Annual Report 2022

TNO Early Research Programs

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TNO Early Research Programs

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Contents

Results 2022 of TNO's Early Research Programs

In this report we proudly present the 2022 progress of TNO's Early Research Programs (ERP) portfolio whose development over time is visualized as a 'funnel' of maturing programs in Figure 1. The progress of ERPs reverts to the plans published in the 'TNO Early Research Program Annual plan 2022' (reference TNO 2021 R11720, dated September 30th, 2021).

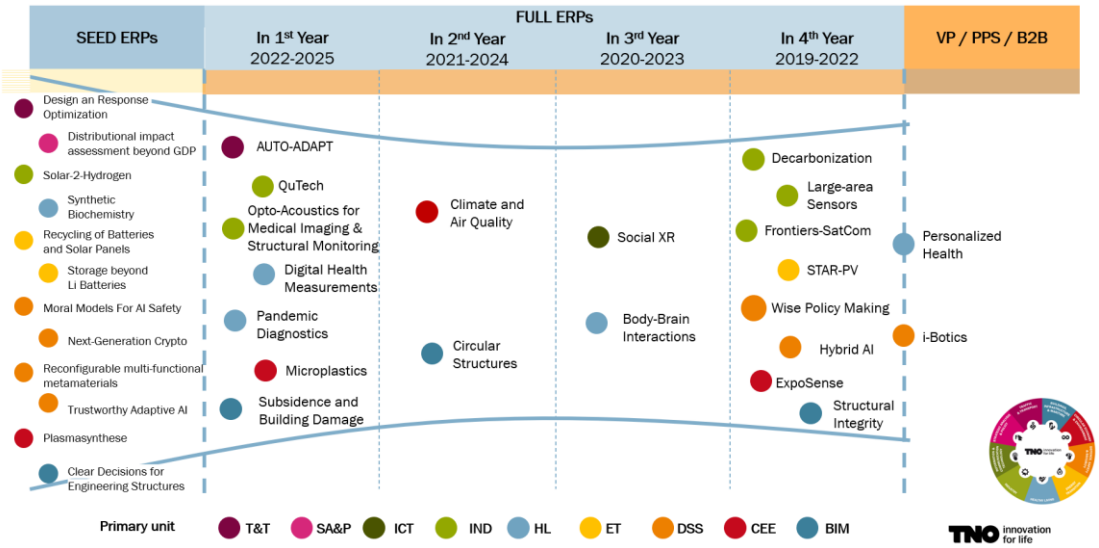

Figure 1: Funnel TNO Early Research Programs 2022

This report describes the progress of in total 21 Full (four-year) ERPs (see Table 1), focused on important societal and economical challenges. ERP-programs develop 'early' or low-TRL knowledge, driven by a demand foreseen by TNO in the longer (4-year) term. Therefore, we deploy a use-case-inspired research approach with emphasis on generating *cutting edge knowledge and technology* together with research partners from academia, and on *building research ecosystems* with stakeholders and sponsors from industry and public organizations. Table 1 lists the Full ERP's and provides highlight(s) of their progress. Figure 1 shows that the numbers of Full ERP's are not equally distributed over the years. This is a legacy of the synchronous start of the ERP methodology in 2015, which we are gradually reducing towards a portfolio in which approximately five new Full ERP's can start every year.

Yearly, the funnel process provides for the exploration of the potential impact and feasibility of emerging technologies in so-called Seed-ERP projects, each running maximally one year. The 12 Seed ERPs running in 2022 are listed in Table 2. A quality promoting selection of 50% of these Seed ERPs (based on scientific quality and expected societal and economic impact) continues the following year as a Full ERP.

In the course of 2022 the Seed ERP's "Distributional impact assessment beyond GDP", "Solar-2-Hydrogen", "Synthetic Biochemistry", "Sustainable recycling of Batteries and Solar Panels", "Moral models for AI Safety", "Next Generation Crypto" and "Plasma Synthis" have been promoted to Full ERPs starting in 2023. The Seed ERP Microplastics was granted with a 2-year Full ERP status. For Seed ERP topics not promoted to Full ERP status, alternative ways to proceed are explored and regularly also found.

