TNO innovation for life

ERP Annual Plan 2025

TNO Early Research Programme

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Strategy

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ERP Annual Plan 2025

TNO Early Research Programme

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Executive Summary

- The Early Research Programmes (ERPs) are a cornerstone of TNO's early research initiatives, representing 5% of TNO's turnover. These programmes are designed to build robust technology positions and address societal challenges, thereby creating significant economic impact. The remaining 95% of TNO's activities are directed by stakeholders, including clients, 'Topsectors', ministries, and various governmental bodies.
- ERPs are strategic projects aimed at establishing knowledge and positions in emerging research and technology areas, with the goal of generating economic and social value for Dutch society. Despite the inherent unpredictability of early research, TNO focuses on mitigating risks along two main axes: scientific and technological risks, and market and societal value creation.
- In 2024, TNO introduced 'impact pathways' to guide early research projects, ensuring they plan not only scientific activities but also outcomes that reduce risks and enhance value. This will be elaborated further in 2025 together with the project teams.
- For 2025, TNO has selected six new four-year Full ERPs and will select eleven single-year Seed ERPs in November. The overall quality and relevance of proposals were high, necessitating a distinction between 'good' and 'even better'. The six selected Full ERPs are "Industrial ethylene electrosynthesis", "BioAlert innovative early warning system through biomarkers", "Future proof smart logistics", "Cyber-secure systems by Design", "Smart Chemical Industry" as well as "HiSensitive and HiSelective Optical Gas Sensing". These projects were chosen for their scientific challenges and societal relevance.
- In 2025, TNO will work on a total of 24 Full ERPs in various stages. Each Full ERP usually runs for 4 years. The ERPs are well-distributed among TNO's 6 units and cover a variety of Key Enabling Technologies (KETs) as well as Key Enabling Methodologies (KEMs).
- The ERP portfolio acts as an incubator for innovative technologies and methodologies, driving value for Dutch society and the economy. TNO's ERP teams estimate a total of 100 scientific peer-reviewed publications and 26 patent first filings in 2025.

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Introduction

TNO's Early Research Programmes

The Early Research Programmes (ERPs) constitute TNO's early research activities. Through these programmes, TNO establishes robust technological positions and collaborates with knowledge partners and stakeholders to address societal challenges and generate economic impact. The ERPs account for approximately 5% of TNO's turnover, while the remaining 95% is directed by TNO's stakeholders, including industrial and public clients, 'Topsectors', ministries and governmental bodies (via consultation and/or task financing).

ERP projects are strategic endeavours where TNO aims to develop expertise and positions for the Netherlands in emerging research and technology areas, addressing gaps and fostering economic and social value for Dutch society. Despite the iterative nature and unpredictability of early research, TNO focuses on mitigating risks along two primary axes: scientific and technological risks to establish a competitive position within international innovation ecosystems, and market and societal value to enhance the applicability and impact of new technologies and methodologies.

In 2024, TNO introduced 'impact pathways' to guide early research projects, ensuring comprehensive planning of both scientific activities and outcomes, thereby reducing risks and maximizing economic and social value.

This document outlines the ERP portfolio plans for 2025, summarising the anticipated outcomes of ongoing projects.

Figure 1.1: TNO's Early Research Programmes serve as the incubator for innovative technologies and methodologies, driving value for Dutch society and the economy.

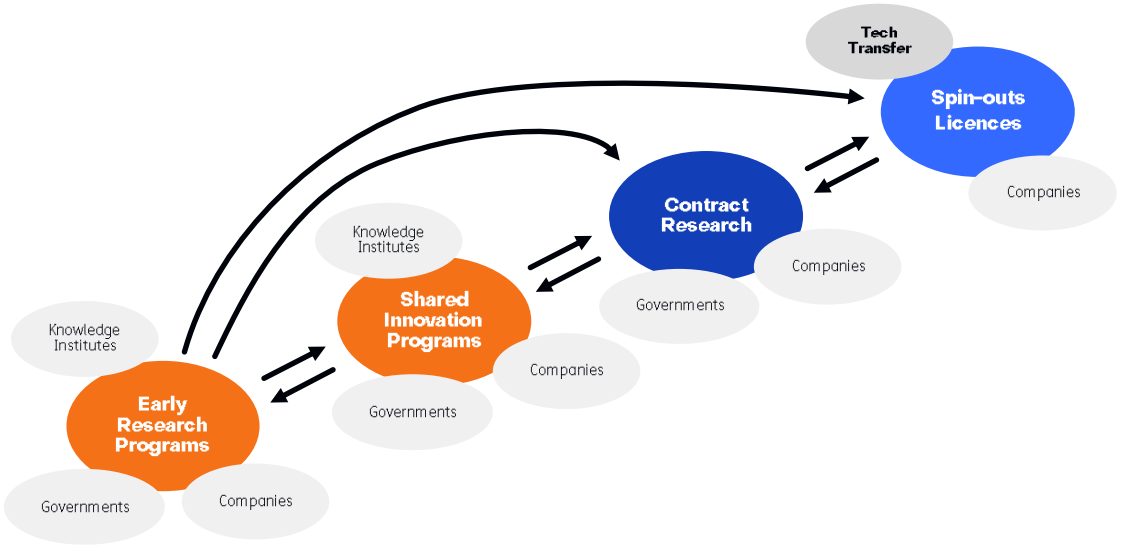


Figure 1.2: A visualisation of how TNO's Early Research Programmes contribute to valorisation.

Portfolio Characteristics

The ERP portfolio acts as an incubator for innovative technologies and methodologies, driving value for Dutch society and the economy. In this section, we present the main characteristics of the ERP portfolio management, highlighting our strategic approach and key initiatives for the upcoming years.

- ERPs strategically establish technology positions within the focus areas outlined in the TNO Strategy Plan 2022-2025. For the upcoming Seed ERPs 2025 and Full ERPs 2025, we have proactively considered the new strategic period in our decision-making process for new topics, aligning with both international and national priorities such as the National Technology Strategy and the Dialogic 'groeimarkten'.
- ERPs are driven by specific use-cases and have well-defined research objectives. ERPs contribute to multiple TNO innovation areas, often spanning various units but sharing common needs for lower-TRL technology breakthroughs. The results from the ERPs are then transitioned to higher TRL shared innovation programmes, contract research, and start-up initiatives.
- ERPs seek to amplify impact through collaboration with knowledge partners, including universities and companies, and by securing co-investments from both public and private sources.
- Full ERPs are well-funded, with each having a budget exceeding EUR 1M per year, and they typically span a duration of four years.
- Full ERPs are typically preceded by one-year Seed ERPs that assess the feasibility of the topic, validate the expected impact, and establish necessary partnerships, thereby shaping the full ERP program. From the ten Seed ERP projects in 2024, the six most promising were chosen to continue as Full ERPs for the 2025-2028 period.
- ERP funnel management is implemented to monitor progress and make necessary adjustments and resource reallocations. This process involves reviews by the TNO Science & Technology Office and the board of TNO's Science Directors.
- In collaboration with our Ministry of Economic Affairs (EZ), we keep the Topsectors and ministries informed about our ERP portfolio, aiming to engage companies and other stakeholders early in public-private cooperation.
- ERP portfolio management works towards a 'steady flow' where roughly the same amounts of ERPs conclude and commence each year. Given the Full ERP runtime of 4 years, portfolio management aims at an 'inflow/outflow rate' of approximately 25%. This approach allows TNO to

continuously and agilely respond to emerging technology trends and needs. Additionally, it encourages TNO researchers to consistently seek out impactful new research directions, knowing there is a mechanism to recognise and adopt the best ideas.

- In 2024, we selected 6 new four-year Full ERPs to commence in 2025. Additionally, a selection of 11 single-year Seed ERPs to be executed in 2025 will be finalized by the end of 2024. We consider a 50% success rate for Seed ERPs transitioning to Full ERPs as optimal, balancing quality promotion and minimising wasted proposal efforts. The overall quality and relevance of proposals were high, requiring us to differentiate between 'good' and 'even better.'
- The selected new Full ERPs are "Industrial ethylene electrosynthesis", "BioAlert innovative early warning system through biomarkers", "Future proof smart logistics", "Cyber-secure systems by Design", "Smart Chemical Industry" and "HiSensitive and HiSelective Optical Gas Sensing". All these concern domains with clear scientific challenges and high societal and economic relevance. The topics were selected out of the ten Seed ERPs of 2024.
- The Seed ERPs 2024 not promoted to Full ERP's are "Greenhouse gas recycling for semicon", "Brain Power", "Enabling safe and sustainable innovation" and "Unravelling the oxidative potential of particulate matter". It has already been decided by TNO's executive board to grant the 2024 Seed ERP "Greenhouse gas recycling for semicon" another Seed ERP phase in 2025.
- The ERP portfolio is a significant source generating new unique knowledge for TNO. The amount of peer reviewed publications and patent filings show this value of the ERPs. TNO's ERP teams estimate a total of 100 scientific peer-reviewed publications and 26 patent first filings in 2026 (see Table 1.1).

