TNO innovation for life

Annual Report 2023

TNO Early Research Programs

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TNO Early Research Programs

Annual Report 2023

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Contents

Introduction

The Early Research Programs (ERPs) 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 the creation of economic impact. The ERPs represent about 5% of TNO's turnover. The remaining 95% is steered by TNO's stakeholders: clients, 'Top Sectors' and Ministries (via consultation) and Defense, EZK and SZW (via task financing).
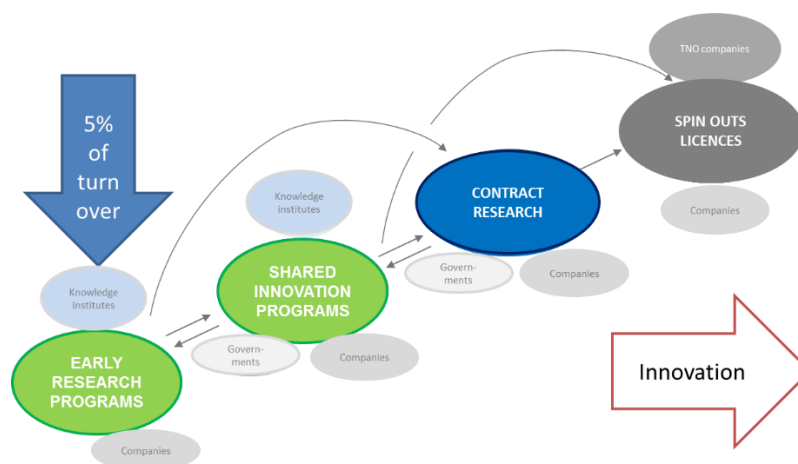

Figure I.0.1: Visualisation of how ERP's contribute to innovation

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 areas 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 M€ 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 2023, the five strongest were selected for continuation as Full ERPs in the period 2024-2027.
- ERP funnel management (involving reviews by TNO Science & Technology Office and by the board of TNO's Science Directors) is in place to select the ERP projects, monitor the progress and to adjust and reallocate resources if necessary.
- Together with our ministry of Economic Affairs (EZK) we inform the Top Sectors and Ministries of our portfolio of ERP's, aiming at early involvement of companies and other stakeholders in public-private cooperation.

An important goal of the ERP portfolio management is to bring and keep the portfolio to a 'steady state' situation in which every year a similar number (4-5) of existing ERP's ends and new ERP's can be initiated. This enables TNO to respond continuously and with agility to new emerging developments in outside world and derived technology and methodology 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. As can be seen in figure 0.1 this situation is almost reached.

The ERP portfolio management steers the ERPs on the following three criteria.

A promise	Attractive to our stakeholders	• Has sizeable impact in NL (societal / economic)
	Attractive to TNO	• Builds defendable unique position for TNO • Leads to sizeable business for TNO • Positions TNO as knowledge integrator
	Credible	• Has appropriate focus, given (typical) full ERP size • Distinghuishes from state of the art, builds upon existing TNO strengths • Has convincing approach / plan and targeted partners

For knowledge retention, we handle conform four TNO policies / procedures:
1. TNO's 'Publication policy' provides guidelines and sets targets with regard to publicizing research outcomes.
2. 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.
3. The 'PhD policy' and the 'PhD procedure' guides project teams on how to properly and effectively involve PhD's in TNO's research.
4. 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.

Summary

In this report we present the 2023 progress of TNO's Early Research Programs (ERP) portfolio. Its 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 2023' (reference TNO 2022 R11816, dated October 10th, 2022).
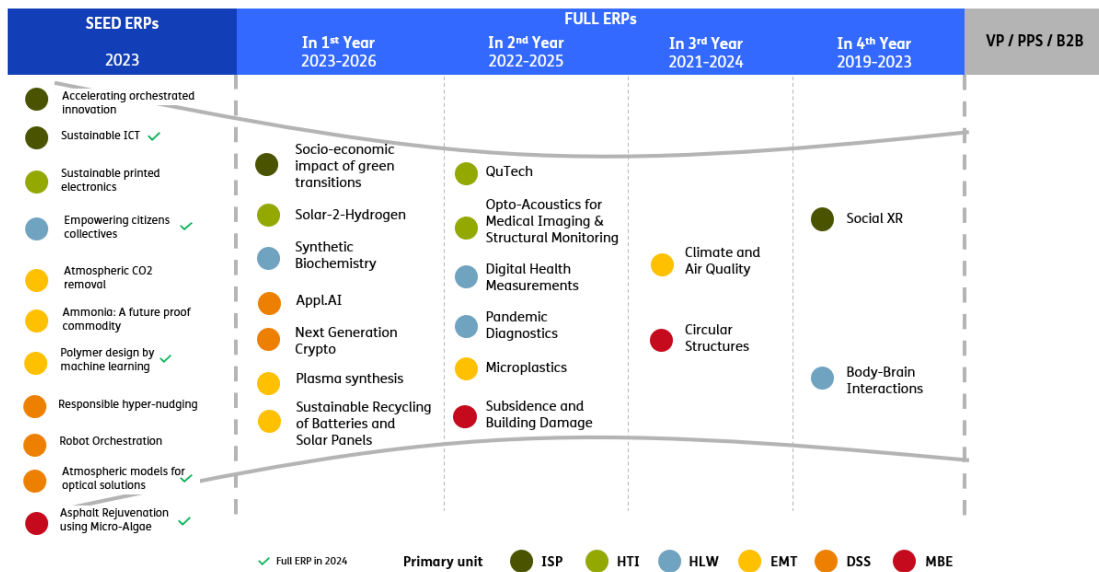

Figure 0.1: Funnel TNO Early Research Programs 2023

This report describes the progress of in total 17Full 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.

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 11 Seed ERPs running in 2023 are listed in Table 1. A 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 2023 the Seed ERP's "Asphalt rejuvenation using micro-algae", "Atmospheric models for optical solutions", "Empowering citizen collectives", "Polymer design by machine learning" and "Sustainable ICT" have been promoted to Full ERPs starting in 2024. For Seed ERP topics not promoted to Full ERP status, alternative ways to proceed are explored and regularly also found. This to show that the investment in these Seed ERPs still was valid, after all it resulted in insights of the feasibility and a quick start towards finding other possibilities for applied research on this topic.

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 140 scientific publications in peer-reviewed journals and a total of 23 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. Beside these dissemination activities we also work with external stakeholders on use cases and propositions during and after the ERP in order to develop solutions and create societal impact. A nice example on how to involve stakeholders in an early phase is by creating a red-team, as one of our second year ERP teams did last year.

In the next chapters the progress in these ERPs is described in a concise form, agreed with the ministry of Economic Affairs and Climate, including a description of the setting of the research in national and international context, highlights of results obtained, cooperation in the ecosystems that we pursue, use cases and contextual dynamics.

The ERP plans for 2024 and beyond are described in 'TNO Early Research Program Annual plan 2024' (reference TNO 2023 R11868, dated October 12th, 2023).

Table I.0.1: Overview TNO 2023 ERP portfolio and its relation to TNO strategic areas (TNO strategy 2022-2025) and to TNO units (dark blue indicates the unit leading the ERP)

Early Research Project (ERP)		Digital Society	Healthy Society	Safe & Secure Society	Sustainable Society	MBE	DSS	EMT	HLW	HTI	ISP
4th year Full ERP projects: Start 2020											
1	Body-Brain Interactions		○				○		●		
2	Social XR	○				○			○		●
3th year Full ERP projects: Start 2021											
3	Circular Structures	○			○	●		○			
4	Climate Air Quality		○		○	○		●		○	
2nd year Full ERP projects: Start 2022											
5	Digital health measurements		○						●	○	
6	Microplastics*	○						●			
7	Opto-acoustics for medical imaging and structural health monitoring	○					○		●		
8	Pandemic diagnostics		○						●		
9	Qutech	○		○						●	
10	Subsidense and building damage	○				●	○				
1st year Full ERP projects: Start 2023											
11	Appl.AI	○			○		●	○	○	○	●
12	Next generation crypto	○					●			○	○
13	Plasmasynthese	○			○			●	○		
14	Socio-economic impact of green transitions	○			○						●
15	Solar-2-Hydrogen				○			○	●		
16	Sustainable recycling of batteries and solar panels				○			●			
17	Synthetic biochemistry		○					○	●		
Seed ERP projects: 2023 – continuing as Full ERP in 2024											
18	Asphalt rejuvenation using micro-algae				○	●		○			
19	Atmospheric models for optical solutions	○					●				○
20	Empowering citizen collectives	○							●		
21	Polymer design by machine learning	○						●		○	
22	Sustainable ICT	○			○						●

Early Research Project (ERP)	Digital Society	Healthy Society	Safe & Secure Society	Sustainable Society	MBE	DSS	EMT	HLW	HTI	ISP
Seed ERP projects: 2023 – not continuing as Full ERP in 2024										
23 Ammonia: a future proof commodity				░			█		░	
24 Responsible hyper-nudging	░	░	░			█				░
25 Sustainable printed electronics	░	░		░			░		█	
26 Robot orchestration	░		░		░	█				░
27 Atmospheric CO2 removal				░			█		░	
28 Accelerating orchestrated innovation			░		░				░	█

Legenda: Icons science related KPI's used in the chapters of this report regarding the individual ERP's

The number of TNO-professors involved in this ERP in 2023

The number of PhDs involved in this ERP in 2023

The number of scientific peer reviewed publications in 2023

The number of patent first filings in 2023

1 ERP Body-Brain interactions

ERP Contacts:	Robert Kleemann, Jan van Erp (Lead Scientists)
	Jasper Kieboom (Program Lead)
	Paulien Bongers – HLW, Adelbert Bronkhorst - DSS (Science Directors)
ERP Duration:	2020 – 2023

ERP Description

We improve life-long health, performance and mental strength via mechanism-based understanding of the connections between body and brain, and develop a Brain-Body interaction technology platform.

Summary Result 2023

We have developed two complementary operational platforms to study a broad range of body-brain interactions. Our end product comprises a human platform and a preclinical platform that use the same readouts which were newly established and validated (e.g. same biomarkers, same type of functional (MRI) tests, same metabolic and inflammatory parameters). The human platform is suitable for observational mental state monitoring studies with endpoints such as cognitive performance, social stress responses, metabolism and inflammation. The preclinical model is unique and translational to humans, hence suitable for complementary studies requiring the molecular analysis of organs.