Following the TNO publication policy and IP policy and the NGWI integrity code ('as open as possible, as closed as necessary') the publication and patenting of ERP results is actively pursued. Overall the ERP programs yielded approximately 150 scientific publications in peer-reviewed journals and a total of 14 patents were filed.

All ERP's actively reach out to external stakeholders. Besides patenting and publicizing in scientific context we do this by e.g. publications in non-scientific media, conference presentations, posters and ERP dissemination events.

The ERP plans for 2023 and beyond are described in 'TNO Early Research Program Annual plan 2023' (reference TNO 2022 R11816, dated October 10th, 2022).

Table 1: Full Early Research Program, Highlight 2022

Full Early Research Programs (four-year programs) Appendix: ERP-title Short overall description	Highlights 2022
5th year projects: Started in 2018	
1: Personalized Health We want to reduce the harm and cost of lifestyle related diseases. For this purpose, we develop a system providing personalized advice on sustainable lifestyle habits based on biological understanding of inflammatory dynamics, dysmetabolism, AI modeling and health community support.	In total, 54 volunteers completed the 6-months SLIMMER+ intervention. First analyses indicate the following effects of the intervention: weight loss (average 4.5 kg), positive changes in biomarkers and prevention of deterioration in prediabetic subtype. Also experiences of the participants and health care professionals with the technology included in the SLIMMER+ study were positive and the study intervention tools helped the professionals to coach the participants efficiently and effectively. This paves the way for an upscaling of personalized intervention. Our goal of delivering a human Proof of Concept (hPoC) using the multidisciplinary evidence based methodology and knowledge base has therefore been reached. Beyond the ERP, analysis of data will continue, data will be collected 12 and 24 months after start of the intervention and results will be further disseminated.
2: i-Botics We want to enable human-controlled robotics for tele-operations not suited for humans. We focus on perception and manipulation capabilities in	We placed 5th in the international ANA Avatar XPRIZE competition! We built a demo of a bimanual tele-operated setup augmented with a third arm. We continued our work on interpreting the VR environment and creating symbolic object

Full Early Research Programs (four-year programs) Appendix: ERP-title Short overall description	Highlights 2022
challenging, unpredictable, dynamic situations. Application areas are installation, maintenance, repair and emergency response; and wearable robots for human enhancement in rehabilitation and heavy work environments.	representations and their transfer to live operators in a multi-sensory VR environment for situational awareness. A demonstrator of an active back support exoskeleton and a controller optimized for effectiveness and usability in practice were built, including multiple algorithms targeting the generation of a real-time estimation of the bending forces in the lower back. We created a sensor-based tool which helps determine the potential for exoskeletons in specific heavy work situations.
4th year projects: Started in 2019	
3: Decarbonisation We target to reduce the dependency of the chemical industry (primarily at the Chemelot site) on fossil sources, by developing climate proof technologies and associated implementation strategies.	To investigate the potential of plasma technologies for decarbonization, a 3D finite element thermal gas flow model for simulating the chemical conversion (improved Hüls) has been developed. With it, the relations between chemical conversion, residence time and gas temperature have been established. Those relations, including the effect of acetylene conversion on gas mixture composition and accompanying thermal properties, have been studied to estimate the resulting acetylene production. In the new Brightsite Plasmalab (opened in 2021) a small, low-pressure, plasma arc system is now operational and experiments are carried out. This is used in order to test, verify and improve the process models and to optimize the design of a larger-scale pilot plant. It is envisioned that a 50kW plasma arc system will become operational in 2023.
4: Large-Area Sensors We develop technology for large area, flexible ultrasound imaging/monitoring systems enabling to bring medical care to the home environment. Our essential approach is to build printed ultrasound transducers using cost effective display fabrication technologies.	As a result of better device processing and understanding ~16x improvement (compared ot the 2021 status) in pulse-echo efficiency was realized with our flexible polymer ultrasound technology. Prototypes of 128-channel linear arrays were realized. Acoustic crosstalk was negligible. Ultrasound images of tissue phantoms were recorded using image capture times of 0.1-1 ms, which is a factor of 10^6 improvement over our last year's imaging results. We tested several versions of wearable ultrasound patches. A study with volunteers gave important information on comfort and wearability.
5: Future Optical Satellite Communication By using laser light instead of radio waves we aim to greatly enhance communication between satellites,	In 2022 we established a system concept of a ground terminal for a feeder link to a Low Earth Orbit (LEO) satellite with high data rate (200 Gbit/s) and minimal latency, to comply with the very high data throughput needs. For ultra-secure