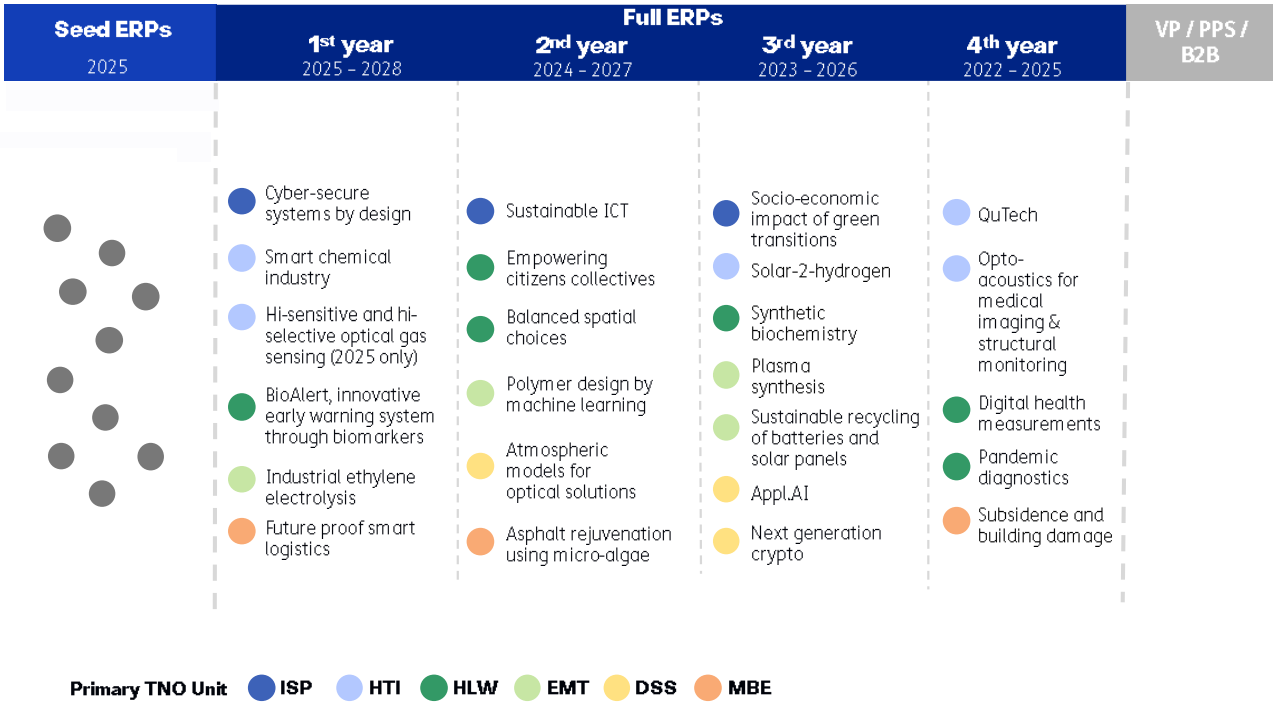


Figure 1.3: The funnel of 'Early Research Programmes' colour-coded through the TNO units: ICT, Strategy and Policy (ISP), High Tech Industry (HTI), Healthy Living and Work (HLW), Energy and Materials Transition (EMT), Defence, Safety & Security (DSS), Mobility and Built Environment.

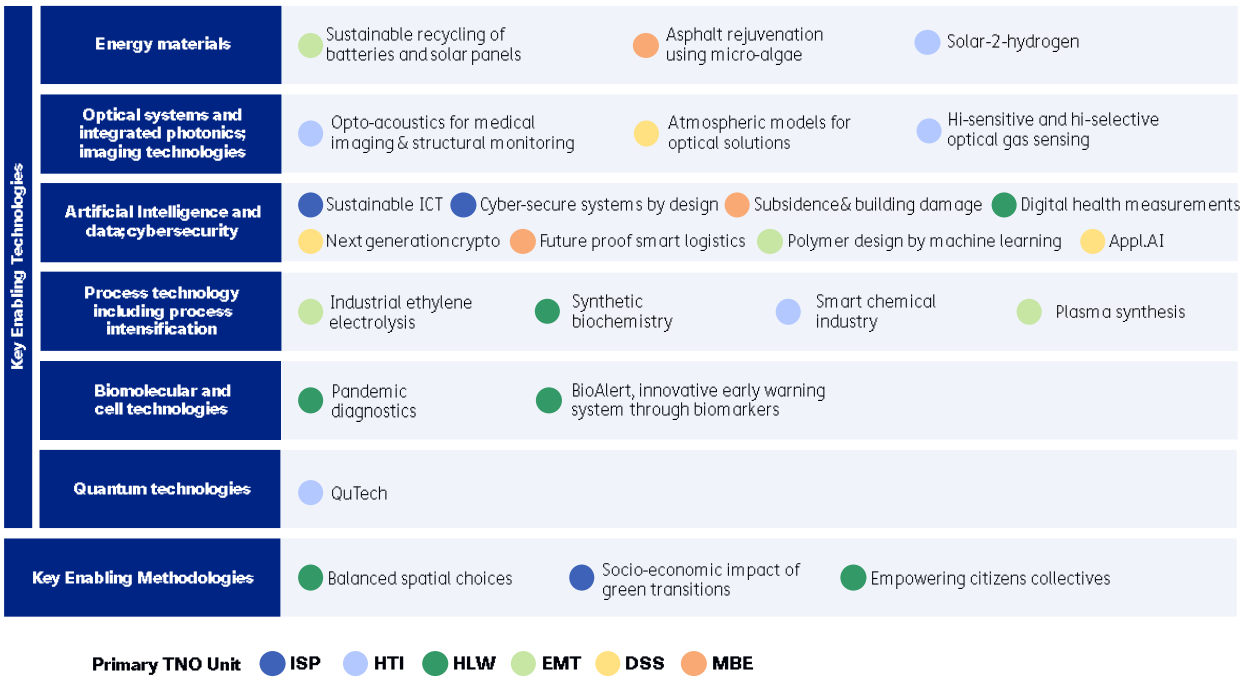


Figure 14: The 'Early Research Programmes' mapped to the key enabling technologies of the 'Nationale Technologiestrategie'. The ERPs are colour-coded by the TNO units: ICT, Strategy and Policy (ISP), High Tech Industry (HTI), Healthy Living and Work (HLW), Energy and Materials Transition (EMT), Defence, Safety & Security (DSS), Mobility and Built Environment.

Table 1.1: An overview of planned scientific peer-reviewed publications and patent first filings in 2025 per ERP. The ERP portfolio is a significant source generating new unique knowledge for TNO. The amount of peer reviewed publications and patent filings show this value of the ERPs.

Early Research Programme	Scientific peer-reviewed Publications (planned in 2025)	Patent first filings (planned in 2025)
Industrial ethylene electrosynthesis	2	1
BioAlert innovative early warning system through biomarkers	2	0
Future proof smart logistics	1	0
Cyber-secure Systems by Design	3	0
Smart Chemical Industry	1	1
HiSensitive and HiSelective optical gas sensing	2	1
Asphalt rejuvenation using micro-algae	1	1
Atmospheric models for optical solutions	2	0
Empowering citizen collectives	3	0
Polymer design by machine learning	2	1
Sustainable ICT	5	1
Appl.AI	25	0
Next-Generation Crypto	5	0
Plasma synthesis	2	2
Socio-economic impact of green transitions	6	0
Solar-2-Hydrogen	2	2
Sustainable recycling of batteries and solar panels	4	1
Synthetic Biochemistry	0	1
Digital Health Measurements	5	0
Opto-Acoustics for Medical Imaging & Structural Monitoring	2	2
Pandemic Diagnostics	2	2
QuTech	20	10
Subsidence and building damage	3	0
Total	**100**	**26**

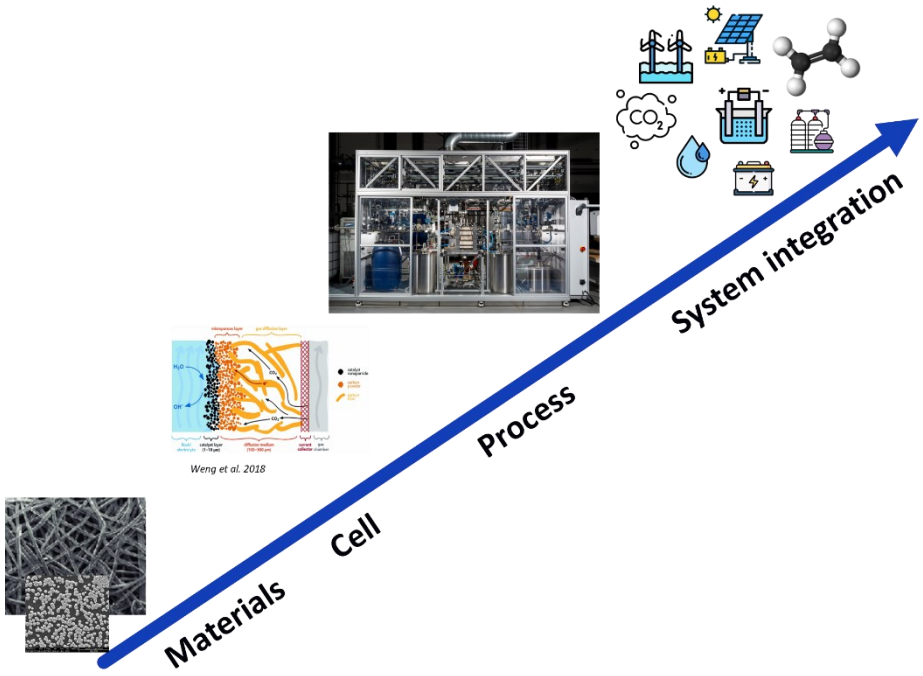
1 Industrial ethylene electrosynthesis

- **Ambition.** Advancing the development of CO2-to-ethylene conversion from material to process level, towards a first-of-a-kind plant at industrial scale. Electrochemical conversion of CO2 into valuable products is one of the key strategies to build a sustainable chemical industry.
- **Impact.** Building a sustainable chemical industry that requires new processes based on renewable source of carbon. Direct CO2-to-ethylene electrochemical conversion has the potential for becoming a game-changer for the chemical industry.
- **Simone Dussi** (Lead Scientist), **Francesc Sastre Calabuig** (Lead Scientist), **Mark Sassenburg** (Lead Scientist), **Michele Tedesco** (Project Manager), **André Faaij** (Director of Science EMT).
- 1st year in 2025. Running 2025 – 2028.

Plans 2025

In 2025, we will focus on modelling-guided electrode design and fabrication, experimental benchmarking, and stabilization of process conditions. Additionally, we will conduct initial system-level assessment for integration of CO_2-to-ethylene electrolysis plants in industrial settings.

Impact Pathway



2 BioAlert innovative early warning system through biomarkers

- **Ambition.** Creating a unique and versatile biomarker technology platform that enables identification of individuals at risk of chronic lung and liver disease, before symptoms arise. This platform features generic technology which in future can be applied for other chronic diseases.
- **Impact.** Delayed diagnoses result in enormous social and economic burden on healthcare systems. By detecting illnesses at their nascent stages, we will enable more effective and less invasive treatments and open possibilities for preventing instead of curing.
- **Lars Verschuren** (Lead Scientist), **Roeland Hanemaaijer** (Lead Scientist), **Jasper Kieboom** (Project Manager), **Paulien Bongers** (Director of Science HLW), **Christa Hooijer** (Director of Science DSS), **Helen Kardan** (Director of Science HTI).
- 1st year in 2025. Running 2025 – 2028.

