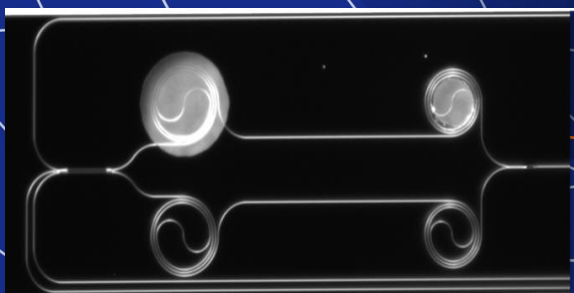




Annual plan 2023

TNO Early Research Program



Strategy

www.tno.nl

+31 88 866 00 00

info@tno.nl

TNO 2022 R11816 – 10 October 2022
TNO Early Research Program

Annual plan 2023

| | |
|-----------------------|-----------------------------------|
| Author(s) | Jaap Lombaers en Stefanie de Hair |
| Classification report | TNO Publiek |
| Report text | TNO Publiek |
| Number of pages | 11 (excl. front and back cover) |
| Number of appendices | 0 |

All rights reserved

No part of this publication may be reproduced and/or published by print, photoprint, microfilm or any other means without the previous written consent of TNO.

This document may contain strategic technology that is subject to Dutch/EU and US export control regulations and may require prior written approval from the applicable government agency before re-transfer or re-export.

© 2022 TNO

Contents

| | |
|--|----|
| Contents..... | 3 |
| Executive Summary..... | 4 |
| General goal and characteristics of the ERP Portfolio..... | 4 |
| ERP plan 2023..... | 5 |
| Contribution to TNO strategic themes..... | 12 |

Executive Summary

General goal and characteristics of the ERP Portfolio

The Early Research Programs (ERP's) represent TNO's early research activities. With these, TNO builds strong technology positions and contributes, together with knowledge partners and stakeholders, to answers to societal challenges and to creation of economic impact. The ERP's represent about 5% of TNO's turnover. The remaining 95% is steered by TNO's stakeholders: clients, 'Topsectors' and Ministries (via consultation) and Defense, EZK and SZW (via task financing).

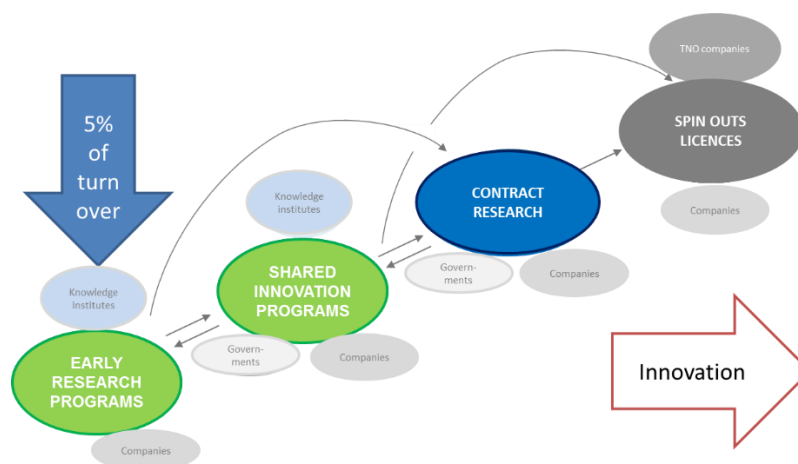


Figure Error! No text of specified style in document.1: TextVisualisation of how ERP's contribute to innovation

The main characteristics of the ERP portfolio are as follows:

- ▶ The programs build technology positions within the focus areas defined in the TNO Strategy Plan 2022-2025
- ▶ The programs are use-case inspired and have clear research goals: ERPs feed multiple innovation roadmaps of TNO, often of various units but with common requirements for lower-TRL technology breakthroughs. The output of the ERPs is transferred to (higher TRL) shared innovation programs, contract research and start-up initiatives.
- ▶ The programs aim for added mass through collaboration with knowledge partners such as universities and companies and for co-investments from public and private sources.
- ▶ The programs have substantial mass (> 1 mln Euro ERP budget per program per year) and have a typical duration of four years.
- ▶ 'Full ERP' programs are usually preceded by one-year 'Seed ERP' projects that explore the feasibility of the topic, substantiate the impact to be expected and build required partnerships, thus developing the full ERP program. Out of the ten 'Seed ERP' projects 2022, the five strongest were selected for continuation as Full ERPs in the period 2023-2026.