Full Early Research Programs (four-year programs) Appendix: ERP-title Short overall description	Highlights 2022
ground stations and airplanes, providing ultra-high data throughput and ultra-secure and multi-point communication.	communication, we successfully verified and demonstrated an adjustable spectral filter to optimally reject background radiation. This will contribute to future daylight Quantum Key Distribution (QKD) links. Finally, to enable multi-point communication, we made a detailed design and started the construction and experimental verification of an extremely low volume, large aperture space telescope.
6: STAR-PV By gaining insight in and by developing improved control of basic degradation mechanisms we enable improved reliability and sustainability and lifetime extension (e.g. beyond 20 years) of photovoltaic and other thin-film opto-electronics integrated in building components and products.	We completed our novel methodology to inspect integrated PV on square km scale, to carefully extract degraded samples, and to perform post mortem nanometer-scale analysis. Lifetime-determining degradation mechanisms of integrated (flexible) PV have been identified under multiple stress exposure. Comparative LCA models were developed. Our reliability research approach for stretchable electrical interconnection lines in wearable electronics has been successfully applied to flexible PV semi-fabricates for customized integration.
7: Wise Policy Making We develop a suite of instruments and methods to support policy makers to assess the expected impact of policy options on wellbeing and to engage in unbiased and well-informed dialogue leading to decisions that prioritize sustainable societal wellbeing.	In this ERP, we have developed the capability to assist in prioritising wellbeing for policymakers by means of a practical Manual and WISE Cube software. With this capability TNO is able to help municipalities, provinces and ministries with developing wellbeing oriented policies. The WISE methodology being part of the broader Brede Welvaart context has proven to be a welcome addition to the “programmatische samenwerking’ with the ministry of I&W
8: Hybrid AI This ERP, our largest, consists of a coherent set of program lines, two of which being the ‘flagships’ of the program: SNOW (AI capabilities for self-aware autonomous systems that can operate safely and effectively in an open world) and FATE (AI to provide fair advices by continuous learning from multiple potentially confidential and biased data sources). These two flagships are complemented by a set of use case projects.	The main characteristic of this program is its integral approach. The ERP Hybrid AI program develops capabilities for autonomous systems and decision support in a unique AI ecosystem: connections to the academic world, two flagship projects, and 19 use case projects with over 25 external stakeholders. Within the flagship project SNOW we developed new functionalities for autonomous systems and tested these using our SPOT robot in an industrial inspection use case. These capabilities are 1) the ability to detect specific situations by combining deep learning with symbolic reasoning, such as how to handle a jerrycan that is leaking liquid on the floor, 2) the ability to abort its current task when detecting such a specific situation, and report back to the user and 3) the ability to assess the quality of a sensor