Plans 2025

In 2025, we will identify novel pre-symptomatic biomarkers for both chronic lung and liver disease. In addition, we will develop suitable analysis methods and platforms, and, furthermore, expand our ecosystem to include more clinical and societal stakeholders.

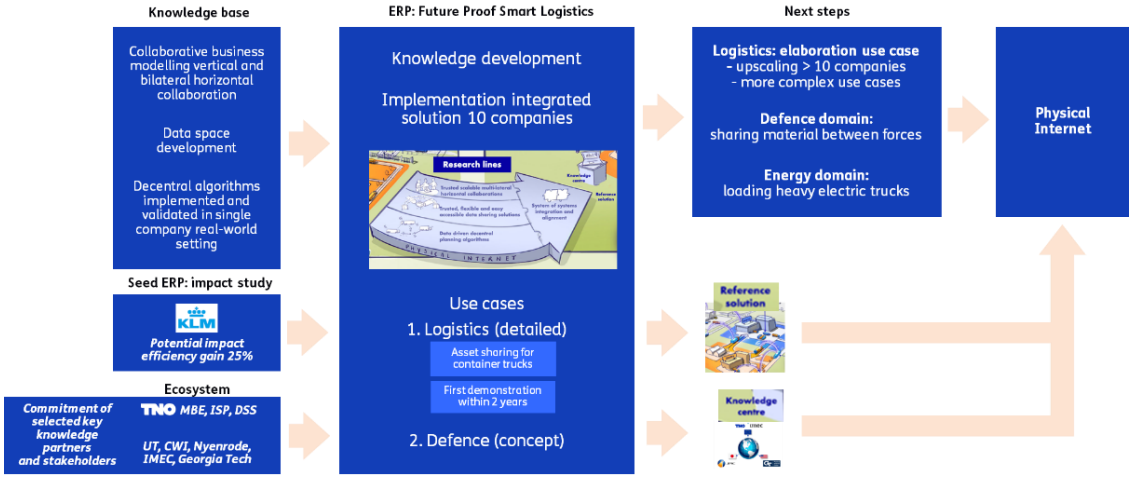
3 Future proof smart logistics

- **Ambition.** Provoking a system change in logistics for urgent improvements in efficiency, sustainability and resilience. Towards this goal, we will develop new methods and decentral algorithms for trusted scalable collaborative planning solutions for asset sharing in systems of connected logistics networks.
- **Impact.** Equipping the Dutch Logistics sector to meet sustainability targets, ensure security of supply and deal with scarcity of infrastructure and work force. This contributes to the Sustainable Development Goals SDG 13 (climate action) and SDG 9 (industry, innovation and infrastructure).
- **Jaco van Meijeren** (Lead Scientist), **Harrie Bastiaansen** (Lead Scientist), **Björn de Jong** (Project Manager), **Arjen Adriaanse** (Director of Science MBE), **Omar Niamut** (Director of Science ISP), **Christa Hooijer** (Director of Science DSS).
- 1st year in 2025. Running 2025 – 2028.

Plans 2025

In 2025, we will determine stakeholders and system requirements, develop the ecosystem, initiate the Knowledge Centre on Physical Internet, and create concepts and prototypes of methods, algorithms, and technologies. We will further elaborate the logistics and defence use cases and organise the respective collaborations with our stakeholders. Besides, the system integration and alignment will be an important result in 2025 to prepare for the first demonstration of a reference solution for the logistics use case in 2026.

Impact Pathway



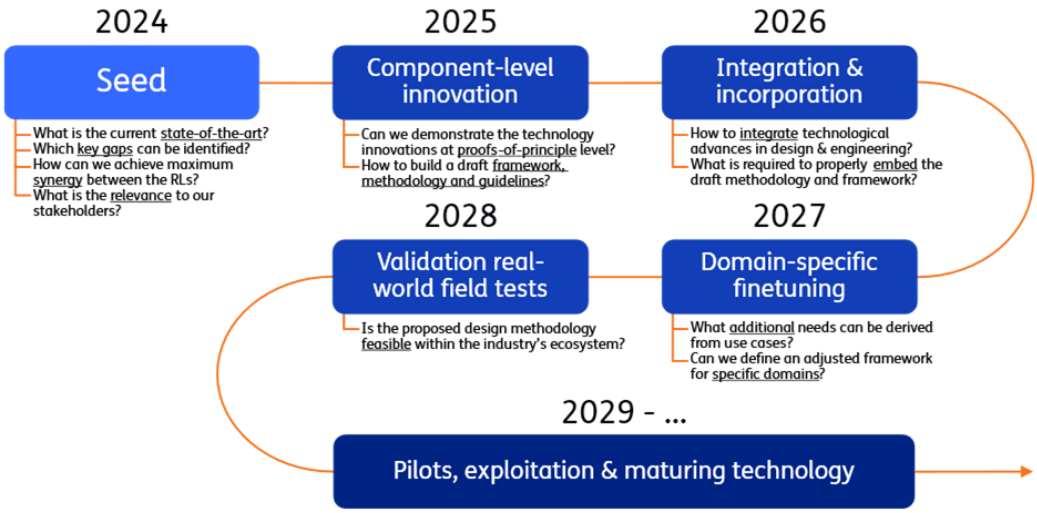
4 Cyber-secure Systems by Design

- **Ambition.** Transforming product development by integrating cybersecurity at every stage of the process, ensuring secure and reliable cyber-physical systems. Our research delivers a methodology, technology innovations and transformative guidelines that lay the foundation for this transition.
- **Impact.** Enabling the design of inherently secure systems equipped to deal with the changing threat landscape, allowing the digital transition to further advance for systems becoming more complex, dynamic and exposed through scalable approaches for cybersecurity.
- **Thomas Rooijakkers** (Lead Scientist), **Bert Jan te Paske** (Project Manager), **Omar Niamut** (Director of Science ISP), **Christa Hooijer** (Director of Science DSS), **Helen Kardan** (Director of Science HTI).
- 1st year in 2025. Running 2025 – 2028.

Plans 2025

In 2025, we will focus on drafting a methodology for cyber-secure systems by design, developing component-level technology innovations, and publishing a research agenda for realising the integral embedding of cyber-resilience in product and systems engineering.

Impact Pathway



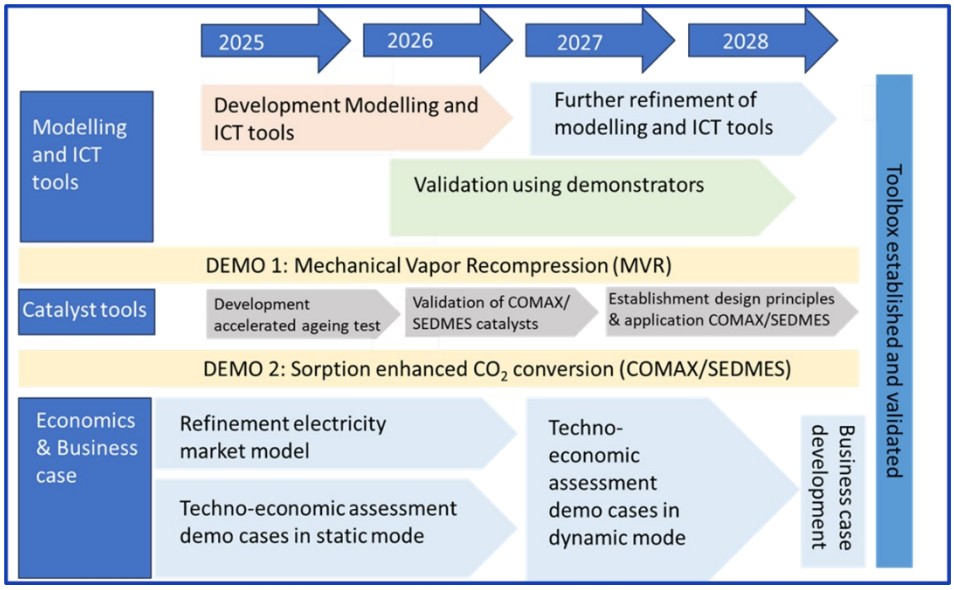
5 Smart Chemical Industry

- **Ambition.** Developing a toolbox to facilitate autonomous adaptation of chemical processes and demonstrate this for ≥ 2 e-powered processes on large lab/small pilot scale (TRL = 5).
- **Impact.** Enabling the EU's chemical industry to transition towards sustainable electricity as main energy source. Towards this goal, the chemical industry must abandon fossil fuels and embrace sustainable energy, such as sustainable electricity. Since supply and price of sustainable energy inherently fluctuate, chemical processes need to continuously adapt to ensure optimum use of energy and economic feasibility.
- **Pascal Buskens** (Lead Scientist), **Jurriaan Boon** (Lead Scientist), **Nicole Meulendijks** (Project Manager), **André Faaij** (Director of Science EMT), **Omar Niamut** (Director of Science ISP), **Helen Kardan** (Director of Science HTI).
- 1st year in 2025. Running 2025 – 2028.

Plans 2025

In 2025, we will develop a toolbox to facilitate autonomous adaptation of chemical processes and demonstrate this for ≥ 2 electricity driven chemical processes with fluctuating sustainable electricity supply on large lab/small pilot scale (TRL = 5).