- ▶ ERP funnel management (involving reviews by TNO Corporate Science Office and by the board of TNO's Science Directors) is in place to monitor the progress and to adjust and reallocate resources if necessary.
- ▶ Together with our ministry of Economic Affairs (EZK) we inform the Topsectors and Ministries of our portfolio of ERP's, aiming at early involvement of companies and other stakeholders in public-private cooperation.

The ERP portfolio (as illustrated in Error! Reference source not found.) includes a lower number of programs in their 3^d and 4th year and a higher number in their 1st and 2nd year. An important goal of the ERP portfolio management is to bring the portfolio to a 'steady state' in which every year a similar number (4-5) of existing ERP's ends and new ERP's can be initiated. Only then will TNO be able to respond continuously and with agility to new technology trends and needs. Moreover, TNO's researchers will thus be stimulated to continuously be on the outlook for impactful new research directions, knowing that there is an instrument to award and adopt the best ideas. Our multiannual financial planning now allows for this desired 'steady state'.

ERP plan 2023

In 2023 six new ERP's will start, of which one initially for a single year. These concern 'Socio-economic impact of green transitions', 'Solar-2-Hydrogen', 'Synthetic biochemistry', 'Sustainable recycling of batteries and solar panels', 'Plasma synthesis' and 'Next generation crypto' (single year). These all concern domains with clear scientific challenges and high societal relevance. The topics were selected out of the ten 'Seed ERP' topics of 2022. In addition to these five, our ERP activities in the Artificial Intelligence domain ('Appl.AI') will be funded for a second four-year term ending in 2026. This ERP has a special status: it actually represents a portfolio of TNO activities in the Artificial Intelligence domain, involving all TNO units and having a significantly larger size than other ERP's.

In 2022, in line with our intended 'steady state' for portfolio renewal, we selected 10 new single-year Seed ERP's and 6 new Full ERP's (of which one initially for a single year). We see a success rate of about 50% for Seed ERP's to be promoted to Full ERP's as a healthy situation: a balance between promoting quality and avoiding wasted proposal efforts. We need two more years to reach the 'steady state' equilibrium of 5 projects also on the funnel *outflow*.