Results 2020-2023 – ERP Body-Brain interactions

Key results	Result 2020-2023

Operational preclinical BBI platform
- trained personnel, unique translational preclinical model, analytical technologies

Operational human BBI platform
    trained operators, unique mental state monitoring tool box, predictive algorithms & data science technologies.

Biomarker, biobank & non-invasive tools
- linking both platforms: by MRI, wearables, unique sensitive biomarkers and organ-specific assays
- Unique biobank for studying organ-organ interactions including cognition tests, brain readouts, plasma and microbiota.

New mechanisms
- Molecular knowledge on how organs interact via biochemical signalling molecules:): gut/microbiota <> brain, fat-tissue <> brain, muscle <> brain, liver <> brain

Uncovered new adipose tissue/liver-brain associations and first neuroimmune circuits
- Why and how chronic stress causes inflammation and (brain) disease. Anatomy of new nerve-immune cell structures.

New methodology and tool box incl.
- Demonstrators of experimental expertise; new biomarkers for metabolic and mental stress; mathematical algorithms to predict stress responses and cognitive performance; first clinical body-brain interaction trial with human tissue biobank.

Result 2020-2023:
- 3
- 8
- 27
- 1

Partnership & Dissemination	Valorisation

Partnerships
- Medical Centers: Rijnstate Hospital, Donders Institute, Radboud UMC, LUMC:, Inst. Stoke & Dementia Research
- Universities: Enschede, Nijmegen , Wageningen, Tilburg, Cardiff, Munich, Nevada, Thessaloniki, Oslo
- NATO partners

Stakeholder involvement
- Diagnostic, nutrition and pharma companies
- Government: Ministry of Defence

Dissemination
- Preclinical BBI: e.g. FASEB J 2020; Nature 2022; IJMS 2022; Front Cell Neurosc. 2023; FASEB J 2023
- Human BBI: Neurology 2022; Front. Comp Sci 2022; Sensors 2023; JAMA Network 2023

Actions taken towards valorisation

Visibility:
- presentations and conferences: >20; combined with visits of pharma & nutrition industry

Acquisition
- Business development for specific elements:
- Gut health (gut-brain, microbiota)
- Stress & performance biomarkers
- Ageing (muscle, pharma & nutrition)
- Metabolic fluxes (dynamical; tracers)

Technology
- Integrated in propositions of Healthy Living

Disease models, Functional biomarkers and Defense Research Programs **Achieved valorisation**
- PPS GloBAL (with international partners)
- Products sold: Biomarker & animal studies
- External knowledge invest.grants: LipidInflammaGenes; NWA ORC 'Heals"

2   ERP Social XR

ERP Contacts:	Sylvie Dijkstra – Soudarissanane (Lead Scientists) Maria Boen (Program Lead) Omar Niamut – ISP, Adelbert Bronkhorst – DSS, Paulien Bongers – HLW, Marieke Martens - BME (Science Directors)
ERP Duration:	2020 – 2023

ERP Description

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.

Summary Result 2023

In this final year, we further deepened and developed SXR technology to enhance the feeling of being present with each other, encompassing elements such as virtual HMD removal, XR environment capture, real-time and scalable experience, and slice adaptation for SXR applications. We designed and integrated our modules to mainly cater for the use-case class 2, eXpeRtise-at-a-distance, where we put a focus on creating robust and state-of-the-art methods for the final integration of modules in our reference platform. We published and presented our results in various high-impact journals and conferences.

Results 2020-2023 – ERP Social XR

Key results

	Result 2020-2023

Key knowledge/technologies
- **Photorealistic 3D representation** of humans and environment using NeRFs and point clouds for better social connection
- **Mediated Social Touch** through an adaptive haptic proxy for conveying emotions remotely
- **Tiled MCU** (Multipoint Control Unit)
- High-performance through **network-based media processing** and transmission
- HCI designs integrating **key factors for social presence** in XR scenarios
- **SXR ethical considerations** for a responsible design of the experience

13 demonstrators – top 5 demos:
- VR Collaboration Space for Search & Rescue (PoN, ERP & VP ICT)
- AR Virtual Visits for Elderly at Nursing homes (User Trials with UT & Meander)
- VR meetings enabled with TNO Metaverse 2.0
- Mixed Reality Assistance Space for Maintenance (ERP, PoN)
- Blended realities: You AR' in front of Me

Operational SXR platform
- Modular platform catering for participants scale and device flexibility

Result 2020-2023
- 🎓 3
- 🎖 2
- 📄 62
- 💡 0

Partnership & Dissemination

Valorisation

Knowledge partners
- Connecting multidisciplinary talents at TNO (ISP, DSS, MBE, HLW, HTI)
- Key knowledge partners: CWI, UT,TU Delft, SURF, Fraunhofer

Stakeholder involvement
- Government: MinEZ, MinJenV
- Companies: Meander, Vodafone/Ziggo, Meta, Connec2, ArboUnie, Senseglove, KPN
- Consortia: Proeftuin op de Noordzee, SMITZH, CIIIC

Dissemination
- 62 Key (Scientific) publications, conferences, presentations
- 3 Disclosures
- 3 Best paper awards
- Booklet SXR Now & Future
- YouTube channel with 8 professional videos

Valorization actions 2023
- BD involvements from Units DSS, ISP, HLW, HTI for new proposals
- Tech Transfer MetaCap
- Current focus on adjacent external knowledge investments (NGF CIIIC, MinEZ Immersive Experience Lab, Horizon calls …)

Valorisation goals 2023
Transfer via Collaboration projects (for further developments):
- Impuls, Expertise@aDistance (TNO/Fraunhofer)
- Proeftuin op de Noordzee (EFRO)
- Future of Work (Meta)
- SMITZH (IQ, MRDH)
- Virtual Visits/Elderly at Care Homes XR Communication (Connec2, Vodafone/Ziggo, Meander)
- Social XR Telemetry (SURF)
- Brains4Works – Arctic, XR Almotion, Sharecare
- XR technology for mediated communication (NATO)
- KPN ARTV and LTR Projects

3 ERP Circular structures

ERP Contacts: Angnieszka Bigaj-van Vliet, Siska Valcke (Lead Scientists)
Francesco Cinquini (Program Lead)
Arjen Adriaanse – MBE, André Faaij - EMT (Science Directors)

ERP Duration: 2021 – 2024

ERP Description

We develop knowledge and technology that enables for concrete structures a shift from traditional specification-based design strategies to new performance-based engineering design approaches driven by interaction of material quality with performance demand. ERP Circular Strcutures delivers a novel and transparent design framework for multi-objective optimization and decision support for the design of sustainable concrete structures made of Construction and Demolition Waste (CDW), in which CDW quality serves as one of the design constrains. A range of innovative circular solutions based on CDW is addressed, including reuse of reclaimed elements, use of recycled concrete aggregates and use of innovative binders based on CDW.

Summary Result 2023

Extensions are added in the multicriteria optimisation approach to account for design stages with varying levels of uncertainty and to enable optimization with computationally demanding numerical FEA models. Data-informed performance models enable precise determination of the service life and loadbearing capacity of concrete structure with reclaimed elements, allow for structural analysis of concrete with CDW-based binders and aggregates incl. time-dependent creep analysis of concrete structure with recycled aggregates. A robust approach to uncertainty assessment and model-updating in life cycle analysis (LCA) and life cycle costing (LCC) is proposed. Model extensions are implemented for evaluation of structural performance, costs, environmental impact and circularity (including material flow analysis) of (1) a CDW-based concrete floor system and (2) a bridge system incorporating reuse of reclaimed elements. An visualisation method in support of design deciosion-making is formulated and tested in use cases

Result 2023 – ERP Circular structures

⚛ Key results

Algorithmic approach to multi-objective optimization (WP1)
- Optimisation strategy for phased design strategy with stepwise increase of availability of information and uncertainty consideration
- Approach to decision making and evaluation of candidate solution at Pareto front involving transitioning from continuum solutions space to the selection of feasible (discrete) solutions
- Interactive visualisation framework for decision support

New generation parametric performance models (WP2 & WP3)
- Data-informed reliability and durability assessment for reuse of reclaimed elements
- Environmental impact and circularity assessment involving microscale hybrid model, balancing supply and demand
- Predictive models for mechanical performance and durability properties of CDW-based concrete, considering effect of CDW binder quality

Validating developments in Use Cases (WP4)
- Optimization of design with of CDW-based concrete in floor use case
- Optimization of bridge design with use of reclaimed elements in the bridge use case
- Applicability of multicriteria approach in decision making from stakeholders perspective

Result 2023

🎓 0

🏅 1

📄 3

💡 0

🤝 Partnership & Dissemination

Knowledge partners
- Research groups of: AG, BMS, CAS, DBE & SR
- University of Twente (pdEng), University of Delft (phD, MSc), Wageningen University, University of Eindhoven, H2020 (ReCreate), incl. international partners

Stakeholder involvement
- RWS
- Lagemaat, Consolis, IMdR, Planologic

Dissemination & Outreach
Peer review papers:
- Performance-based approach: Working on future-oriented standardization (Bigaj-van Vliet A et al)
- Semi-probabilistic approach reclaimed elements (Allaix D et al) *in preparation*
- Multi-phase multi-objective optimisation (Barros E et al)

Keynotes:
- Bringing circular economy principles into the mainstream design (Bigaj-van Vliet A)

Activities in commissions:
- fib SPECIAL ACTIVITY GROUP SUSTAINABLE CONCRETE STRUCTURES
- Several RILEM, fib, NEN, CROW, CB23 commissions on sustainable concrete (incl. reuse)
- NPOV - Ruim baan voor duurzaam beton

EU DG MOVE Work Group Decarbonization of transport infrastructure construction

📊 Valorisation

Valorization actions 2023
- Multi-criteria optimisation embedded in PMCs & VPs, Buildings & Infrastructures, e.g. Materials
- KIA/CE Proposal with BAM, Prorail, BTE on optimisation of new materials for demountable infra
- Collaboration with Arcadis on multi-criteria optimisation for green buildings, including MSc
- Embedding multi-criteria optimisation in NGF project initiation (e.g., NGF TBL, to be resubmitted NGF Beton Reinvented)
- Horizon EU proposal AI Build

Achieved valorisation 2023
- "Knowledge agenda for non-traditional sustainable concrete structures" (RWS B2B, delivered)
- "Safety philosophy for reuse of reclaimed elements" (RWS B2B, ongoing)
- "Monitoring geopolymer concrete in structural applications" (RWS B2B in collab with a.o. SKG-IKOB, ongoing)
- H2020 "ReCreate: development technologies for reuse of structural concrete elements" (in collab with a.o. IMdR, TU/e, international partners, ongoing)
- RVO granted PPP on CDW based concrete for precast (BTE, Enci, ongoing)
- KIA/CE Project with BAM, Prorail, BTE on optimisation of new materials for demountable infra (granted)

4 ERP Climate air quality

|	
ERP Contacts:	Martijn Schaap (Lead Scientist)
	Rianne Dröge (Program Lead)
	André Faaij – EMT, Christa Hooijer – HTI, Marieke Martens - MBE (Science Directors)
ERP Duration:	2021 – 2024

ERP Description

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.