Impact Pathway



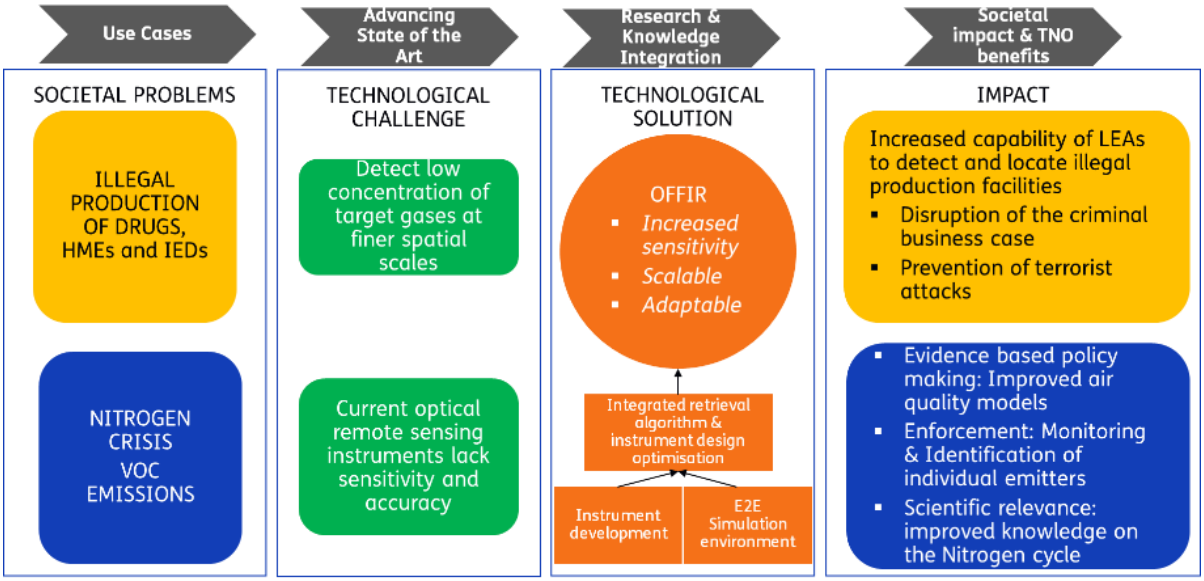
6 HiSensitive and HiSelective optical gas sensing

- **Ambition.** Developing highly sensitive and highly selective, scalable remote sensing architectures for deployment on multiple platforms based on a robust, credible, and cost-effective approach, using a comprehensive end-to-end simulation environment, resulting in a prototype.
- **Impact.** Battling the nitrogen crisis, fight climate change, and counter threats from homemade explosive labs and illegal drug manufacturing. For this, accurate detecting by remote sensing of low concentrations of ammonia (NH3), nitrous oxide (N2O) and VOCs (Volatile Organic Compounds) at high spatial resolutions is urgently needed.
- **Gerard Otter** (Lead Scientist), **Bart Waaijer** (Project Manager), **Helen Kardan** (Director of Science HTI), **Christa Hooijer** (Director of Science DSS), **André Faaij** (Director of Science EMT).
- 1st year in 2025. Running in 2025.

Plans 2025

We will refine the gas species detection requirements and ConOps for an OFFIR capability deployed within the conditions of the two use cases with input from knowledge partners to establish mission level requirements. We will also advance the maturity of the E2E scene simulation environment, conduct instrument concept trade studies and to conduct feasibility studies in both bulk optical and on-chip filter technologies. Finally, we will also focus on Project Management (PM) and Systems Engineering (SE) activities as well on-going knowledge transfer and industry partnership development to assure capability realisation after the ERP period.

Impact Pathway



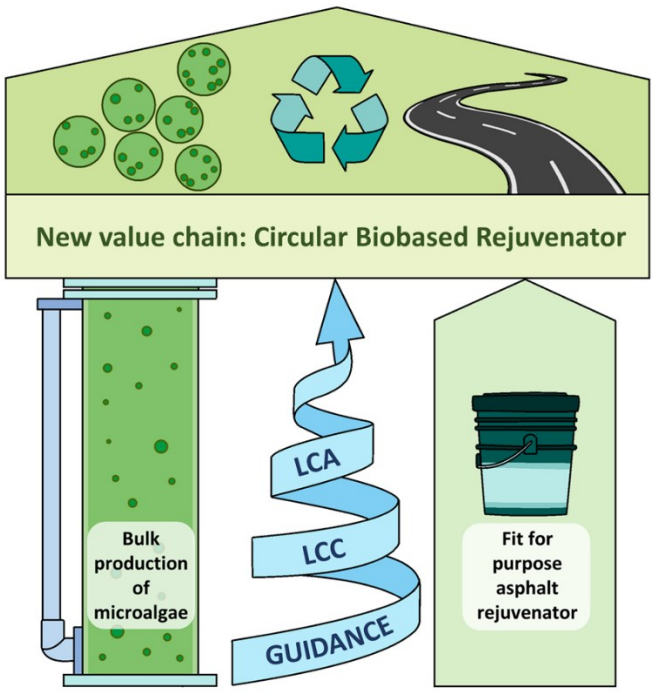
7 Asphalt rejuvenation using micro-algae

- **Ambition.** Developing a fit-for-purpose asphalt recycling agent based on wastewater grown micro-algae at an industrial scale to keep the Dutch road network operational in a new circular value chain.
- **Impact.** Enabling environmentally friendly maintenance approaches for a sustainable road network. This is essential for achieving at least 5 of the 17 Sustainable Development Goals.
- **Greet Leegwater** (Lead Scientist), **Tim Dijkmans** (Project Manager), **Arjen Adriaanse** (Director of Science MBE), **André Faaij** (Director of Science EMT).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025, we will select a suitable wastewater source and micro-algae strain and start optimizing the cultivation. We aim to select the optimal technique for extracting the rejuvenator from the biomass and get a better understanding of the asphalt rejuvenation process. We will set up the new value chain for asphalt rejuvenation using micro-algae with the stakeholders involved.

Impact Pathway



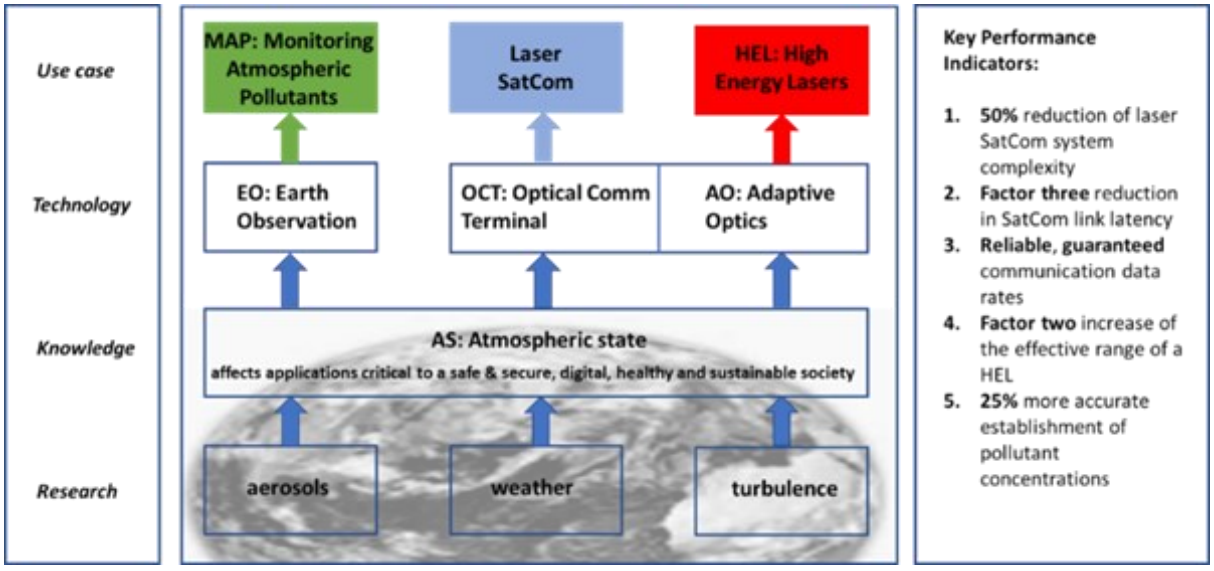
8 Atmospheric models for optical solutions

- **Ambition.** Mastering the impact of the Atmospheric State (AS) on Adaptive Optics (AO), Optical Communication Terminals (OCT) and Earth Observation (EO). This strengthens our position for Laser Satellite Communication (laser SatCom), High-Energy Lasers (HELs) and Monitoring Atmospheric Pollutants (MAP), resulting in effective communication, successful military operations and accurate monitoring of climate and pollution.
- **Impact.** Enabling the verification of the Paris Agreement through extremely accurate monitoring of climate and pollution. We enable highly reliable communication through laser SatCom, and we enable more effective military operations by mastering the performance of the high-energy laser.
- **Lex van Eijk** (Lead Scientist), **Heather Young** (Project Manager), **Christa Hooijer** (Director of Science DSS), **Helen Kardan** (Director of Science HTI), **André Faaij** (Director of Science EMT).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025, we will continue the iterative process started in 2024. Insights gained in 2024 from the application to the use cases of the improved models will further sharpen our calculations and current parameters, which will subsequently be tested again in the use cases. The focus of 2025 will remain on the modelling of the atmospheric state, and turbulence and aerosols in particular. We will explore new areas including clouds and other members of the numerical weather prediction family of models.