Full Early Research Programs (four-year programs) Appendix: ERP-title Short overall description	Highlights 2022
	reading and change the conditions if this is not good enough. SNOW's integration efforts over the past few years have resulted in a system architecture that is modular and flexible, so that it can be used on different robotic platforms. The selected case for the flagship project FATE was to match job seekers to jobs based on skills/competencies instead of experience and job history. In FATE we developed a method that quantifies biases in (current) skills formulations, and another method that shows that such (gender) biases indeed affect gender imbalance in the corresponding jobs. We developed a method and quality criterions for dynamically adapting a skills ontology towards changing job requirements and new jobs. We proposed and published an ontology of explainable AI types and methods and designed a user experiment for suitable XAI in the skills matching use case setting. In October 2022, a large Appl.AI event was organized to show case the results of the flagships and use cases to our stakeholders.
9: ExpoSense We develop solutions for personalized promotion of health based on non-invasive assessment of external and internal exposure to Particular Matter (PM), by developing accurate, reliable and calibrated PM sensors and by predicting and interpreting personal external and internal exposures by quasi real-time modelling. The aim of ERP Exposense is to deliver comprehensive equipment and models for the management of the impact of particulate matter (PM) exposure on human health, both in the general environment and in the occupational domain.	In 2022 we transfered the design of a portable chemical identification sensor for PM detection to a breadboard system and subsequently to a functional wearable prototype, achieving a size reduction of a factor ~6 and a cost reduction of a factor ~5. Communication, hardware, and power solutions were implemented in cooperation with an SME partner. At the conclusion of the ERP, two demonstration devices were constructed for field tests, which are linked with the sensor data infrastructure from the research and prototyping platform EXCITE. Two approaches were developed for the interpretation of sensor data in workplace settings. Firstly, the creation of dynamic 2D maps by applying kriging. Secondly, the interpretation of peaks in exposure profiles by adding context sensors. This development was guided by a focus group of end users in the construction industry. With respect to the interpretation of sensor data in the environmental setting, we demonstrated the added value of heterogeneous mid- and low-cost sensor observations by data assimilation method implemented around the LOTOS-EUROS chemistry transport model. In addition, approaches were developed to translate PM2.5 concentration maps

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	into actual expected health damage to the exposed human population, expressed by disability adjusted life years and oxidative potential.
10: Structural Integrity We develop digital twins (simulation models fed with sensor data) mimicking the behaviour of macro-structures such as bridges and guiding the design and management of these structures. Main challenges are multi-scale modelling, advanced sensing techniques, high speed computing and AI learning capabilities.	The ERP-SI developed and validated several structural digital twins (DT's). The DT for Steel Bridges assesses the residual service life of the Moerdijkbrug, in a fieldlab together with Rijkswaterstaat. The DT for bolted connections of extreme sized offshore wind structures has been validated with lab tests. The DT for combining several traffic intensity data sources resulted in a map of normalised traffic loads, the Loadmap. The Bridge-WiM system transformed strain data into traffic loads on a bridge. And a optimisation algorithm for the design of composite materials in military applications has been developed. These digital twins successfully combine monitoring data of the performance of structures under loading, knowledge and tools on structural safety and artificial intelligence.
3rd year projects: Started in 2020	
11: Social XR We want to better facilitate human interactions in virtual (augmented) reality for remote teaming and working applications. For this purpose we create 3D representations of humans and haptic feedback.	We have developed technology to convey important social cues around the eyes, such as eye gaze and eye blinking, by developing AI-based Head Mounted Display removal (virtually removing a person's XR glasses and replacing these by an AI-based point cloud representation). Key insights were generated in XR environment capture and representation, combined with the placement and rendering of digital 3D participants. Our efforts were placed on participants scaling, meaning that we increase the number of participants in the experience, and device flexibility, meaning that our systems cater for a various range of capture and rendering equipment, by developing a faster Multi-Point Unit module that combines all streams, allowing for more media functions for interoperability and adaptive processing. Our functional and technical requirements were direct output for network-based media processing and transmission, where we developed a cross-layer adaptation based on objective metrics of performance. Finally, we validated and published our Social XR questionnaire, which is a reference evaluation tool for assessing XR experiments. All developments are integrated into a Reference Social XR Platform, resulting in a complete system