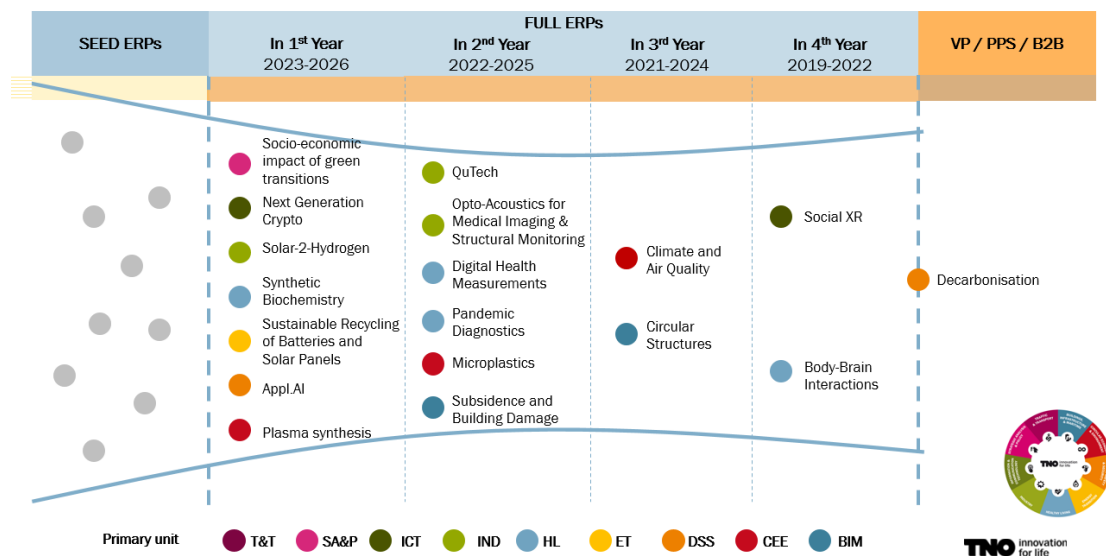


Figure Error! No text of specified style in document..2: ERP Funnel 2022

Legend – TNO unit names: ICT – Information and Communication Technology, HL: Healthy Living, BIM: Buildings, Infrastructure & Maritime, IND: Industry, DSS: Defence, Safety & Security, SA&P: Strategic Analysis & Policy, ET: Energy Transition, T&T: Traffic & Transport, CEE: Circular Economy & Environment

In the following chapters of this report each of the ERP’s is described by its overall goals and approach and by its results achieved in 2022 and intended results in 2023.

The ERP portfolio management conforms to four TNO policies / procedures. TNO’s Publication policy provides guidelines and sets targets with regard to publicizing research outcomes. The IP policy describes TNO’s way of working and goals regarding protectable intellectual properties. Publications and IP are key outcomes of all ERP projects. The PhD policy guides project teams on how to properly and effectively involve PhD’s in TNO’s research. TNO’s Professorship policy provides guidance with regard to the establishment of professorship positions of TNO scientists at universities. PhD’s as well as TNO-enabled professorship play an important role in the execution of our ERP research.

Error! Reference source not found. summarizes our 2023 Full ERP portfolio, providing for each ERP a short overall description (in the left column) and a listing of the key targeted results in 2023 (in the right column).

Table Error! No text of specified style in document..1: Highlighted results 2023 as planned in TNO’s Full ERP’s

| Overview Full (4-year) ERP’s | |
|---|---|
| Chapter #: ERP-title Short description | Planned results 2023 |
| 5th year projects: Start 2019 | |
| 1: DECARBONISATION (BRIGHTSITE) 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. | We will demonstrate an optimized second generation (improved Hüls) plasma process producing hydrogen and acetylene with an improved selectivity towards acetylene. We will experimentally confirm the practical and commercial application possibilities of Upwash® and liquid phase pyrolysis (LPP®) technologies, focused on case(s) on the Chemelot site. The possibilities of a digital twin for gasification based on complexity science, artificial intelligence and smart industry building blocks will be demonstrated. |