Impact Pathway



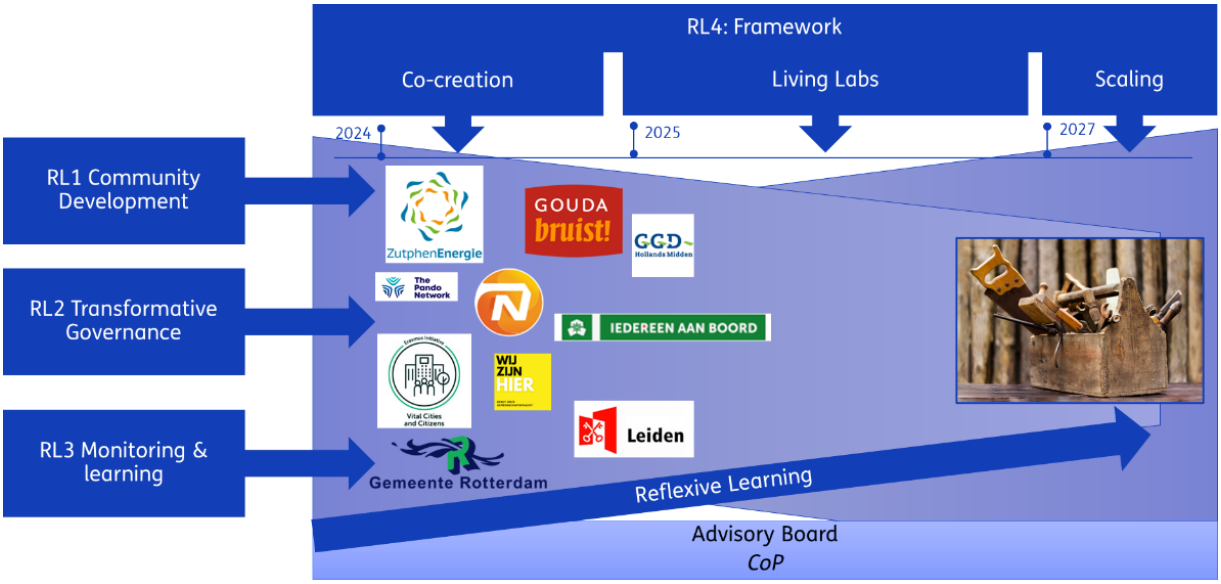
9 Empowering citizen collectives

- **Ambition.** Empowering citizen collectives by developing an evidence-based method to accelerate and scale societal transitions in neighbourhoods. This will be achieved by improving the agency of citizen collectives at neighbourhood level and engaging them in participatory policy making.
- **Impact.** Increasing trust, social cohesion and support for governmental decisions that are needed for every societal transition.
- **Wessel Kraaij** (Lead Scientist), **Pepijn van Empelen** (Lead Scientist), **Geiske Bouma** (Lead Scientist), **Ellian Lebbink** (Project Manager), **Paulien Bongers** (Director of Science HLW), **Omar Niamut** (Director of Science ISP), **André Faaij** (Director of Science EMT).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025, we will focus on the further development of tools for community engagement and governance strategies for empowering citizen collectives and apply and evaluate these tools in the living labs. Furthermore, we will implement, evaluate and improve a quantitative impact dashboard in living labs, driven by their needs. Finally, we will implement and evaluate the learning framework in living labs, reflexive monitoring of the TNO role and set up a community of practice with enabling partners. We will maintain an advisory board of relevant (private) stakeholders.

Impact Pathway



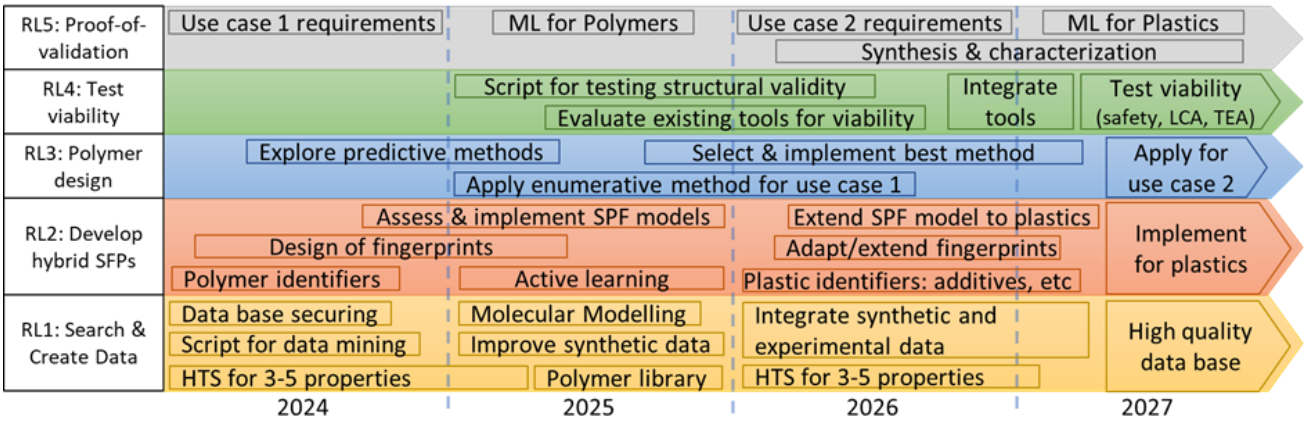
10 Polymer design by machine learning

- **Ambition.** Developing and validating a Polymer Informatics engine that realistically captures the complexity of polymers to design novel candidates that match with requirements for safe & circular plastics.
- **Impact.** Accelerating design of polymers that are needed for future-proof plastics that are safe & sustainable by design, circular, sourced from CO2 & biomass to decarbonize industry, whilst reducing systems' complexity.
- **Jan Harm Urbanus** (Lead Scientist), **Lina Rambausek** (Project Manager), **André Faaij** (Director of Science EMT), **Omar Niamut** (Director of Science ISP).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025, we will further develop machine learning algorithms, apply active learning to guide experimental and automated data acquisition and will explore novel inverse design methodologies. We will also investigate integration of modules for structural validity and sustainability in our machine learning models.

Impact Pathway



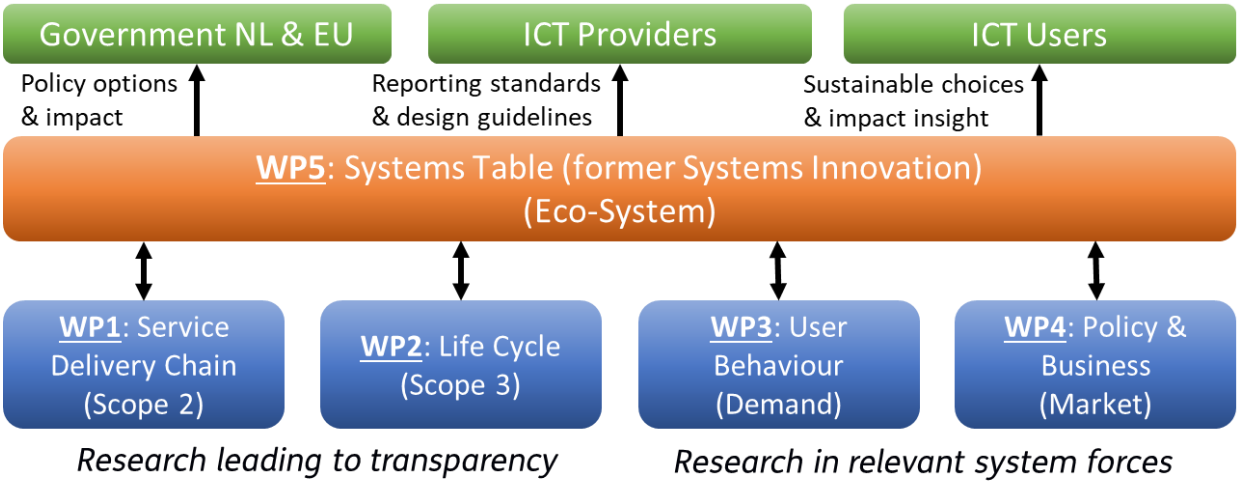
11 Sustainable ICT

- **Ambition.** Facilitating policy makers in comprehending the environmental impact of the ICT sector and enable ICT companies to react to governmental policy.
- **Impact.** Improving the sustainability of the ICT sector and limit its greenhouse gas emissions by creating action perspectives for policy makers and ICT companies.
- **Hans Stokking** (Lead Scientist), **Julie Cammell** (Project Manager), **Omar Niamut** (Director of Science ISP), **André Faaij** (Director of Science EMT), **Anne Fleur van Veenstra** (Director of Science TNO Vector).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025, we aim to achieve a first full end-to-end environmental service impact, including both electricity use and hardware impact. For change, we start creating pathways to digital sufficiency in consumer and business segments, including behavioural, policy and business aspects.

Impact Pathway



12 Balanced Spatial Choices

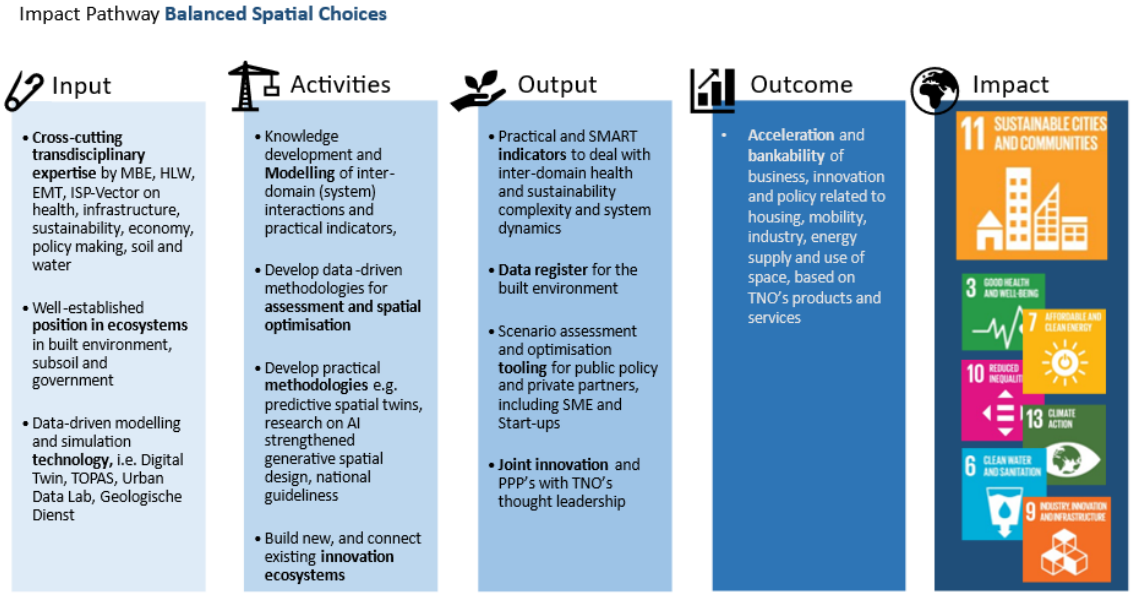
Balanced Spatial Choices is an ERP of *status aparte* as it is funded through the ERP portfolio but governed through the usual business processes in the units.

- Space is scarce. Especially in the Netherlands, while the demand for space keeps on increasing and several transitions are transforming the living environment and use of space. Social, environmental and economic needs and requirements like health, biodiversity, inclusiveness, climate change, competitiveness, safety, mobility, housing, autonomy, social cohesion and inclusion influence how we use, preserve and adapt the space around us. We need to integrate all these claims, functions and needs when making balanced spatial decisions. The leading question for the Balanced Spatial Choices program (BSC) is therefore: how can we drive, support and substantiate integrated spatial decision making, by balancing social, environmental and economic needs?
- **Heleen de Kraker** (Project Manager).
- 2nd year in 2025. Running 2024 – 2027.