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	for delivering a Social XR system and assessing its value.
12: Body-Brain Interactions We improve life-long health, performance and mental strength via mechanism-based understanding of the connections between body and brain, realized into a Brain-Body Interaction technology platform.	The program has now established two complementary unique body-brain research platforms: 1) a platform to non-invasively study body-brain interactions in humans using a human tissue biobank; and 2) a preclinical platform using patented mice with human-like metabolism to study mechanisms at the molecular level and test new treatments. The platforms can be coupled using same (translational) biomarkers and same data science tools to predict biological effects. New interactions (between: diet - brain, liver-brain and adipose tissue – brain) were identified and highlights were published in Nature 2022 and Neurology 2022.
2nd year projects: Started in 2021	
13: Climate and Air Quality We develop a globally applicable, multi-scale atmospheric modelling system with resolution down to 25m to fully exploit the emerging observation capacity from satellites and sensors.	In 2022, we have prepared the first modules of the operational modelling system: 1) an emission model system, by integrating the developed emission models into a prototype operational system, and 2) a smart data management system, by developing an architecture and proof of concept for automatic data acquisition and storage of different data types needed in the model system. The developed emission model system has been provided with data-driven calculation chains to derive high resolution emissions for road traffic, agriculture and power plants. These have been tested by comparing modelled concentrations with in-situ measurements. For local air quality modelling, we have implemented a nitrogen deposition routine in DALES, which can now model the effect of local landscape changes on nitrogen deposition.
14: Circular Structures We develop knowledge and technology that enables a shift from traditional design strategies for concrete structures to a new engineering design method driven by integration of supply quality and demand.	In 2022, the multi-objective optimisation software was further developed for multi-stage optimization, in line with building practice. Software interfaces were aligned for complex optimisation using numerical models of material (concrete) as well as structures. The effect of data-informed optimisation taking uncertainties in consideration was shown for service life calculations and led to principles of survey and to testing protocols for reclaimed elements. A PhD proposal was made based on an exploratory numerical study on effects of a.o. shrinkage on prestressed elements with recycled concrete aggregate. For setting up macro-economic

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	optimisation indicators on 'supply-demand' balance, a first material flow analysis was conducted on construction and demolition waste. An approach was set up for multi-scale modelling of concrete, starting from its ingredients up to the structural level, which will be developed further in 2023. ERP findings led to an adjacent project for RWS ("Safety philosophy for reuse of reclaimed elements"), that will provide input for NEN standardization activities.
1st year projects: Started in 2022	
15: AUTO Adapt We develop self-learning adaptive methods to maximize overall performance and dramatically reduce development time and costs of high-tech systems. We do this by automatically adapting the controlled system behaviour and configuration.	In the first year of AutoADAPT, we focussed on the development of the self-adaption methodology and the realization of virtual and experimental demonstration platforms. Based on probabilistic reasoning, a concept has been developed for joint situation and system awareness. This concept has been demonstrated in a hardware-in-the-loop set-up for condition-aware logistics situations with battery aging. In parallel, the optimization framework for battery-life conscious energy management of a battery electric distribution truck as well as for satellite use case has been defined. For the latter, preliminary models for awareness and optimization are developed, and the potential of self-optimization of the pointing performance is demonstrated in simulation. As a first step, the architecture for an adaptation engine for short- and long-term horizons are specified. In addition, discussions with potential partners have been held and joint spin-off research projects are defined. Also, an industrial steering group has been started with (so far) ESA, Airbus, DAF, DENSO and LightYear.
16: QuTech We aim to demonstrate fault tolerant quantum computing and quantum internet.	The demonstrators were developed according to plan, and are available online. The Quantum Computing demonstrator (www.quantum-inspire.eu) was greatly improved with a second 2-qubit device and improved spin control with up-conversion, while the superconducting transmon system was extended with automatic tuning and calibration, which improves up-time and reliability. Our Quantum Internet demonstrator program launched its demonstrator with a simulated back-end, as a world-first. Through www.quantum-network.com, users can build and simulate applications of a future quantum internet.