Summary Result 2023

The development of the multi-scale atmospheric modelling system in 2023 focussed on expanding the emission models, introducing chemistry in DALES and demonstrate the new functionalities. Emission models included road transport (use of floating car data) and agriculture (cutting/mowing and manure application of grassland), which result in more accurate emission estimates and a smaller bias between measured and modelled concentrations. The implemented chemistry scheme in DALES provided more realistic estimations of the different nitrogen species and showed the important mechanisms behind nitrogen dispersion and deposition. Demonstration materials have been disseminated through websites (TOPAS) and symposia and congresses.
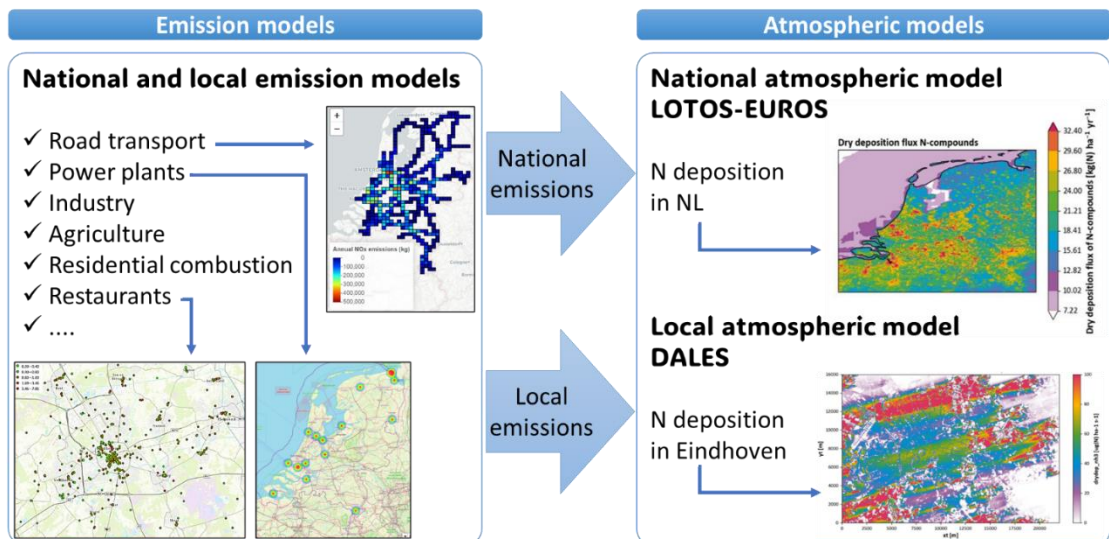
Result 2023 – ERP Climate air quality

Key results

| | **Result 2023** |

A. Emission modelling
- Fuel-CO2-NOx augmented emission maps for estimating emissions of road transport
- Dynamic Agricultural emission model using AI driven activity timer for manure application
- Fortran implementation of sectoral emission modules to allow forecasting of spatial and temporal emission variability

B. Hyperlocal modelling
- DALES version including chemistry, boundary conditions and deposition
- Chemistry: Nitric acid formation causes rising deposition with distance away from a highway
- Dry deposition process validation at Cabauw/Veenkampen sites

C. Evaluation and assimilation
- LOTOS-EUROS and OPS show the same patterns in systematic biases in NH3
- Dynamic emissions increases LOTOS-EUROS model skill for NH3, NO2, O3
- Major short coming identified for timing of emissions from grassland (manure applications)

D. Model system
- Containerisation and cloud computing results in factor 3-4 increase in speed
- TOPAS extended with CH4, observations and forecasting functionality (topas.tno.nl)

Result 2023 indicators: 1, 3, 3, 0

Partnership & Dissemination

Knowledge partners
- Units: EMT, MBE, HTI, ISP, HLW
- Emissions: BSC, FUB, FMI, RWS
- National Knowledge Program Nitrogen (NKS): RIVM, WUR, CML, KNMI
- DALES: WUR, TUD, VU, FUB
- ECCC

Stakeholder involvement
- Discussions with RIVM, OnePlanet
- Municipality of Eindhoven (a.o. via ILM network and Eindhoven Engine) & Prov. N-Brabant
- Schone Lucht jaarcongres & themagroepen
- Working visits van der Wal & parlement members

Dissemination
- 3 peer review publications published, 5 in preparation
- International conference presentations (EGU, ITM, NCGG, CAMS)
- National workshop presentations (GTL, NAC, NKS, SLA)
- TOPAS source apportionment service
- Samen meten nieuwsbrief
- TNO media campaign Air Quality in collaboration with Eindhoven Engine

Valorisation

Actions towards valorisation
- Preparation of value propositions
- Combined BD activities EMT/MBE
- Adjacent external knowledge investments (2 postdocs + 1 PhD at FUB, 2 CML PhDs in National Knowledge Program Nitrogen)
- Development & Application of ERP tooling integrated into proposals of VP CAQ and environmental sensing

Achieved valorisation
- Acquired funding 1,850 kE in e.g. National Knowledge Program Nitrogen (NKS), EU projects (e.g. RI-Urbans, AVENGERS, PAUL) and assignments (Prov Utrecht)
- Proposals worth 1,000 kE outstanding for e.g. UBA, Flevoland, Rotterdam, Ministry of Defense

5   ERP Digital health measurements

| ERP Contacts:	Suzan Wopereis (Lead Scientist)
	Sanne Kuijper (Program Lead)
	Paulien Bongers – HLW, Christa Hooijer - HTI (Science Directors)
ERP Duration:	2022 – 2025

ERP Description
We will develop tools and methodologies for meaningful, inclusive, digital health measurements, which are a cornerstone in the upcoming transitions of healthcare.

Summary Result 2023
In 2023 this ERP has continued the developments of meaningful digital health measurements for remote patient monitoring by optimising TNO's health patch, sleep mat and photonics to support the health care transition by focusing on cardiometabolic health derailments and preventive interception by research of chronobiology for sleep improvement.
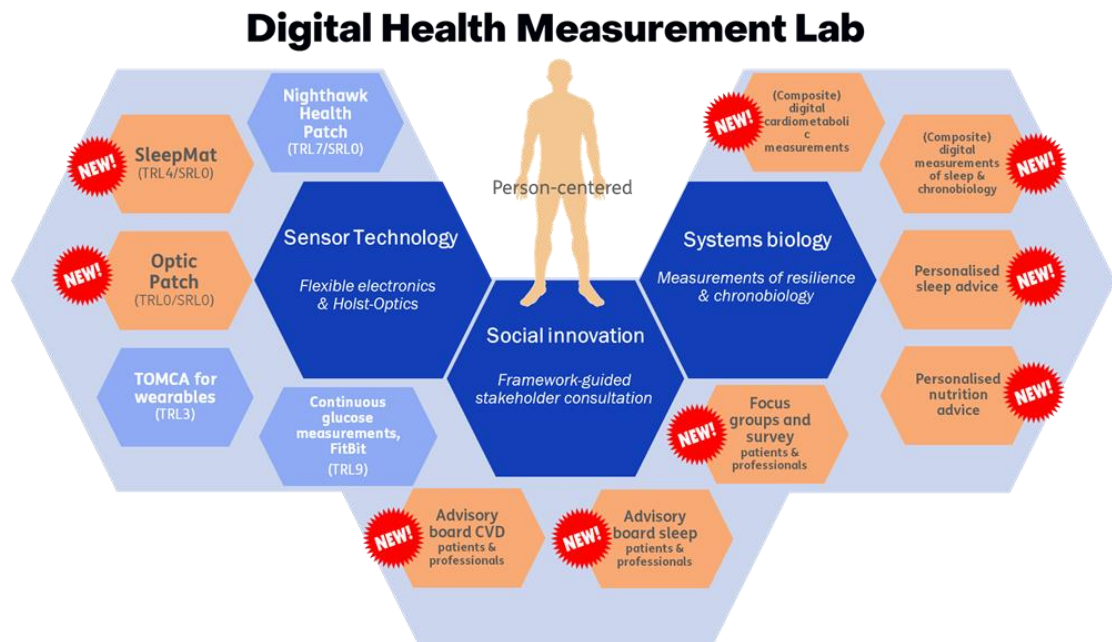
Result 2023 – ERP Digital health measurements

Key results

Result 2023

Research line A cardiovascular
- User Advisory group meeting
- Paper on validation Nighthawk health patch
- 2 use cases identified: QTc prolongation & cardiovascular resilience screening

Research line B sleep
- Bioclock study has started
- Partnership Kempenhaeghe
- Dime digital sleep standards

Research line C Digital health measurement lab
- First-generation photonic sensor developed and tested
- Non-obtrusive sleep mat developed and tested
- eCMC partner in ecosystem
- Safety and IMDD documentation for METC volunteer study submission.
- Successful initial exploratory testing of multiwavelength signal acquisition within lab settings

🎓 1

📛 3

📄 4

💡 1

Partnership & Dissemination

Knowledge partners
- TNO DSS
- ERP NextGenCrypto
- External knowledge partners
- Utwente
- LUMC

Stakeholder involvement
- Kempenhaeghe
- Sioux (AI pipeline)
- Dime society
- Harteraad

Dissemination
- ERP Determine was presented at the Holst Innovation Day
- RL-A: Paper regarding meaningful aspects of cardiometabolic health in progress
- RL-A: Paper validation Nighthawk study in progress
- RL-A: Opinion paper in progress
- RL-A: patent filing in progress
- RL-C: Opinion paper: The future of digital biomarkers: need and potential for sleep as window for measuring cardiometabolic health

Valorisation

Actions towards valorisation
- Orchestrating innovation
- Projects in preparation, such as PPS IBDigital, PPS Remote, PhotonMed (EU)
- Growth fund involvement: EdisonRPM
- Collaboration with TU Twente on eCMC
- BD involvement from both HLW & HTI

Achieved valorisation
- Projects granted incl. PPS 2DIAREM, PPS ENGAGE, Biocurity (EU), ICARE4CVD (EU)
- B2B project with Swiss Sense

6 ERP Microplastics

ERP Contacts:	Jan-Harm Urbanus (Lead Scientists)
	Alex Leighton (Program Lead)
	André Faaij (Science Director)
ERP Duration:	2022 – 2023

ERP Description

We investigate the formation and release of microplastics, and use this knowledge to develop microplastic mitigation strategies.