Plans 2025

In 2025 we set up and implement three research lines on balanced spatial decision making for I) health & wellbeing, II) infrastructures and functions, III) soil and water. For each research line, activities include: Knowledge development and modelling (system) interactions and practical indicators; Develop data-driven methodologies for assessment and spatial optimization; Build innovation ecosystems, joint innovation and co-creation with public and private partners, and customer relations.

Impact Pathway



13 Appl.AI

- **Ambition.** Building new AI capabilities into Autonomous Systems and Federated Decision Making and to integrate AI into System Engineering and Lifecycle Management.
- **Impact.** Solving societal problems by combining our domain knowledge, multidisciplinary expertise and our knowledge of AI technology. For this, AI systems need to have capabilities that are flexible, trustworthy, and engineered for lifetime validity.
- **Cor Veenman** (Lead Scientist), **Frank Benders** (Lead Scientist), **Johan Janssen** (Project Manager), **Christa Hooijer** (Director of Science DSS), **Omar Niamut** (Director of Science ISP), **Arjen Adriaanse** (Director of Science MBE).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

The ERP Appl.AI consists of several flagships with the following plans for 2025.

SNOW. In 2025, we will focus on the robust integration of the earlier developed autonomous capabilities in stackables based on the requirements from the stakeholders (KMAR and police). We will develop the stackables such that other partners can easily expand this architecture to other robotic platforms.

FATE. In 2025, we will focus on the trade-off between fairness, confidentiality and explainability, especially when they conflict for the given showcase and user role. This will enable interactive decision making with integrated trustworthiness aspects.

AutoADAPT. In 2025, we focus on real-world demonstration of the fully integrated, self-adaptive concept. We will pay special attention on runtime implementation of a distributed control architecture based on bilateral cloud communication. For the vehicle energy management show case, a hardware in the loop (HIL) demonstration on the battery set-up is foreseen.

SEAMLESS. In 2025, we lift our fit-for-purpose modelling concept of an AI-based system towards a maturity level that is sufficient to convince industry of our approach. The fit-for-purpose modelling approach includes essential systems engineering and lifecycle capabilities to ensure trust in AI, its adaptive behaviour, and even self-adaption over the system's full lifecycle.

MMAIS. In 2025, we continue our research in the development, evaluation, regulation, and interaction with an AI system that uses a formalization of moral values and ethical and legal principles to determine its behaviour.

GRAIL. In 2025, we develop both in-depth and practical, applied knowledge about the risks and benefits of GenAI along the research lines: Critical thinking, Evaluation and Governance. We do this in close interaction with stakeholders that either participate in use cases or in relevant B2B project.

14 Next-Generation Crypto

- **Ambition.** Bringing secure analysis of distributed data to the next level (automatic validation, big data, real-time, quantum-safe).
- **Impact.** In 2028, secure data sharing solutions can be engineered, validated, and subsequently exploited, for applications that use large amounts of data, and require real-time output.
- **Thijs Veugen** (Lead Scientist), **Sjoerd-Jan Wiarda** (Project Manager), **Christa Hooijer** (Director of Science DSS), **Omar Niamut** (Director of Science ISP).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025, our focus will shift towards scalability of our solutions (eventually released open source in our PET lab), such as proof systems for AI applications, suitability for heterogeneous data, and side-channel resistance. For these new technologies suitable governance models will be studied, in relation with regulations.

Impact Pathway

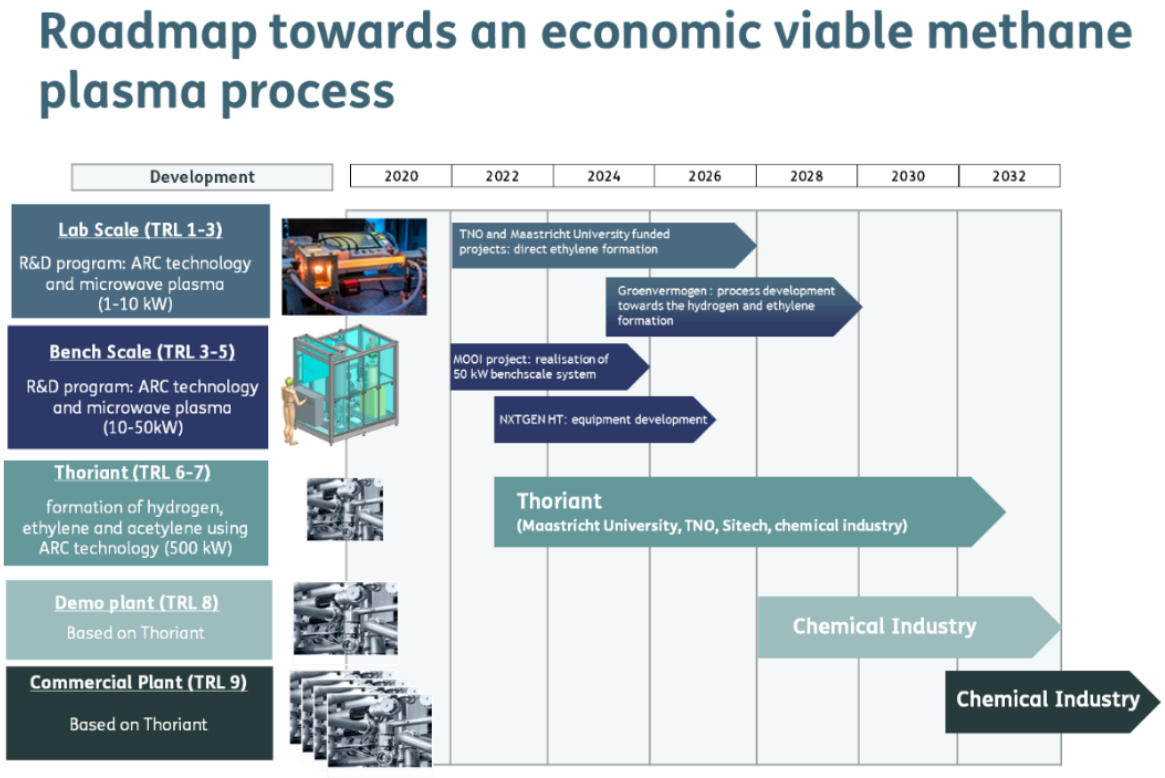
15 Plasma synthesis

- **Ambition.** Facilitating the electrification of the chemical industry by focussing on direct production of Ethylene; an important large volume, high value chemicals (HVC) for the polymer industry. Electrification of the chemical industry is crucial to reduce CO2 emissions. Plasma synthesis is employed for electrically converting methane to value added chemicals.
- **Impact.** Enabling a zero-emission Naphtha cracking process and a circular chemical industry.
- **Dirk van den Bekerom** (Lead Scientist), **Hans Linden** (Project Manager), **André Faaij** (Director of Science EMT), **Helen Kardan** (Director of Science HTI).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025 we aim to obtain better estimates of the economic viability of scaling up the process. During the first 1.5-year initial results were obtained in modelling, experiments, LCA, and TEA. Ultimately all this work is coupled, meaning that the output of one will be the input for the other. With the results obtained in the past year, we are now in pole position to start putting all the pieces of the puzzle together.

Impact Pathway



16 Socio-economic impact of green transitions

- **Ambition.** Developing a comprehensive microsimulation approach to quantitatively assess the integral impact of the energy and mobility transitions on households' economic well-being. A grand societal challenge is to implement the transition to a sustainable and green society while maintaining and redefining societal welfare ('Brede Welvaart'). We work together with CBS, CPB, PBL and academic partners.
- **Impact.** Providing decision-makers with the necessary information to design well-targeted and cost-effective policy measures to promote an inclusive green transition and create societal support.
- **Peter Mulder** (Lead Scientist), **Caroline Schipper** (Project Manager), **Anne Fleur van Veenstra** (Director of Science TNO Vector), **André Faaij** (Director of Science EMT), **Arjen Adriaanse** (Director of Science MBE).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025, we will further extend existing models, continue linking of models and perform scenario analyses based on geo-coded micro data.