| 4 th year projects: Start 2020 | |
|--|--|
| <p>2: Social XR We create a shared Social XR (eXtended Reality) environment, where participants feel that they are in the presence of, and can interact with other persons at a remote location.</p> | <p>The ERP SXR focuses on conveying social and spatial presence in the metaverse by providing seamless and scalable real-time high-quality multi-modal interaction through eXtended Reality experiences. Our full end-to-end immersive experiences encompass 3D volumetric media capture, processing, and transmission along with an adaptively tailored Social XR network slice to deliver a convincing and lifelike shared XR experience. In 2023, we focus on generating expertise and technologies in five core topics in the Research Line, which will be directly feed into the Integration Line reference SXR platform to deliver tailored end-to-end communication chains for specific collaboration projects. Our research focuses on the two main use-case classes: XR meetings and Expertise at a Distance. We continue to strengthen collaboration with external parties especially in virtue of the knowledge transfer and establish partnerships to build a community of SXR stakeholders that will further develop use-case and technologies based on the reference SXR platform.</p> |
| <p>3: BODY-BRAIN INTERACTION 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.</p> | <p>In the last year of the ERP, we will complete the analyses of various (human and preclinical) studies, to deliver complete databases for further use in PMCs and cross-unit projects as well as publications. We will deliver an integrated body-brain technology platform including a trained dedicated team (DSS/HL) to operate the platform with its physiological, biochemical and computer science modules. Regarding Covid-delayed clinical human trials, we will finalize the outstanding biochemical analyses until 24 months follow up time point, manage the initiated collaborations with partners (together with DoS of HL and DSS), and complete the respective unique human biobanks and data bases.</p> |
| 3 rd year projects: Start 2021 | |
| <p>4: 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 capacities of satellites and sensors.</p> | <p>The ERP Climate and Air Quality aims to develop novel high resolution modelling approaches to determine citizen and ecosystem exposure to air pollutants. The activities in 2023 focus on developing dynamic emission algorithms for particulate matter, extending DALES for modelling city concentrations (chemistry and flow around obstacles), development of the prototype model system and the showcase Eindhoven.</p> |
| <p>5: CIRCULAR STRUCTURES We develop knowledge and technology that enables for concrete structures a shift from traditional design strategies to a new engineering design method driven by supply quality-demand integration.</p> | <p>The plan for 2023 leads to development of novel approach to suitability-driven design of concrete structures, which employs multi-criteria optimisation and enables circular use of materials after the end of service life based on new models for predicting the performance of non-traditional solution (incl. recycling of construction and demolition waste and reuse of reclaimed structural components).</p> |
| 2 nd year projects: Start 2022 | |
| <p>6: QUTECH We exploit quantum effects in customized systems, materials and concepts, such as quantum computing and communication to pave the way for a quantum revolution.</p> | <p>In 2023 we will further develop Quantum computing by creating online 6-qubit NISQ system with limited functionality and no direct spin readout. On Quantum internet we will develop a first long-distance entanglement generation between Delft and The Hague. We will realize a 3rd node, with control of an additional qubit based on 13C. Further two NV based nodes will be created to be ready for experimenting by the public via a web interface. The last point of improvement is on cooling and micro wave driving design compatible with Tin vacancies</p> |

| | |
|--|--|
| <p>7: OPTO-ACOUSTICS FOR MEDICAL IMAGING AND STRUCTURAL MONITORING The ERP Opto-Acoustics will create a next generation acoustic platform, using optical means only, to generate and receive acoustic waves. Such a system will radically outperform existing (often piezo based) acoustic systems, can be miniaturized, or multiplexed to cover large structural areas over long distances.</p> | <p>The work proposed is to use our in-house model to optimize single PUT performance for the two main applications addressed. For the composite structure case this will result in a FOPUT array of at least 5 transmitter and 5 receivers. For medical application case this will result in an IPUT receiver, grouping a high number of IPUT's to further reduce NEP, compared to a single IPUT.</p> |
| <p>8: DIGITAL HEALTH MEASUREMENTS We will develop tools and methodologies for meaningful, inclusive, digital health measurements</p> | <p>In 2023 we will continue the developments of meaningful digital health measurements for remote patient monitoring by TNO's health patch, sleep mat and photonics that support the health care transition by focusing on cardiometabolic health derailments and preventive interception by research of chronobiology for sleep improvement.</p> |
| <p>9: PANDEMIC DIAGNOSTICS We want to protect our society against the impact of future pandemic outbreaks by developing a scalable and multilevel testing strategy, optimally aligned with the needs during different phases of a pandemic outbreak</p> | <p>In 2023, the aim is to evaluate 3D printed filter designs for bioaerosol virus capturing and to validate its use in de novo shotgun mass spectrometric based virus identification. We further aim to improve LAMP and CRISPR-Cas based detection for high throughput and point of care diagnostics.</p> |
| <p>10: SUBSIDENCE AND BUILDING DAMAGE We aim at the reduction of huge costs for subsidence induced damage by building a chain of models which will be used to assess the causal relationship between subsidence and damage to the built environment.</p> | <p>The objective of 2023 is to develop the V0 Python-based model chain towards version V1 accounting for: (1) feedback of our stakeholders and (2) key novel ingredients: downscaling of subsidence predictions, soil-structure interaction, fragility functions, calibration and calibration with field observations.</p> |
| <p>11: MICROPLASTICS The ambition is to mitigate microplastic formation and release in the circular economy based on knowledge on microplastic formation and release.</p> | <p>In 2023, the focus lies on the material. Stresses – thermal, chemical and physical – during recycling change the properties of the recycled product that may lead to increased MP release. The big question: which materials are best suited for multiple recycling loops with minimal MP formation?</p> |
| <p>1st year projects: Start 2023</p> | |
| <p>12: SOCIO-ECONOMIC IMPACT OF GREEN TRANSITIONS A grand societal challenge is to implement the transition to a sustainable and green society while maintaining and redefining societal welfare ('Brede Welvaart'). This ERP develops a comprehensive microsimulation approach to quantitatively assess the integral impact of the energy and mobility transitions on households' economic well-being, together with CBS, CPB, PBL and academic partners.</p> | <p>In 2023, we will start to (further) develop a novel spatial general equilibrium model, in collaboration with the department of Spatial Economics at VU Amsterdam. Also, we will further develop a link between TNO/PBL's novel HESTIA spatial simulation model for the built environment and CPB's MIMOSI purchasing power model. Finally, we develop CBS micro data sets, including the set-up of data routines within the coalition of involved knowledge institutes.</p> |