Summary Result 2023

This year, we investigated mitigating microplastic (MP) release through 1. polymer grade choice and 2. process, both during use and recycling of plastic. We validated that the Microplastic Index (MPI) predicts polymer grade MP formation, and that additives can improve the MPI of some polymer grades. We quantified the release of microplastics from materials in everyday use scenario's, and reduced emission of MPs to air in a full scale recycling trial by process optimization. Interviews and proposition development was a major part of this final ERP year, to secure future research into MPs.

Result 2023 – ERP Microplastics

Key results

New knowledge/technologies/methods/insights
- Demonstration that repeated recycling of PP increases both the MPI and formation of microplastics
- Demonstration that repeated recycling of PET increases formation of microplastics
- Understanding the effect of knife design on particle formation
- Development of an in-line extrusion tool to measure viscosity and FTIR spectrum during extrusion of plastics, to assess degradation and composition, related to the MPI
- Development of the simplified MPI, which uses readily available polymer properties to calculate the MPI for any polymer grade to assess tendency towards microplastic formation.
- The effect of additives in a polymer can have both a positive or negative effect on the MPI, depending on the polymer grade and concentration of additives
- Development and testing of sampling and analysis methodology, to quantify microplastic release in a plastic recycling facility
- Pre-treatment and analysis methodology for microplastics in (recycling)(waste) water

Prototypes/demonstrators/models
- Full scale (800kg) demonstration of mitigation of microplastic emission to air during recycling can be reduced by lowering speed settings on mechanical dryer

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Partnership & Dissemination

Valorisation

Knowledge partners
- National Test Centre Circular Plastics (NTCP)
- Wetsus
- Brightlands Material Center

Stakeholder involvement
- Interviews with sustainability leads of various stakeholders on their view of the Microplastics issue

Dissemination
- Scientific paper: Microplastic index – how to predict microplastic formation? Polymers 2023; 15(9):2185
- Scientific paper: Plastics in the global environment assessed through material flow analysis, degradation and environmental transportation. Science Total Environment Vol 875, 2023, 162644
- Scientific paper: Experimental Validation of the Microplastics Index – Two approaches to understanding microplastic formation. Microplastics 2023, 2(4), 350-370
- Scientific paper: Life cycle assessment of advanced grade PLA product with novel end-of-life treatment through depolymerization, Science of the Total environment, Vol 905, 2023, 167020
- Presentation in 5th annual advanced plastics recycling hybrid conference, Berlin 27-28 November 2023
- Stand at Ocean Race 2023 in Scheveningen
- Presentation at Momentum 1.0 consortium meeting 2023 on the MPI

Actions towards valorisation
- Interviews with many public and private stakeholders.
- Project proposal submitted in Growth Fund CPNL
- Project proposal submitted in JTF program
- Collaboration initiated with TU/e

Achieved valorisation
- Several new and continuing projects on the topic Microplastics, including first B2B quote
- Development of three propositions surrounding microplastics
- Market analysis of above propositions with largest microplastic-producing sectors
- Use of MPI modelling tool in projects outside ERP

7 ERP Opto-acoustics for medical imaging and health monitoring

ERP Contacts: Paul van Neer (Lead Scientist)
Rob Jansen (Program Lead)
Christa Hooijer – HTI, Adelbert Bronkhorst - DSS (Science Directors)

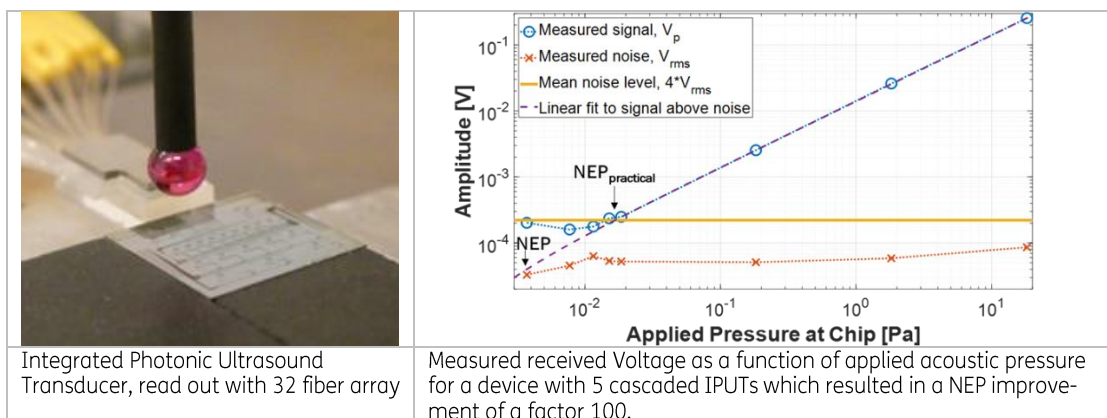ERP Duration: 2022 – 2025

ERP Description

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 systems, can be miniaturized or multiplexed to cover large structural areas and long distances.

Summary Result 2023

In 2023 we continued our strong effort in Photonic Ultrasound Transducer (PUT) modelling and design. Compared to 2022 improvements were made on the receiver and the transmitter for the two technology lines considered. One based on a photonic chip, entitled Integrated Photonic Ultrasound Transducer (IPUT) and the other using a fiber, entitled Fiber Optic Ultrasound Transducer (FOPUT).

In the 2021 SEED ERP Opto-Acoustics there was a mismatch in IPUT performance prediction accuracy of a factor 20-20x(1). In 2023 this has been improved to a mismatch of 2x lower performance than experimentally measured which was an important milestone. The improvement in modelling resulted in a Noise Equivalent Pressure (NEP) improvement of a factor 100 compared to the State-of-the-Art (SOTA) piezotransducer NEP, which is around 2 Pa in practice. In Q3 of 2022 a NEP of 0.02 Pa was measured, shown below.

| Integrated Photonic Ultrasound Transducer, read out with 32 fiber array | Measured received Voltage as a function of applied acoustic pressure for a device with 5 cascaded IPUTs which resulted in a NEP improvement of a factor 100. |

Result 2023 – ERP Opto-acoustics for medical imaging and structural health monitoring

Key results

Result 2023

New knowledge/technology/insights
- The Opto-Acoustic model is improved and partly validated on a component level for both transmitter & receiver.
- For PUT receiver effort was made to build the model chain which has been experimentally validated. This resulted in a much better understanding which enabled us to properly predict the performance for the two Photonic Ultrasound Transducer (PUT) types considered:
  - Integrated Photonic Ultrasound ransducer UT (IPUT)
  - Fiber OPtic Ultrasound Transducer (FOPUT)
- Opto-acoustic modelling is nontrivial and active topic of research in scientific community. Our IPUT receiver model improved from a factor 20-50 mismatch (2021 SEED ERP) between theory and experiments to a factor 2 difference in 2n year ERP 2023.

Prototypes/demonstrators/models
- PUT transducers designed, fabricated and measured, promising results
- Tested and evaluated novel FOPUT & IPUT transmitters/receivers arrays

Outcome
- FOPUT receiver sensitivity 100x improved
- IPUT receiver Noise Equivalent Pressure (NEP) improved with a factor 100
- Registered 10 Premier Depots patents since the start of the ERP in 2022, year 1 and in 2023, year 2.

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Partnership & Dissemination

Knowledge partners
- TNO Internal: Acoustics & Sonar, Optics, Opto-Mechatronics, Metabolic Health Research, Reliable structures & Wind Energy Systems
- University: TU Delft (NL), ErasmusMC (NL), TU Twente (NL)
- RTO: VTT (Finland)

Stakeholder involvement
- Government: RVO NL
- Companies: Ligentec (Switzerland), EIBIR (Austria), VERMON (France), Optics11 (NL), Somni (NL), Photonfirst (NL), Lionix (NL), Hobré (NL), Airborne (NL), Kaminari (NL)

Dissemination
Publications:
- PIC Summit Europe 2023: keynote
- IEEE Ultrasonics 2023: poster
- NVMU 2023: presentation
- Web page EU project Med-IPUT
Patent filings (focus):
- 7 patents filed (Premier Depot)
- 3 patents pending (registered internal or at the Vereenigde)

Valorisation

Actions towards valorisation
- The Opto-Acoustics technology is embedded within the PMC "medical" roadmap Semicon & Quantum (Unit HIT) and the PMC "Offshore Renewable Energy (ORE) within the roadmap "Maritime & Offshore (Unit MBE)
- We also team up with the roadmap Sensor Technology (Unit DSS), PMC "Smart Industry" (Unit HTI), PMC" Lifestyle-related disease models" (Unit HL&W)

Achieved valorisation
- EU project: Med-IPUT
- EU project: 14AMI
- RVO project: Globalstar Blade Monitoring
- RVO project: Green Transport Delta - Waterstof
- NGF: 'Duurzame luchtvaart – optische sensoren'
- NWA TNO - TUD: IPUT sensor & ultrasonic microbubbles for proton therapy dosimetry
- EU project proposal: PhotonMed

8   ERP Pandemic diagnostics

ERP Contacts:	Bart Keijser (Lead Scientist)
	Jasper Kieboom (Program Lead)
	Paulien Bongers – HLW, Adelbert Bronkhorst - DSS (Science Director)
ERP Duration:	2022 – 2025

ERP Description

To protect our society against the impact of future pandemic outbreaks, we aim to develop a scalable and multilevel testing strategy, optimally aligned with the needs during different phases of a pandemic outbreak. The testing strategy comprises of an untargeted, mass spectrometry based method for identfication of pandemic pathogens in bioaerosols, as well as a ultrafast targeted point of care diagnostic tool for pathogen detection.