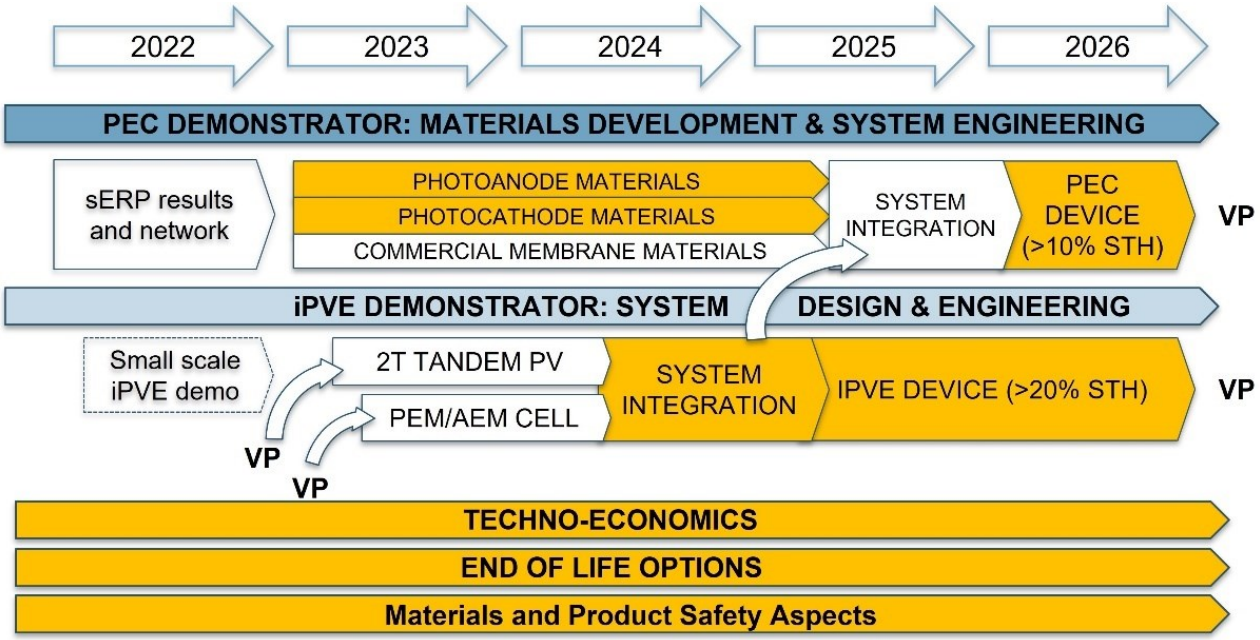
17 Solar-2-Hydrogen

- **Ambition.** Developing and demonstrating devices for water splitting that use sunlight as sustainable energy source and yield green H2 at a levelized cost of H2 (LCOH) comparable to green H2 from electrolysis.
- **Impact.** Based on commonly accepted scenarios for the energy transition in NL and EU, there will be a large demand for green hydrogen (H2) that is unlikely to be fully covered by large scale electrolysis. We will research alternative technologies with the potential to produce green H2 at similar or lower costs.
- **Pascal Buskens** (Lead Scientist), **Nicole Meulendijks** (Project Manager), **André Faaij** (Director of Science EMT), **Helen Kardan** (Director of Science HTI), **Paulien Bongers** (Director of Science HLW).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025, we aim at manufacturing an iPVE panel comprising a 2T Si-perovskite tandem and a tailored low-cost electrolyser module which meets the efficiency target set within this ERP for iPVE devices, viz. 20%. This panel will then extensively be tested in 2026 and optimized based on test results and insights from techno-economic and life cycle assessments. For PEC, we aim to boost the performance of BVO by improving its intrinsic material quality and introduction of tailored nanopores. Furthermore, we will validate the H2 production performance of a range of photocathode materials incl. protected perovskites, copper bismuth oxide, copper niobium oxide and copper iron oxide.

Impact Pathway



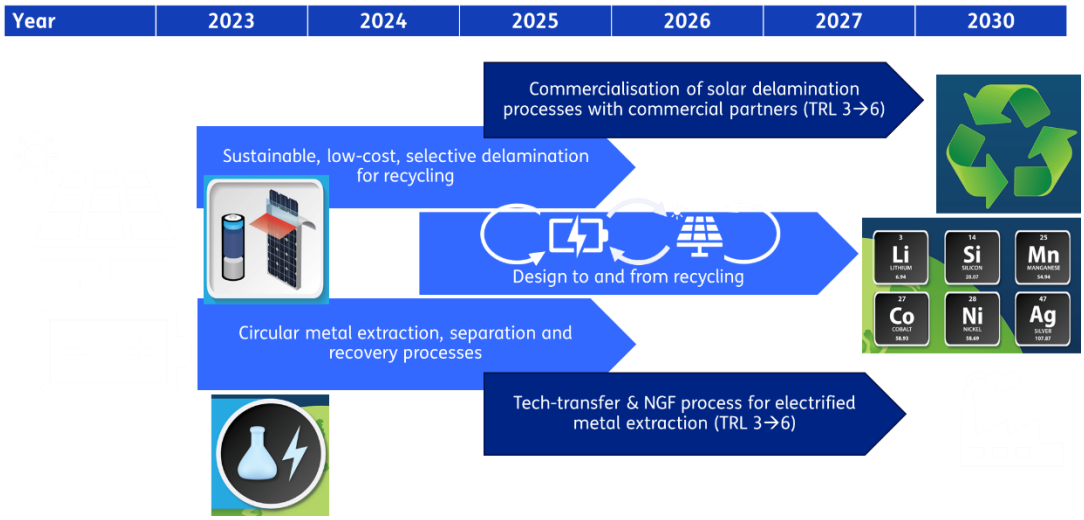
18 Sustainable recycling of batteries and solar panels

- **Ambition.** Developing new sustainable technologies to promote strategic materials independence of the Dutch industry by recycling of electronic products and their design from and to recycling. Our focus will be on batteries and PV panels as primary use cases.
- **Impact.** Closing material loops by design from and to recycling by developing sustainable technologies for recycling of batteries and solar panels within a system level approach. These sustainable technologies are of generic relevance to utilize (electronic) waste streams.
- **Mirjam Theelen** (Lead Scientist), **Devin Boom** (Lead Scientist), **Ahmed Fawzy** (Project Manager), **André Faaij** (Director of Science EMT).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025, we will further optimise the selective delamination process towards a scalable process. Sustainable metal extraction will develop the process sub-steps further and translate the existing process to the PV silver leaching. The design from and to recycling will kick-off by mainly exploring the feasibility of using the recovered materials in various applications.

Impact Pathway



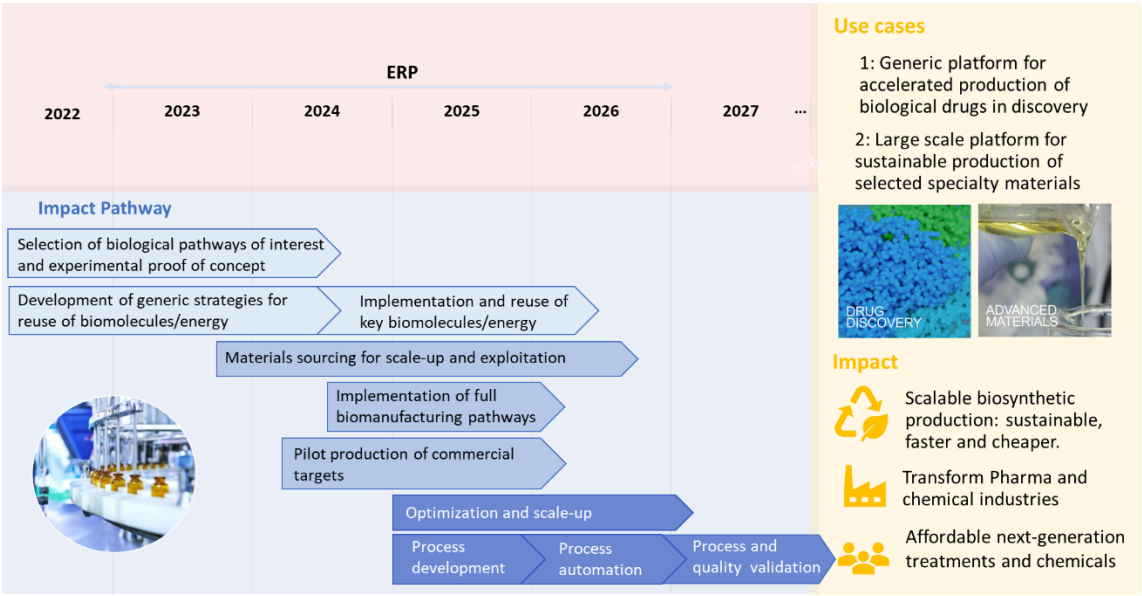
19 Synthetic Biochemistry

- **Ambition.** Developing the world's most sustainable biosynthetic version of a biomaterials and biopharmaceuticals production platform with process efficiencies >90% enabled at 10-20% of current production costs.
- **Impact.** Accelerating R&D timelines in pharma, biotech, chemical and energy carrier industries. Lowering the cost of goods while increasing technical success and achieving sustainability goals. Initiating a paradigm shift through bottom-up biological production instead of isolation of by-products from mainly waste.
- **Olaia Álvarez Bermúdez** (Lead Scientist), **Niamh Whelan** (Project Manager), **Paulien Bongers** (Director of Science HLW), **André Faaij** (Director of Science EMT).
- 3rd year in 2025. Running 2023 – 2026.

Plans 2025

In 2025, we will implement previously developed generic strategies for the scaled-up and optimized production of strategically selected therapeutic proteins/peptides and biodegradable biopolymers.

Impact Pathway



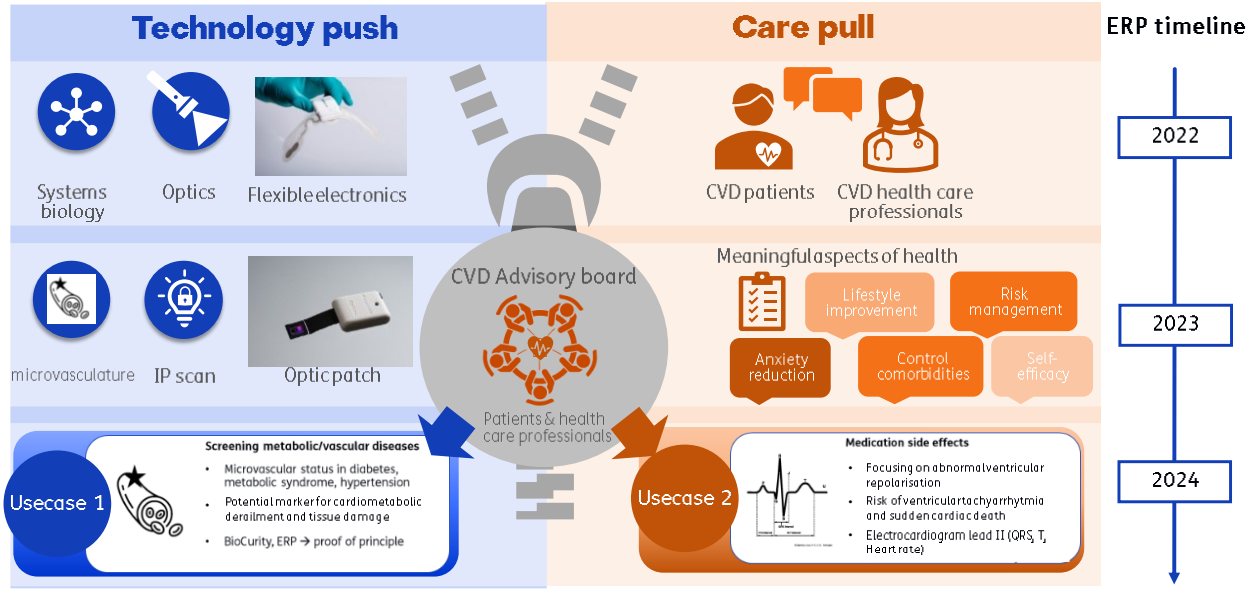
20 Digital Health Measurements

- **Ambition.** Developing tools and methodologies for meaningful, inclusive, digital health measurements, which are a cornerstone in the upcoming transitions of healthcare.
- **Impact.** The Generic Digital Health Measurement lab will facilitate seamless development of meaningful and inclusive digital health measurements with lead applications in CVD and sleep apnoea.
- **Suzan Wopereis** (Lead Scientist), **Sanne Kuijper** (Project Manager), **Paulien Bongers** (Director of Science HLW), **Helen Kardan** (Director of Science HTI).
- 4th year in 2025. Running 2022 – 2025.