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17: Opto-Acoustics for Medical Imaging and Structural Monitoring We develop an acoustic platform, using optical means only, to generate and receive acoustic waves. Such a system will radically outperform existing (often piezo based) acoustic systems. Another advantage is that this system can be miniaturized or multiplexed to cover large structural areas and long distances.	We established two clear applications to further develop the opto-acoustic sensor system, one focusing on medical (ultrasound) imaging and the other one on monitoring of composites structures such as offshore wind turbine blades. We demonstrated, using a Photonic Integrated Chip, that we already at this early stage have the same performance as state-of the art, piezo-based sensors. Our opto-acoustic design tools, although very basic, showed to be helpful and reliable. We performed proof of principle tests on a novel opto-acoustic emitter, based on an idea patented by TNO. In 2023 this concept will be further explored within an array of transmitters and receivers.
18: Digital Health Measurements We aim to develop a generic (implementation) framework aimed at validation, security, data governance and utility of digital health measurements	We are developing a multiparameter non-invasive research platform to deliver high-quality continuous medical grade data with diverse types of sensors. This platform enables the development of diverse novel clinical-grade digital biomarkers. Within this ERP we focus on the development of meaningful digital biomarkers: contextual biomarkers for sleep and chronobiology and physiological biomarkers for cardiometabolic health. We performed a technical validation of our research sensor suite as well as an analytical validation against the golden standards. To apply the contextual digital biomarker in a non-medical setting, we are complementing the objective sleep quality measurement with actionable feedback (e.g., what can you do to improve sleep quality) and we are improving usability (e.g., ensuring painless easy removal). Feedback is of less relevance for the clinical application, where clinical reliability has the highest priority. These insights in different contexts forms the basis for a generic social innovation and co-design methodology toolbox, which is essential for improved implementation. TNO will offer this toolbox to other technology developers to support development of meaningful digital measurements.
19: Pandemic Diagnostics We establish generic analytical strategies to identify novel, pandemic infectious agents and to establish efficient strategies for diagnostics and population-level surveillance.	In Research line 1 "improved bio-surveillance of (respiratory) viruses based on mass spectrometry", we developed a database and algorithm allowing identification of nearly 2000 viruses based on proteome data profiles. We further developed a water soluble filter for virus bioaerosol capturing. In research line 2 "targeted point of care and high throughput detection", we established and patented a novel method to improve CRISPR

Full Early Research Programs (four-year programs) Appendix: ERP-title Short overall description	Highlights 2022
	sensitivity a factor tenfold. We further established a first database for an improved algorithm for assay primer design. As demonstrator, we used these to develop a rapid LAMP based assay for Legionella pneumophila.
20: Microplastics We develop mitigation strategies for microplastic based on knowledge on the formation and release of microplastic.	We established a correlation between Microplastics formation and polymer characteristics: with this we can predict the amount and size of microplastics formed, based on the mechanical properties of the polymer. This allows us to assess and adapt processes to reduce microplastics formation and to improve material properties or material choice to reduce microplastics formation. This is the basis for future microplastics mitigation strategies. Furthermore, we connected to relevant academic and industrial stakeholders to evaluate several opportunities for future collaboration.
21: Subsidence and building damage We develop a workflow and a preliminary model chain to predict subsidence resulting from human subsurface activities and to derive from it an estimate of the potential for damage to the built environment.	In 2022 we improved our subsidence workflow: the disentanglement of the multiple sources of subsidence and the probabilistic downscaling of our subsidence predictions caused by shallow-sources. On the building side, we deployed models to study the soil-structure-interaction and the damages of building induced by small-scale subsidence. These last building models will be the starting point of our probabilistic damage predictions. We also implemented a workflow to derive InSAR-based subsidence observations at the building scale. This workflow will help validating our probabilistic subsidence and damage predictions. In 2022, we also held our first stakeholder event where we received input from intended end users of our knowledge, which will be basis for the further development of our model chain in coming years.