Summary Result 2023

Work was performed along the two research lines. For Research line A, aiming to develop an early detection of novel pathogens in bioaerosols, a water-soluble filter has been developed and evaluated to capture viral bioaerosols compatible with mass spectrometric analysis. For Research line B, focusing on improved methods for pandemic pathogen detection, we have enhanced the primer design pipeline, optimized test performance, and implemented methods on a point-of-need platform. Advancements were made in sensitivity of CRISPR-Cas-based detection of bacteria with both fluorescent and lateral flow detection.

Result 2023 – ERP Pandemic diagnostics

⚛ Key results	Result 2023

- In search of the unknown
- ▪ Novel Polyvenylacetate nanospin filters were made and performance evaluated under laboratory conditions.
- ▪ External validation of MS-based viral identification in two clinical microbiology laboratories

In pursuit of the known
- ▪ Experimental LAMP dataset of synthetic primer design for machine learning input
- ▪ Evaluation of non natural primer modification LAMP
- ▪ Successful implementation of LAMP and CRISPR on microfluidic POCT platform.

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- ▪ TNO High Tech industry on nanospin filters. Systems Engineering on pandemic innovations; presentation at SE day
- ▪ Shared PhD with Wageningen University on CRISPR Cas.
- ▪ Collaboration with VU Athena institute on LAMP IP landscape

Stakeholder involvement
- ▪ Discussion with key stakeholders on pandemic preparedness and testing and alignment of ERP programme, including VWS and RIVM/LFI as well as other private and public organisations.
- ▪ Companies contacted on rapid diagnostics and potential for pandemics. Discussion strategic collaboration on microfluidic test platform technology.

Dissemination
- ▪ Patent on CRISPR – POISER technology approved
- ▪ Patent on Legionella LAMP target filed
- ▪ Presentations (and price for best oral presentation) at KEMRI KASH conference, Medical Biodefense Conference (MBDC) Munich and European Congress on Tropical Medicine and International Health
- ▪ Organisation of first Dutch CRISPR/Cas expert day
- ▪ Publication in Journal of Clinical Virology Plus

Actions towards valorisation
- ▪ BD active in DSS domain. New vacancy for HL BD on Diagnostics

Achieved valorisation
- ▪ VWS agreed on multistakeholder innovation programme on pandemic diagnostics, coordinated by TNO (P3IVDx)
- ▪ VWS agreed on post COVID-19 programme, also including modelling diagnostic efforts.
- ▪ MOD approved short cyclic innovation programme on rapid CRISPR diagnostics
- ▪ HL investment in 4 year IVD programme on POCT
- ▪ Ongoing discussion on transfer of MS pathogen identification to clinical laboratory.

9 ERP Qutech

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ERP Contacts:	Richard Versluis (Lead Scientist)
	Kees Eijkel (Program Lead)
	Christa Hooijer – HTI, Adelbert Bronkhorst - DSS (Science Directors)
ERP Duration:	2022 – 2025 (2nd period)

ERP Description
We exploit quantum effects in customized systems, materials and concepts, such as quantum computing and communication to pave the way for a quantum revolution.

Summary Result 2023
In 2023, we continued to create progress in building options for scalable technology for quantum computing and quantum internet, in lifting the most promising technologies to higher TRL and in integrating them in fullstack systems. A few examples are: notable successes in creating Kitaev chains and Fluxonium designs, the realization and integration of a 6-qubit silicon spin-qubit device in the Quantum Inspire demonstrator, and the proof-of-principle demonstration of entanglement-based quantum internet between Delft and The Hague over commercial fiber.
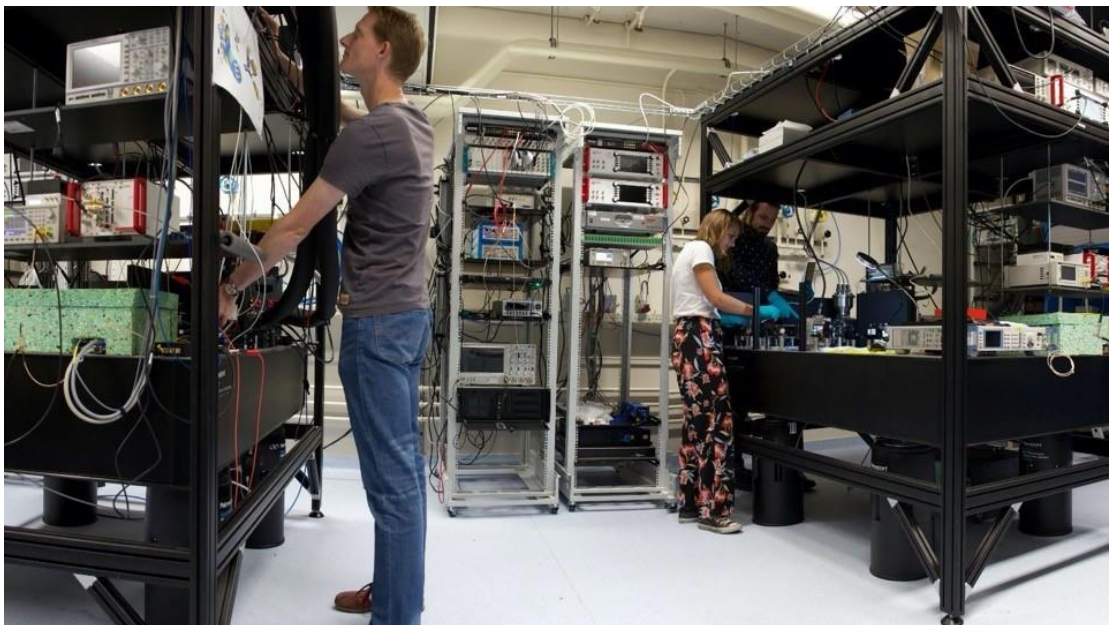
Result 2023 – ERP Qutech

Key results	Result 2023

Qubit research
- Develop state of the art fluxonium Qubit
- Develop Kitaev chain

Quantum computing
- Reproducible fabrication of 6 spin-qubit quantum processor
- Prototype fabrication of Traveling Wave Parametric Amplifiers (TWPA).

Quantum internet
- Successful demonstration of single click entanglement distribution between Delft and The Hague
- Engineering roadmap made

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Partnership & Dissemination	Valorisation

Knowledge partners
- TNO internal
- Fraunhofer ILT
- SURF
- QuantWare
- Many others

Stakeholder involvement
- Government: EZK, OCW, Defensie, TKI, EU
- Fujitsu, Intel, Eurofiber,

Dissemination
- Yearly >70 papers together with TUD, leads to #1 or #2 global ranking
- 20 filings together with TUD
- Present at many events, talks, presentations
- Various awards

Actions towards valorisation
- TNO starts B2B program next to QuTech in close collaboration
- QuTech and TNO prepare for Chips Act Quantum proposal
- QuTech and TNO prepare for TKI Strategic Program
- NWO is partner in QuTech
- MinDef ramps up investment
- NGF is strong investor in Quantum

Achieved valorisation
- Position in 5 out of 7 EU FPA's
- Fujitsu starts R&D lab in Delft and grows current project by 30%
- Launch of Q*Bird
- Start of HectoQubit project with local ecosystem partners
- License agreement with Q*Bird

10 ERP Subsidence and building damage

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ERP Contacts:	Chris Geurst, Thibaut Candela (Lead Scientists)
	Andreas Höllbacher, Joop Hasselman (Program Leads)
	Arjen Adriaanse – MBE, André Faaij – EMT, Anne Fleur van Veenstra - ISP (Science Directors)
ERP Duration:	2022 – 2025

ERP Description

We aim at the reduction of huge costs for subsidence induced damage, while enabling the safe continuation of pre-existing and future subsurface activities, by building a chain of models applied to assess the causal relationship between subsidence and damage to the built environment.

Summary Result 2023

In 2023 the V0 Python-based model chain has been further developed towards version V1. This version V1 includes novel insights in the downscaling and disentangling, the soil-structure interaction and the fragility functions as well as the calibration with observations. This V1 provides probabilistic subsidence induced damages to housing for one source of subsidence (groundwater changes) and one building type (masonry houses with shallow foundations). Further highlights are the development of a novel interface to couple subsidence predictions with soil-structure interaction, the first (TNO) in-house processing of INSAR raw data, and a successful stakeholder event held at the Knowledge Centre for Land Subsidence in Gouda.
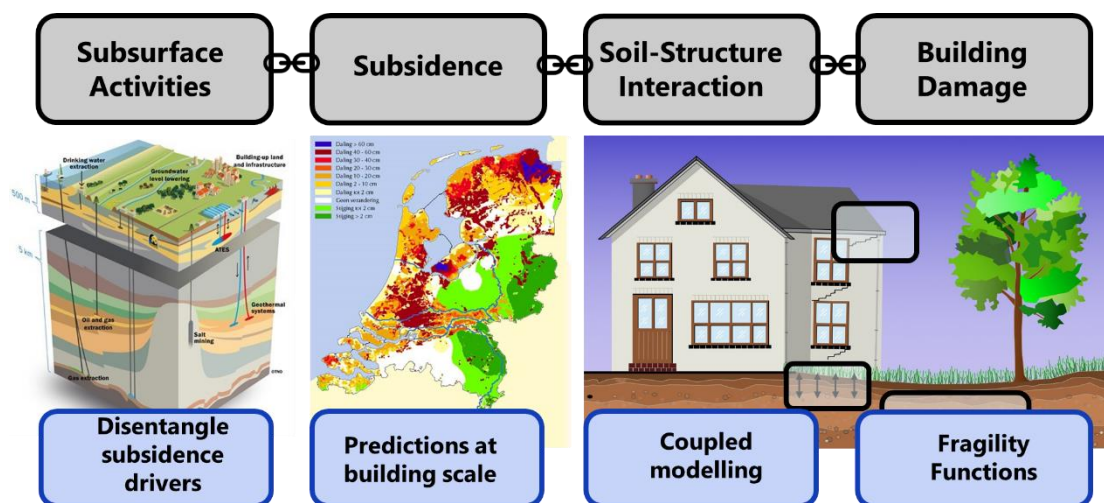
Result 2023 – ERP Subsidence and building damage