Plans 2025

In 2025, we will continue the developments and clinical and analytical validation of meaningful digital health measurements for remote patient management, non-obtrusive sleep mat and wearable optics patch.

Impact Pathway



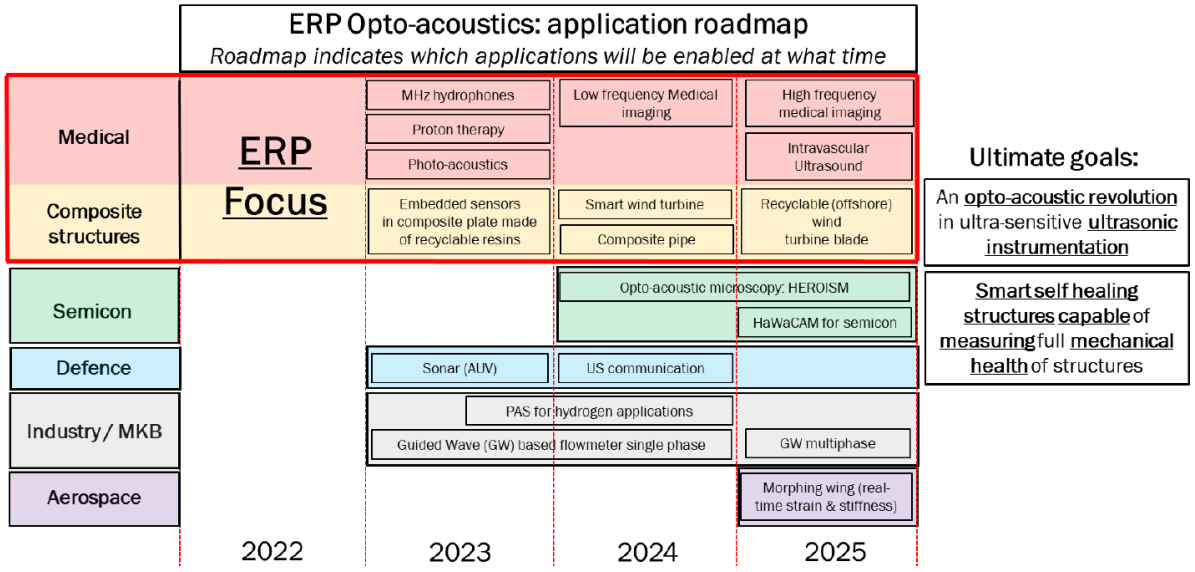
21 Opto-Acoustics for Medical Imaging & Structural Monitoring

- **Ambition.** Creating a next generation acoustic platform, using optical means only, to generate and receive acoustic waves. Such a system will radically outperform existing systems and can be miniaturized or multiplexed to cover large structural areas and long distances.
- **Impact.** Increasing patient health and well-being by providing high quality images resulting in earlier, better and specific diagnoses. Speeding-up the clean energy revolution by extending lifetime of light-weight composite structures and accelerate material developments in re-use or recycling.
- **Paul van Neer** (Lead Scientist), **Rob Jansen** (Project Manager), **Helen Kardan** (Director of Science HTI), **Christa Hooijer** (Director of Science DSS), **Paulien Bongers** (Director of Science HLW).
- 4th year in 2025. Running 2022 – 2025.

Plans 2025

In 2025, we will expand our research into material platform dependencies and manufacturability and place more emphasis on PUT transmitters. In the first two years of the ERP Opto-Acoustics we focussed on improving the efficiency of the PUT platform technologies on a component level and having a design model for both technologies, IPUT and FOPUT, to transmit and receive an acoustic wave. In 2024, the predictive model was further refined, and steps were taken towards a prototype proof-of-concept. This included investigations into material platform dependencies and manufacturability.

Impact Pathway



22 Pandemic Diagnostics

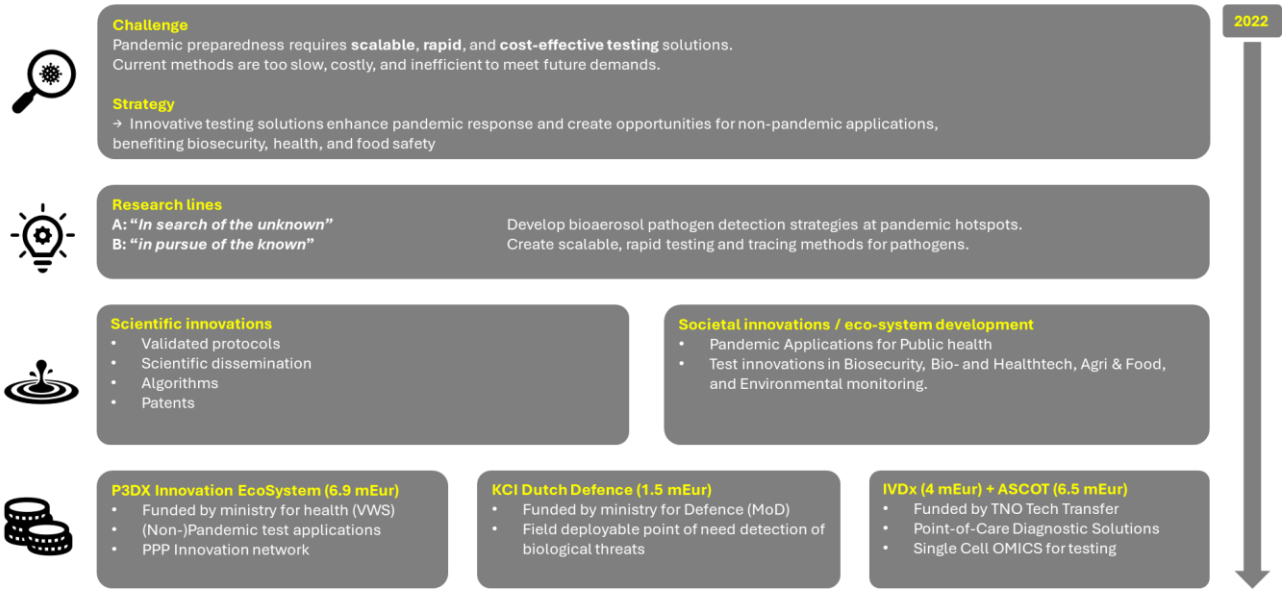
- **Ambition.** Developing a bio-surveillance system for non-targeted identification of pathogens at pandemic hotspots (e.g. airport), a platform for on-site pathogen detection for contact tracing and a pandemic diagnostic platform for population level molecular testing.
- **Impact.** Protecting our 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.
- **Bart Keijser** (Lead Scientist), **Jasper Kieboom** (Project Manager), **Paulien Bongers** (Director of Science HLW), **Christa Hooijer** (Director of Science DSS).
- 4th year in 2025. Running 2023 – 2025.

Plans 2025

In 2025, we will focus on establishing a solid IP position, establishing demo cases for diagnostic innovations and establish strategic business relations. We use synergies with related projects on test innovations for pandemic and biosafety threats.

Impact Pathway

Impact roadmap ERP Pandemic Diagnostics



23 QuTech

- **Ambition.** Building scalable prototypes and underlying technology for Quantum Internet and Quantum Computing. QuTech is a multi-year collaboration, where the TNO contribution focuses at specific parts of the entire stack, at raising TRL of specific promising technology solutions, and at the systems engineering aspects of the entire stack.
- **Impact.** Quantum technology harnesses the properties of quantum (superposition and entanglement), to achieve exponential improvements in calculation power for problems that are hard to solve using conventional computers, and by realizing inherently safe communication. Envisioned applications range from design of materials and medicines to logistics, finance and climate change models.
- **Richard Versluis** (Lead Scientist), **Kees Eijkel** (Project Manager), **Helen Kardan** (Director of Science HTI), **Christa Hooijer** (Director of Science DSS).
- 4th year in 2025. Running 2022 – 2025 (second phase).

Plans 2025

We will generally focus on extending the B2B activities in the final year of this ERP. To support this activity 3 dedicated Business Developers have been appointed. The portfolio with leads is very extensive and multiple of them have high chance of proceeding. Next to that, the main activities in ERP 2025 will be focused on European projects in which we acquired a strong position, most mentionable QLSI-2 and Arctic. We also intend to further increase our testing facilities. The testing facilities are heavily used, for internal projects as well as for external customers. The QITT facility for instance has already been booked completely for 2025, with an outstanding request for access for another full year. Furthermore, we expect that the project Qu-Test and Qu-pilot and the upcoming phase 3 of the National Growth Fund Quantum Technology and the Chips act will lead to a further interest in testing and characterization of devices.

24 Subsidence and building damage

- **Ambition.** Developing, integrating and implementing knowledge to guarantee a society where damage to the built environment caused by subsidence can be prevented or mitigated. We will build a chain of models applied to assess the causal relationship between subsidence and damage to the built environment.
- **Impact.** Reducing the huge costs for subsidence induced damage, while enabling the safe continuation of pre-existing and future subsurface activities.
- **Chris Geurts** (Lead Scientist), **Thibault Candela** (Lead Scientist), **Andreas Höllbacher** (Project Manager), **Joop Hasselman** (Project Manager), **Arjen Adriaanse** (Director of Science MBE), **André Faaij** (Director of Science EMT), **Anne Fleur van Veenstra** (Director of Science TNO Vector).
- 4th year in 2025. Running 2022 – 2025.

Plans 2025

In 2025, we focus on consolidation of existing functionality and delivering a working and tested model chain. The validation of the model chain is an important activity, where real-world data will be deployed, both from externally available data but also from a monitoring campaign in this ERP. Furthermore, we will implement a strategic market plan. At the end of 2025, at least 2 spin-off projects will be initiated.

Impact Pathway

Strategy

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