Table 2: Seed Early Research Programs, Highlights 2022

Full Early Research Programs (single-year projects) Appendix: ERP-title Short overall description	Highlights 2022
Seed ERP's 2022 continuing as Full ERP in 2023	
22: Distributional impact assessment beyond GDP We strengthen and extend existing TNO tools for making transition scenarios with economic impact analyses that make a difference in policy discussions. New and improved microsimulation tools based on real data at the individual household level will enable us to provide insights into the distributional and multidimensional effects of energy and mobility policies, that can help policy makers to target specific groups rather than imposing generic measures policies.	We have made first quantifications of social benefits (1) simulation of income (purchasing power) effects of imposing home renovation up to energy level B for the entire housing stock and 2) calculating the multiple impacts of imposing a zero emission zone (ZEZ) in the Amsterdam region. In the full ERP we will continue to develop an integral economic impact assessment framework that typically allows to quantify multiple social benefits, thus providing decision-makers with the necessary information to design well-targeted, cost-effective policy measures to promote an inclusive green transition and create societal support.
23: Solar-2-Hydrogen We develop devices for water splitting that use sunlight as sustainable energy source and yield green H2 at a levelized cost of hydrogen (LCOH) ≤ 2 €/kg (benchmark is green hydrogen from electrolysis).	In 2022, a technoeconomic and sustainability analysis of sunlight-powered green hydrogen production, based on PEC device concepts reported in literature and established at TNO has been performed. A lab scale device demonstrator comprising a photovoltaic cell and a photoanode has been delivered. Independent water splitting was shown with results equivaling the state of the art. The technology roadmap for a 4-year full ERP program SOLAR-2-HYDROGEN has been established. Furthermore, a programmatic collaboration on sunlight-powered chemistry, including production of green H2 in a Netherlands-Flanders research ecosystem with TNO, IMEC and UHasselt as lead partners has been initiated.
24: Synthetic Biochemistry We develop the most sustainable and efficient biosynthetic version of a biomaterials production platform with full focus on the ultimate product.	We delivered proof of concept for an innovative biosynthetic approach for production of proteins using a small scale version of the envisioned platform.
25: Sustainable recycling of Batteries and Solar Panels We develop Innovative separation and recovery processes for solar panels and	We found much milder reaction conditions (than current in industry) under which lithium-ion battery cathode materials can be efficiently extracted, reaching concentrations similar to current industrial processes.

Full Early Research Programs (single-year projects) Appendix: ERP-title Short overall description	Highlights 2022
batteries to selectively recover high-value materials for advanced applications, while ensuring sustainability, scalability and low costs; from waste to materials.	For both crystalline silicon and thin film solar panels we developed a method for clean separation of mini modules.
26: Moral models for AI Safety We develop methods for human-centric design, development, and use of AI systems that behave in a morally acceptable way through alignment with human moral values.	In 2022, we developed a methodology that describes how the development of ethical AI systems can be realized. We built a demonstrator that shows how humans might regulate the behaviour of an autonomous shuttle by providing feedback on its behaviour. The shuttle was equipped with an adaptive moral model that included moral values identified in the literature. In an experiment, we evaluated the performance and completeness of this model with human participants. We built a dialogue agent to elicit participants' own moral values, and used their feedback to improve the model. By conducting this experiment, we were able to identify some very fundamental questions about the development process of ethical AI systems. This was valuable input for refining the methodology that was developed and for identifying the associated research questions, which have now become main topics for the Full ERP.
27: Next Generation Crypto We develop secure future-proof solutions to high-impact sharing problems with sensitive data, and ensure their adoption.	We developed a scientific roadmap for multi-year research activities. We started the Privacy Enhancing Technologies laboratory (PET-lab) to prepare exploitation of multilateral-cryptographic software. We had several publications at top-level cryptographic venues. We developed the first differentially private learning algorithm (a quantum safe data sharing solution) with hard privacy and quality guarantees.
28: Plasma Synthesis We develop a plasma process to convert excess methane directly into ethylene, a high value chemical and precursor for plastics, to reduce the CO2 footprint of the chemical industry.	The seed-ERP served to concentrate the strong but scattered plasma knowledge within TNO and consolidated plasma knowledge among the consortium's partners (TNO, UM, Sitech). An unique lab scale setup was realized and proved to be robust and reliable. Collaborative experiments by TNO and UM demonstrated direct production of ethylene by plasma synthesis. In this setup, an ethylene to acetylene ratio of 3x was obtained. Future work will focus on reducing the energy requirements, which is still about 7x times too high for a viable business case.
Seed ERP's 2022 not continuing as Full ERP in 2023	