⚛ Key results	Result 2023

Results
- V1 version of Model chain ready and running, for one subsidence source and one building type
- Downscaling procedure subsidence to building scale ready and implemented
- A fast and novel approach for soil-structure interaction developed and ready for use
- Modelling procedure for fragility functions ready
- First validation of post-processing InSAR and extensometer deployment
- ERP Use Case selected as result of external stakeholder day
- Establishment and first meetings with our Red Team, to discuss and challenge our methods and results
- First outline of a Strategic Market Plan drafted

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- PhD projects with Universities of Utrecht, Padova and Delft
- Red Team input from University of Alicante and ETH-Zürich

Stakeholder involvement
- 16 (semi-)public entities, 11 knowledge partners, 6 engineering entities, 5 Geodata entities and 2 interest groups

Dissemination
- Tenth International Symposium on Land Subsidence (TISOLS), Delft: 3 oral and 1 poster presentation
- International Science and Subsidence Day, Leading 2 workshops, Gouda
- External stakeholder day with 50 attendees

Actions towards valorisation
- Strategic Market Plan defined
- BD team extension and onboarding
- Choice of ERP target area
- Network activities at KBF, Platform Slappe Bodem, Coalitie Stevige Steden, NWO NWA Living on Soft Soil, NWO call on effects of drought

Leads
- Fugro, AvecodeBondt: Valorize datasets
- IMG/EZK, damage by deep and shallow subsidence
- SENSAR, InSAR analysis at building scale (NDA signed)
- DDO, ERP-model chain part of the GDN portal

Achieved valorisation
- Information Sessions 'gas fields and damage'; invited by EZK for citizens, NAM, CM, and SodM (Drenthe, Groningen, Friesland)

11 ERP Appl.AI

TNO has concentrated its AI efforts in an integrated program, called Appl.AI. TNO's ambition is to build on an already strong position and accelerate AI innovation through focus on integrational aspects of AI for complex task where safety and strict governance are at stake. Within Appl.AI, a research-oriented focus on generic technology and methodology development (the flagships) is combined with demonstration and development within use cases of our customers.

11.1 Flagship – SNOW

ERP Contacts: Judith Dijk (Lead Scientist)
Willeke van Vught (Program Lead)
Adelbert Bronkhorst (Science Directors)

ERP Duration: 2023 – 2026

ERP Description
The overall goal of the SNOW flagship is to develop, integrate, demonstrate, and evaluate AI capabilities for a self-aware autonomous system that can operate safely and effectively in an open world.

Summary Result 2023
The AI capabilities studied in 2023 are to enable the robot to recognize both affordances of objects and their causal effects when interacting with these objects (physically) in order to fulfil a mission objective given operational rules set by its team members. This will allow the robot to perform physical manipulations in the environment and manipulate the objects when necessary for the mission and allowed by the operational rules. The results of SNOW include 1) methods and an implemented pipeline for knowledge driven affordance detection, 2) a methodology for using operational rules and 3) an implemented pipeline for combining tactical and active inference planning. Furthermore we developed a stand-alone demonstration of an industrial inspection with a robot with AI capabilities such as task delegation, tactical planning, causal reasoning on system capabilities and goal-directed perception. This work resulted in seven scientific publications, a master thesis, two internal reports, development of the required technology, two evaluation studies, three demonstrators and multiple demonstrations at events.

Example of an autonomous system, the SPOT robot from Boston Dynamics. At this demonstration, the behaviour was coordinated by an operator (left person in the image). The goal of the SNOW flagship is to develop capabilities for such robots so that they are able to perform tasks autonomously in the open world.

Result 2023 – ERP Appl.AI: Flagship SNOW

⚛ Key results

Result 2023

Results
- Methods for Knowledge driven affordance detection
- Pipeline for affordance detection
- Combining tactical and active inference planning
- Methodology for using operational rules
- Definition of use case: search and rescue
- Integrated roof demo
- Stand-alone results from 2022 in an integrated demo
- Integrated demo "How to open a door"
- Seven scientific papers

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🤝 Partnership & Dissemination

Knowledge partners
- NWO proposal OpenBots with UvA, TUDelft and KMAR approved
- Fraunhofer IOSB
- Applied Physics Lab
- Boston Dynamics
- NASA JPL

Stakeholder involvement (use cases)
- Fusing Plans - Defence
- RATIO - Defence
- PredictAI - Defence
- SENS - Hortivation
- FUSESS - Brainport Eindhoven
- AI for network orchestration - KPN

Dissemination
- Paper "improved Zero-Shot Object Localization using Contextualized Prompts and Objects in Context" ICRA2023
- Paper on "Information Gathering in POMDPs using Active Inference", in writing
- Paper "Open-World Visual Reasoning by a Neuro-Symbolic Program of Zero-Shot Symbols", submitted to IJCLR
- Paper "Extending reward-based hierarchical task network planning to partially observable environments", submitted to ICARA 2024
- Paper "Language-Based Augmentation to Address Shortcut Learning in Object-Goal Navigation", IEEE IRC 2023
- Paper "Lightweight Uncertainty Quantification with Simplex Semantic Segmentation for Terrain Traversability.", submitted to ICRA 2024
- Paper "Open-World Visual Reasoning by a Neuro-Symbolic Program of Zero-Shot Symbols", submitted to ICPRAI 2024
- Paper "Affordance Perception by a Knowledge-guided Vision-Language Model with Efficient Error Correction", submitted to ICPRAI 2024

📊 Valorisation

Actions towards valorisation
- Moonshot
- Product catalogue
- BD involvement, adoption by VPs
- Adjacent external knowledge investments: NWO
- Presentations @ relevant networking events: Vision, Robotics & Motion

Demonstrations
- ReAIM
- AI parade
- ICRA 2023
- ICT Open
- Rescue Zeeland
- Innovation festival Rijkswaterstaat
- Vereniging van Nederlandse Gemeenten
- World Summit AI
- Demo Automotive Week on AI for situational awareness (a.o. FUSESS)

Achieved valorisation
- VP VM Robotica
- Brains4work
- Sitech project (spot-it)
- Valorisation via other projects

11.2 Flagship – FATE

| ERP Contacts: | Cor Veenman (Lead Scientist) |
	Milena Kooij-Janic, Lizette Maljaars (Program Leads)
	Omar Niamut (Science Directors)
ERP Duration:	2023 – 2026

ERP Description

The FATE Flagship project is a research project to integrate capabilities for an adaptive decision support system prepared for the requirements for a trustworthy AI system, being robust, transparent/explainable, privacy respecting, and able to adapt to fairness constraints and other norms of the respective norms of the application. For demonstration we use prediction of Diabetes Type 2.

Summary Result 2023

In 2023, FATE focussed on the synergies between fairness, explainability, confidentiality and adaptivity in the context of healthcare. We investigated fairness of counterfactual explanations, and we obtained insights in and created an overview of privacy threats pertaining to privacy and several explainability methods. For adaptivity, we worked on three different aspects: adding new knowledge, evaluating the consistency of knowledge, and combining different types of data, models, and input. Finally, we created an interactive story which explains and demonstrates the working of the FATE components.
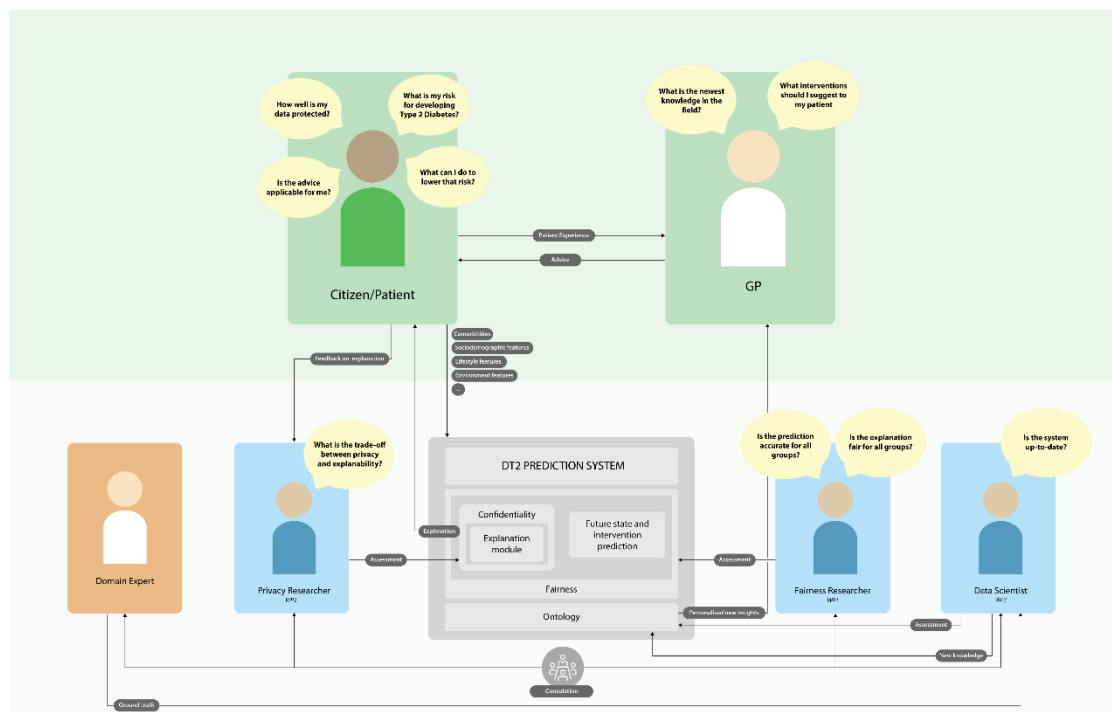
Result 2023 – ERP Appl.AI: Flagship FATE

Key results

Integrating Fairness and Explainability
- Minimum Viable Product to answer the question: To what extent do state of the art explainable AI methods result in explanations that vary in quality for different patient groups?