| | |
|---|---|
| <p>13: SOLAR-2-HYDROGEN Development and demonstration of devices for water splitting that use sunlight as sustainable energy source and produce green hydrogen at a targeted levelized cost of hydrogen ≤ 2 €/kg (using electrolysis as benchmark).</p> | <p>In 2023, we will focus on the realization of a 1st generation lab scale iPVE device demonstrator with a STH efficiency $\geq 15\%$. Furthermore, we will focus on the design of stable photoanode and photocathode materials for PEC devices with the potential to reach a STH efficiency $\geq 10\%$. As an intermediate step towards these photoelectrode materials, we will develop stable lab scale photoanode and photocathode materials with a STH efficiency of $\geq 6\%$ and $\geq 3\%$, respectively. Furthermore, we will submit a position paper on the industrial potential of Solar-2-Hydrogen technologies, and establish a programmatic collaboration with IMEC, UHasselt and other partners.</p> |
| <p>14: SYNTHETIC BIOCHEMISTRY This ERP's moonshot is to develop the world's most sustainable and efficient biosynthetic version of a biomaterials production platform with full focus on the ultimate product: biomass that consists of $>90\%$ of the product of interest at 10-20% of current production prices.</p> | <p>A proof of concept for the application of TNO's unique biosynthetic approach for production of proteins was accomplished during the Seed phase of this program. Conditions concerning SYN BIO's freedom to operate, identification of key opinion leaders and assessment of the competitors' landscape were also found favourable for future technological developments. Further discussions with a selected network within Pharma and Biotech companies revealed high interest on the aimed technology, as a key enabler for multiple markets. In 2023, SYN BIO's efforts will be dedicated to the development of generically applicable technologies for two use cases related to the markets of therapeutic proteins (TPs) and bulk chemicals and energy carriers (BCECs). The main impact drivers from an application perspective will be identified and used for selecting this ERP's candidate products of interest. Along with the specific exploration of both use cases, the evaluation of operational freedom will be continued while defining potential strategies for IP protection and technology valorisation.</p> |
| <p>15: SUSTAINABLE RECYCLING OF BATTERIES AND SOLAR PANELS This ERP will result in new sustainable technologies to promote strategic materials independence of the Dutch industry by recycling of electronic products and their design from and to recycling. Focus will be on batteries and PV panels as primary use cases.</p> | <p>In first year of the full ERP program three technologies; selective delamination, high grade silicon recovery, and strategic metal extraction and recovery will be (further) developed in parallel. Additionally, the research on the fundamental aspects of all three key technologies will be initiated</p> |
| <p>16: NEXT GENERATION PLASMA SYNTHESIS Electrification of chemical industry is crucial to reduce CO₂ emissions. Plasma synthesis is employed for electrically converting methane to value added chemicals. The focus of the ERP will be direct production of Ethylene; an important large volume, high value chemicals (HVC) for the polymer industry.</p> | <p>The goal for 2023 is to design and realize a next-generation plasma system to determine the optimal conditions for highly selective plasma synthesis. The conversion, selectivity, and energy efficiency of methane into value added is maximized by optimizing a.o. flow & temperature profiles, incorporating a systems approach.</p> |