Full Early Research Programs (single-year projects) Appendix: ERP-title Short overall description	Highlights 2022
29: Design and response optimization We develop new optimization approaches and supporting methods to optimize large-scale, costly investments in infrastructure and materiel, involving multiple stakeholders and users, that that intrinsically optimize their own objectives.	We created a proof-of-principle implementation of an design and response optimization framework and demonstrated the promise of the approach for a use case in Amsterdam. At the same time we investigated the extent to which it is possible to generalize this approach such that it can cover a wide range of design problems.
30: Storage beyond Li Batteries We develop hybrid electricity storage concepts and devices that have enhanced safety, affordability, storage density, sustainability, and circularity compared to contemporary technologies. The project concerns development of two electricity storage concepts: Dissolution Deposition Batteries (DDBs) and Organic Pseudo-Capacitors.	The research objective was to repeat measurements done by Li et al to obtain a proof of concept (PoC) and baseline for future development on DDB (Zn/MnO2). Results showed that the electrolyte composition impacts the cyclic performance of the DDB and that the discharge plateau was longer for the electrolyte with higher concentration of Mn2+ ions (lower pH). A CFD model was built to assist with the reactor design, which would give insight on how to optimize the performance of the flow battery. Several redox active molecules have been tested. Different strategies were evaluated for the electrode deposition of methylene blue, including immobilizing it on two different types of carbon particles
31: Reconfigurable multi-functional metamaterials The aim is to fully master the breakthrough technology of metamaterials/metasurfaces (MMS), implementing a revolution in the control of electromagnetic waves and the realization of reconfigurable and cognitive electromagnetic nanoengineered materials/surfaces. Three main application areas relevant for TNO are signature control for defence platforms; Reflecting Intelligent Surfaces (RIS) for wireless networks and spectro-polarimetric instruments for Space Observation.	Two demonstrators of optical metasurfaces (a metalenses and a spectro-polarimetric metasurface filter) have been manufactured and tested. Furthermore, an ecosystem of industrial, technological and academic partners has been established, leading to two new big European and national project proposals in two of the three application areas identified for the ERP: signature control for defence platforms and future wireless communication networks. For the third application area (novel spectro-polarimetric space instrument concept enabled by optical metasurfaces) contacts have been established with the European Space Agency. Future activities on this topic, supported by the Agency, are expected in 2023.
32: Clear Decisions for Engineering Structures We develop a unified method for decision making on Engineering Structures and Systems from a	In the Seed ERP a single bridge structure was modelled consisting of a system of structural elements that was optimized on a system level. A case study was presented in which two different materials (concrete and steel) were used.

Full Early Research Programs (single-year projects)	
Appendix: ERP-title Short overall description	Highlights 2022
system perspective, integrating structural modelling, uncertainty quantification /communication, multi-objective stochastic modelling and engagement with decision makers.	Furthermore, a first model of a risk communication tool was developed and demonstrated. Finally, international cooperation on this topic within three different countries was initiated.

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