Integrating Explainability and Confidentiality
- Insights in 1) what sensitive information can be leaked from explainable AI, 2) vulnerability of explainable AI to privacy attacks and 3) the Quantification of Privacy

Adaptivity
- Adapting a medical / diabetes decision support system to new knowledge in an interactive and continuous manner and adapt the current system and model based on detected changes in knowledge.

Interactive demonstrator highlighting the FATE Diabetes type 2 system aiming at
- Prediction of Diabetes type 2 development and the effect of interventions
- Machine Learning model combined with adaptive knowledge model
- Holistic approach, based on the needs and values of multiple types of users.

Result 2023

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Partnership & Dissemination

Knowledge partners
- TNO internal
- Collaboration with HI zwaartekracht programma
- Radboud University (PersOn)
- Utrecht University (ICAI AI4Oversight)
- Leiden University (ICAI AI4Oversight)

- *Opening ICAI Lab AI4Oversight 19/10/23*

Stakeholder involvement
- AI Oversight: OM, IND
- AI for Industry 5.0: EU
- Alliance Fin Crime: Banks
- Cyber Security: Tax Authority
- Judicial Anticipation: MinJ&V, OM, DJI
- TAIRS: BZK

Dissemination
Publications (a.o.)
- PERFEX: Classifier Performance Explanations for Trustworthy AI Systems (AAAI Workshop)
- ECAI/RAAIT workshop
- Most publications are planned at the end of the year
Presentations
- at a.o. Appl.AI events

Valorisation

Actions towards valorisation
- Moonshot in development
- BD involvement HLW and ISP in relation to FATE and Transfer Lab
- Coordinated at program level links to units roadmaps and PMCs

Adjacent external knowledge investments
- PersOn (NWO-Perspectief)
- ICAI Lab AI4Oversight (Inspectorates)

Achieved valorisation
- Vaardig met Vaardigheden (NGF): UWV, SBB, CBS
- Through the use case projecs (see stakeholder involvement)

11.3 Flagship – AutoADAPT

ERP Contacts: Frank Willems (Lead Scientist)
                  Rene Corbeij (Program Lead)
   Marieke Martens - MBE (Science Director)

ERP Duration: 2022 – 2025

ERP Description
AutoADAPT concentrates on challenges related to adaptation by learning from observed current system behavior and predicted, uncertain future behavior. Our goal is to optimize the performance of an AI system over its lifecycle in an open world using automation. AutoADAPT uses physics-based models as basis and adds data-driven/machine learning (hybrid AI) to reduce uncertainties in the entire lifecycle of a system

Summary Result 2023
The AutoADAPT awareness concept was developed and demonstrated for the electric truck showcase, with a probabilistic reasoning model that exceeded previous results in detail and accuracy. The satellite communication showcase includes the first version of the optimization solution (TRL 2), defining the correct configuration parameters for the feedback controller. The automotive showcase features a novel self-optimization solution based on a genetic algorithm, considering both short and long time horizons. For these time horizons, an Adaptation concept with two corresponding loops is developed. A scalable computation platform is realized, which support fast computations.
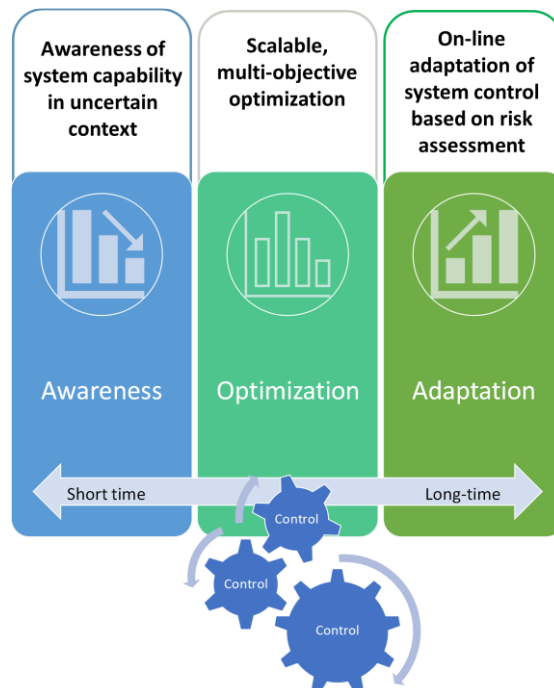
Result 2023 – ERP Appl.AI: Flagship AutoADAPT

Key results

Result 2023

New knowledge/technologies/methods/insights
- Self-calibration of probabilistic reasoner
- Self-optimization based on Genetic Algorithm
- Dual loop risk-aware adaptation concept

Prototypes/demonstrators/models
- Scalable computation platform
- HIL battery vehicle demo: on-line health estimation and awareness mission success
- LEOCAT demo: running set-up

Outcomes of evaluation/tests
- Enhance detail and precision for probabilistic reasoning model
- Universal computational platform: successful implementation for both show cases
- Life-assessment mission success for battery electric delivery truck: use info to avoid stranding
- Optimization concept for sat-com show case

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Partnership & Dissemination

Knowledge partners
- *TNO internal:* Powertrains, Integrated Vehicle Safety, Optomechatronics, Monitoring & Control Services, Intelligent Autonomous Systems
- *External knowledge partners:* TU/e, RUG, Leiden University, TUD, Univ. Valencia (visiting PhD)
- *Four part-time professorships* at TU/e (Willems, Wilkins, Witvoet)), Leiden University (Doelman) and PhD at RUG (Lazovik)

Stakeholder involvement
- Discussion and steering with industrial steering group
- Companies: Airbus, ESA, DAF, DENSO

Dissemination
- Key (Scientific) publications: reference [1]
- Conferences: reference [2]. [3]
- Presentations: APPL.AI event [4], MBE [5]
- TNO APPL.AI website article: AutoAdapt
- Organizer/chair invited session 'Machine Learning in Automotive Powertrains' at IFAC World Congress (Yokohama, Japan)

Valorisation

Actions towards valorisation
- Definition of two 2024 APPL.AI use cases with steering group;
- Proposal EAISI project with DENSO and TU/e. Not supported by TNO.
- NGF3 Hydrogen for mobility proposal: self-learning energy management for fuel cell – not granted

Achieved valorisation
- Results used in accompanying projects

11.4 Flagship – SEAMLESS

ERP Contacts: Michael Borth (Lead Scientist)
                  Zuzanna Domagala-Schmidt (Program Lead)
   Marieke Martens - MBE (Science Directors)

ERP Duration: 2023 – 2026

ERP Description

The SEAMLESS flagship develops the system engineering and lifecycle management methodologies and tools that enable the development and maintenance of trustworthy AI systems. Targetting lasting performance and safety, SEAMLESS advances design as well as validation and verification techniques to integrate system engineering with continuous AI development, such that AI-based systems are fit for their purpose over their whole lifecycle.

Summary Result 2023

SEAMLESS established its research lines together with the outline on how novel Systems Engineering capabilities can be used by stakeholders, already involving industrial parties who confirmed their belief and interest in the SEAMLESS approach. SEAMLESS then developed its first methodologies together with two core technologies, a physics-based Digital Twin and a probabilistic analytical model that ssesses system's fitness for its purpose, and illustrated their use for the main engineering tasks that we address. The work furthermore resulted in three scientific publications and two TNO reports, one on the Digital Twin and one of Digital Threads
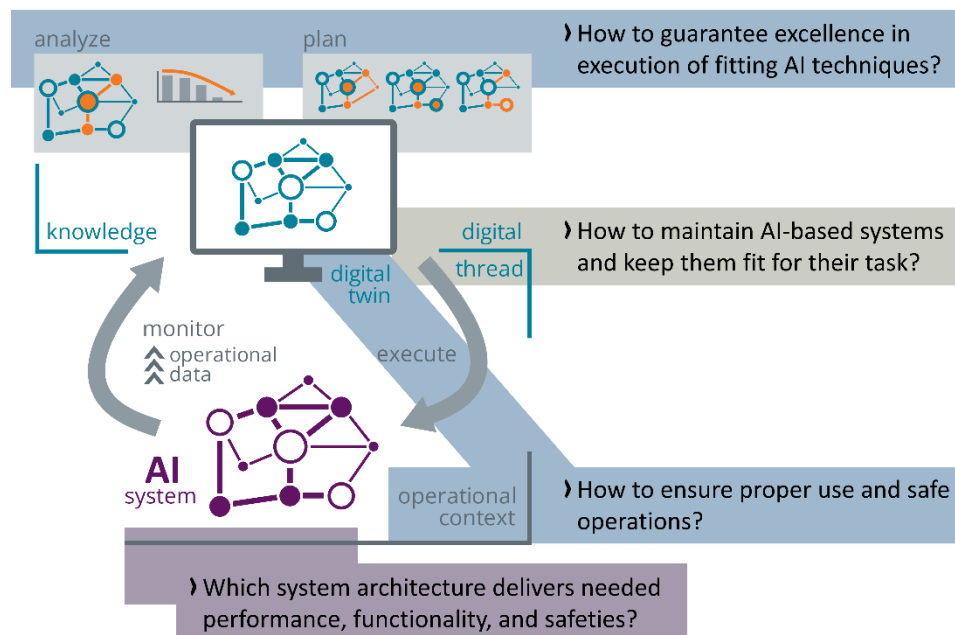
Challenges of SEAMLESS engineering of AI-based systems.

