment in mining, pharmaceutical and ground water applications.

What, and how, do you plan to contribute to the programme?

– To participate in " real life" projects and test the properties of our magnetic materials in laboratory and pilot scale and to assess the economic and environmental credentials for problem owners and society.

FIGURE 29. Radwa Ashour with a sample of Radma's magnetic carbon.

MISTRA'S SUPPORT TO UKRAINIAN RESEARCHERS

In April 2022, Mistra's Board decided to allocate SEK 10 million to support researchers fleeing the war in Ukraine. The funding can be used to offer researchers employment for a limited period of time in Mistra's research programmes. One of the researchers is Serhii, currently working with Mistra TerraClean and hosted by Stockholm University.

The day the war began

When Mistra announced their support to Ukrainian researchers, Professor Serhii was sitting in a laboratory at Johannes Gutenberg University in Mainz, Germany, wondering where he and his wife could settle down and continue work and life together.

They decided to leave Kyiv and Ukraine before a full-scale war developed and headed westwards to the border in February, days before Russia's invasion. On February 24, they crossed the border to Poland.

Serhii used to work at the National Academy of Sciences of Ukraine and from time to time he also taught chemistry at various Kyiv universities. Both Serhii and his wife are chemists in materials science with extensive expertise in, among other things, nanocomposite materials.

– We looked for jobs as researchers in chemistry and sent our CVs near and far. It was important for us to be able to work, not just live on support, says Serhii. In the long term, they wanted to be able to continue working with their own research for a longer period of time.

Via a Ukrainian database for scientists they got in contact with Professor Niklas Hedin at Stockholm University, who found that Serhii's experience and competence could be an asset for the Mistra TerraClean programme. Thanks to the Mistra special funding and additional support from the Swedish Foundation for Strategic Research and Stockholm University, they came to Stockholm in September 2022 for a two-year assignment.

"We looked for jobs as researchers in chemistry and sent our CVs near and far. It was important for us to be able to work, not just live on support."

– I have previously worked on developing products for the industry, such as new generations of sun protection cream where we used nanoparticles that provide stronger protection against UV radiation", says Serhii.

– Serhii's research profile fits well into the Mistra TerraClean mission of eliminating pollutants in water, and Serhii and his wife are very appreciated among the other scientists here , says Niklas Hedin.

According to Serhii, his Ukrainian job network is still working, but funding has dropped drastically and is now 20–30 percent of what it used to be from the government. He believes that there are tangible risks that Ukraine's scientific and educational capacity will deteriorate sharply.

– The lack of sufficient funding and basic needs, like electricity and heating have a negative impact on scientific processes, says Serhii.

The future is still very uncertain for the Ukrainian couple, as their tenure at Stockholm University ends in September 2024

– Today I feel that I have no future, life is focused on one day at a time. I have a desire to continue a meaningful professional life, Serhii says, looking at the window.

(Due to the situation in Ukraine, Professor Serhii does not want to appear with surname or picture.)

SCIENTIFIC OUTPUT AND OUTREACH ACTIVITIES

PUBLICATIONS

Alvarado-Ávila, M.I., Toledo-Carrillo, E., Dutta, J. (2022) Cerium Oxide on a Fluorinated Carbon-Based Electrode as a Promising Catalyst for Hypochlorite Production. ACS Omega, 7 (42), 37465-37475. https://doi.org/10.1021/acsomega.2c04248

Atoufi, Z., Reid, M.S., Larsson, P.A., Wågberg, L. (2022) Surface tailoring of cellulose aerogel-like structures with ultrathin coatings using molecular layer-by-layer assembly. Carbohydrate Polymers, 119098. https://doi.org/10.1016/j.carbpol.2022.119098

Basumatary, I.B., Mukherjee, A., Katiyar, V., Dutta, J., Kumar, S. (2022) Chitosan-based active coating for pineapple preservation: Evaluation of antimicrobial efficacy and shelf-life extension. LWT, 168, art. no. 113940. https://doi.org/10.1016/j.lwt.2022.113940

Fijoł, N., Aguilar-Sánchez, A., Ruiz-Caldas, M., Redlinger-Pohn, J., Mautner, A., Mathew, A., P. (2023) 3D printed polylactic acid (PLA) filters reinforced with polysaccharide nanofibers for metal ions capture and microplastics separation from water. Chemical Engineering Journal, 457, 141153. https://doi.org/10.1016/j.cej.2022.141153

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