| | |
|--|--|
| <p>17: NEXT GENERATION CRYPTO We want to bring quantum-secure analysis of distributed data to the next level, such that in a few years, secure data sharing solutions can be engineered, validated, and subsequently exploited, for applications that use large amounts of data, and require real-time output. This requires a ground-breaking intertwining of new secure data sharing techniques with technologies from various domains...</p> | <p>Secure data sharing should become a basic ingredient of our society to create maximal value from the large amounts of data that are fragmentally stored. We need multidisciplinary innovations to solve high-impact data sharing problems, such as remote patient monitoring and multi-fleet scheduling. In 2023 we start this research through better understanding of use case challenges, their data algorithms and possible variations thereof, and developing first scientific results.</p> |
| <p>17: Appl.AI We research AI technologies for societal problems by combining TNO's domain knowledge, multidisciplinary expertise and knowledge of AI technology.</p> | <p>We focus on integrated capability development for trustworthy adaptive AI systems for multiple purposes involving high-risks, and operating in teams in open environments. New AI capabilities are needed enabling AI systems to be 1) flexible: adaptive to a complex and changing world, 2) trustworthy: the user is in control, the system is robust and reliable, human values are respected, and the system is transparent and explainable to the user, and 3) engineered for lifetime validity.</p> |

Contribution to TNO strategic themes

TNO's Strategy 2022-2025 indicates the four strategic areas in which TNO is active: Safe & Secure Society, Healthy Society, Sustainable Society and Digital Society. Table Error! No text of specified style in document..2 illustrates how the ERP portfolio relates to these TNO strategic areas

Table Error! No text of specified style in document..2: Relation between ERPs and TNO strategic areas (TNO strategy 2022-2025)

| Early Research Project (ERP) | Safe & Secure Society | Healthy Society | Sustainable Society | Digital Society |
|---|---|-----------------|---------------------|-----------------|
| 5th year projects: Start 2019 | | | | |
| 1 | Decarbonisation (Brightsite) | | x | |
| 4th year projects: Start 2020 | | | | |
| 2 | Social XR | | | x |
| 3 | Body-Brain Interaction | x | | |
| 3rd year projects: Start 2021 | | | | |
| 4 | Climate Air Quality | x | x | |
| 5 | Circular Structures | | x | x |
| 2nd year projects: Start 2022 | | | | |
| 6 | Qutech | | | x |
| 7 | Opto-acoustics for medical imaging and structural health monitoring | x | | x |
| 8 | Digital health measurements | x | | x |
| 9 | Pandemic diagnostics | | x | |
| 10 | Subsidence and building damage | x | | x |
| 11 | Microplastics | x | x | |
| 1st year projects: Start 2023 | | | | |
| 12 | Socio-economic impact of green transitions | | x | x |
| 13 | Solar-2-Hydrogen | | x | |
| 14 | Synthetic biochemistry | x | x | |
| 15 | Sustainable recycling of batteries and solar panels | x | x | |
| 16 | Next generation Plasma synthesis | | x | |
| 17 | Next generation Crypto | x | x | x |
| 17 | Appl.AI | x | demo | x |

Strategy

Anna van Buerenplein 1
2595 DA Den Haag
www.tno.nl