Result 2023 – ERP Appl.AI: Flagship SEAMLESS

⚛ Key results

The Why - Insights
- User stories for all System Engineering and Lifecycle Management foci
- AI pain points confirmed by industrial partners + integration of challenges

The How - methodologies
- Information flow modelling approach for the analysis of AI-based systems
- System Engineering and Lifecycle Management process concepts
- Verification & validation methodology that couples scenario-based testing, Failure Mode and Effects Analysis, and parameterized system context

The What – models & demonstration
- Digital Twin of Spot robot
- System-level analytical model of Spot AI, expressing context-dependent fitness for purpose, its causal impact factors, failure modes, and risks

Result 2023

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🤝 Partnership & Dissemination

Knowledge partners
- TNO departments: IVS, IAS, ESI
- Radboud University, TU/e
- In discussion with TUD

Stakeholder involvement
- Government: RDW
- 5 Automotive companies in Advisory Board (more lining up)
- 4 Smart Industry companies and 1 Tool vendor

Dissemination
- TNO website article on AI Systems Engineering
- Conference paper with CareFree on causal diagnostics
- Journal paper on methodology for scenario-based V&V
- Paper on challenges and solutions for engineering AI systems
- Invited talk at System Architecture Study Group
- Invited talk at Yacht

📊 Valorisation

Actions towards valorisation
- Formation of Advisory Board
- Setup of collaboration / use case in the Automotive domain: Project GALVATRON, starting 2024 with Torc (Daimler Trucks)
- Setup of continuation of use case project CareFree in the HighTech Industry domain by ESI with Canon PP
- Investigation of application within Smart Industry programme / EU call

Achieved valorisation
- SEAMLESS system analysis and verification & validation approach was part of TNO RDW ALKS Support

11.5 Flagship – MMAIS

ERP Contacts: Jasper van der Waa (Lead Scientist)
Tjeerd Schoonderwoerd (Program Lead)
Marieke Martens – MBE, Adelbert Bronkhorst - DSS (Science Directors)

ERP Duration: 2023 – 2026

ERP Description
The goal of the flagship MMAIS is to develop, demonstrate and deliver methods that enable ethical regulation of AI systems for high-risk and morally-sensitive contexts. These methods are part of a socio-technical feedback loop that describes how to empower multiple stakeholders (e.g., legislators, developers, end-users) to determine, monitor, and control the adherence of AI systems to relevant ethical norms and values.

Summary Result 2023
MMAIS specified the socio-technological feedback (SOTEF) loop methodology for development and evaluation of ethical AI systems. Given the selected showcase of automated vehicles, two user studies were performed to evaluate the developed methods and design patterns for identifying relevant moral values, and for evaluating the behavior of the AI system. An integrated demonstrator was built to illustrate the challenges and developed, generalizable solutions for building and adapting mathematical moral models for AI systems. Furthermore, an adaptive dialogue process was developed to enable the system to explain its observations, reasoning, and actions in terms of the moral aspects that are optimized.

Result 2023 – ERP Appl.AI: Flagship MMAIS

⚛ Key results	Result 2023
Established the SOTEF research framework ■ submitted as scientific paper **Extended and evaluated Value-Sensitive Design method "Value scenarios" for value elicitation and specification** **Developed and evaluated a generic, technical framework to implement moral models for AI systems** ■　framework was integrated in behaviour planner of autonomous vehicle **Developed and evaluated H-AI interaction design patterns for value alignment, using conversational AI** **Build an integrated demonstrator to illustrate the SOTEF framework and the developed methods** ■	🎓 3 🎖 0 📄 1 💡 0

🤝 Partnership & Dissemination	📊 Valorisation
Knowledge partners ■　Internal: FATE, AI/DS ■　External: TuD / UU (PhD) ■　HI gravitation programme ■　ELSA lab **Stakeholder involvement** ■　EU WG2 TG risk management ■　Government: MoD, RDW ■　TNO Vector: PhD **Dissemination** ■　SOTEF paper ■　REAIM ■　Presentations: MBE unit / AI/DS colloquium / Appl.AI Colloquium / Appl. Event, IAS meeting / Philosophy of Responsible Innovation	**Actions towards valorisation** *UC-projects proposals* ■　CBR (specifying/validating driving beh.) ■　Belastingdienst (SOTEF in organization) ■　AI/DS (specifying moral reqs for military) *BD involvement* ■　Jean-Louis Roso (ISP) ■　Antoine Smallegange (DSS)

11.6 Use Cases

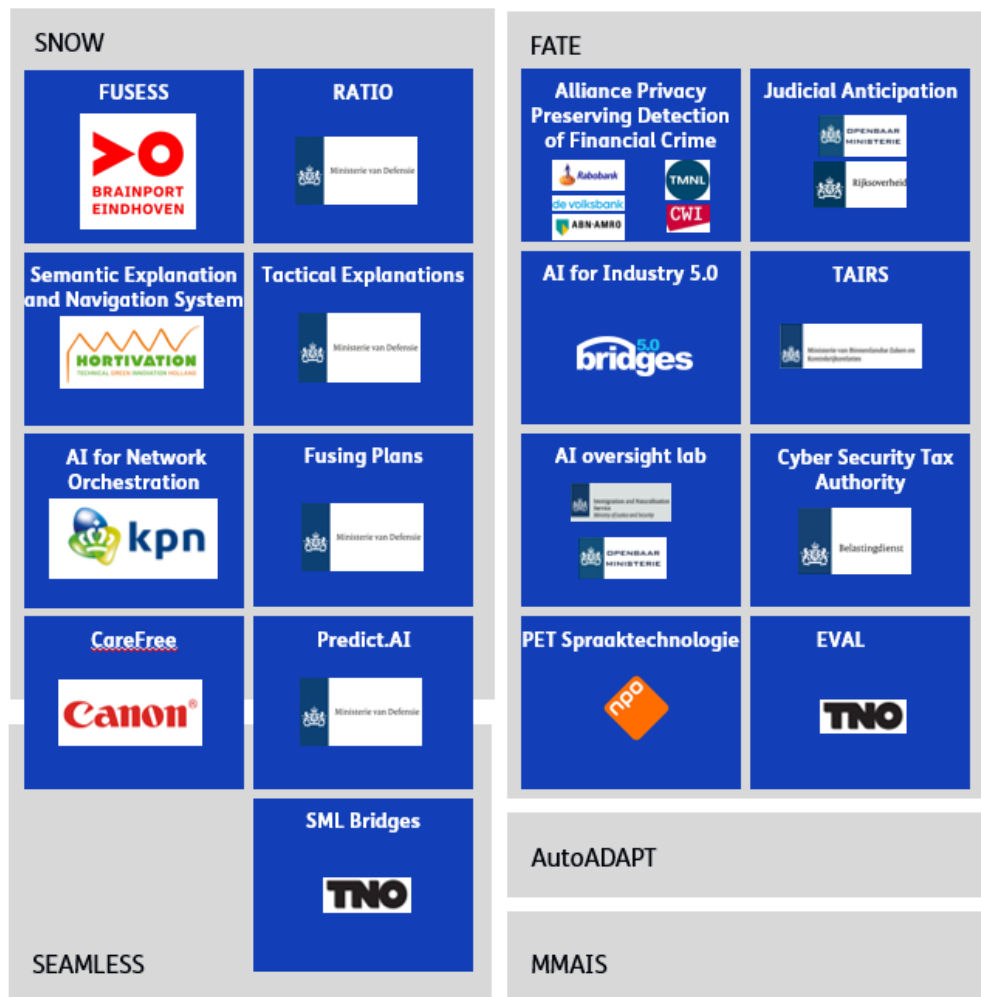| ERP Contacts: | Johan Janssen (Operational manager) |
	Freek Bomhof/ Frans van Ette
	Judith Dijk, Cor Veenman, Frank Benders (Lead Scientists)
	Adelbert Bronkhorst – DSS, Omar Niamut – ISP, Marieke Martens – MBE (Science Directors)

| ERP Duration: | 2023 – 2026 |

ERP Description

Use cases are an important vehicle to enable the management objectives of 2023 of the Appl.AI program:

- Strengthening priority partnerships and TNO's position in external AI community (Zwaartekracht-programma HI, Boston Dynamics, two ICAI labs)
- Continuation of the integration and alignment of all flagship projects
- Facilitation of knowledge sharing
- Further improving research alignment between flagships and use cases
- Further strengthening the internal TNO AI community including involvement of all units

Summary Result 2023

The Appl.AI program has successfully explored capability development for Autonomous Systems, Federated Decision Making and Systems Engineering & Lifecycle Management in a unique AI ecosystem.As in previous years, in 2023 a batch of use case projects are executed (see overview on next page. These use cases contributed to the knowledge development and validation of Appl.AI. Matching with 100% additional stakeholder funding (50% funding by stakeholder and 50% funding by Appl.AI) was a requirement. To be able to access this knowledge reservoir, knowledge is shared and explainable within the context of the TNO portfolio. This year we issued 6 newsletters, organized 8 colloquia, organized a TNO wide symposium with 150 participants and we maintained our Appl.AI website up to date.

SNOW		FATE	
FUSESS	**RATIO**	**Alliance Privacy Preserving Detection of Financial Crime**	**Judicial Anticipation**
Semantic Explanation and Navigation System	**Tactical Explanations**	**AI for Industry 5.0**	**TAIRS**
AI for Network Orchestration	**Fusing Plans**	**AI oversight lab**	**Cyber Security Tax Authority**
CareFree	**Predict.AI**	**PET Spraaktechnologie**	**EVAL**
	SML Bridges	**AutoADAPT**	
SEAMLESS		MMAIS	

AI for Industry 5.0	Enabling matching of jobs to job seekers where the fairness/values of companies and workers are taken into account.
AI for Network Orchestration	Autonomous optimizing 6G networks responses to events that provoke service disruptions.
AI oversight lab	Studying the safe introduction of AI for and together with governmental partners.
Alliance Privacy Preserving Detection of Financial Crime	Generating synthetic data as a measure to support data confidentiality to detect money laundering.
CareFree	Diagnosis and prognosis based on probabilistic reasoning within a hybrid approach that are deployable in soft real-time setups for onboard diagnosis or digital twin realizations.
Cyber Security Tax Authority	Developing methods for detecting and explaining lateral movement on computer networks, that is, unexpected changes in behaviour of entities on the network related to cyber-attacks.
EVAL	Exploring the safety aspects of Large Language Models (LLMs), such as biases, robustness and ethics.
FUSESS	(Future State Estimation for Safer automated Shuttles) AI algorithms for situational awareness in autonomous driving.
Fusing Plans	Combining potential conflicting plans for navy applications; This project focuses on long and short term planning.
Judicial Anticipation	Exploring the feasibility of argument mining, and specifically the use of argument mining for assessing argumentation and a response to arguments in the judicial domain for lowering the workload in high volume cases.
PET Spraaktechnologie	How to learn an aggregated speech model from disparate, decentralized speech datasets in a secure and privacy-preserving manner.
Predict.AI	Performance evaluation of learned AI modules so that the performance of the AI system in the current situation can be predicted.
RATIO	Development of self-assessment capability for an autonomous surveillance use case in which limited training data is available.
SENS	(Semantic Explanation and Navigation System) Applying autonomous robotic systems in greenhouses.
SML Bridges	Develop an adaptive prediction system that supports a proactive maintenance approach of bridges.
Tactical Explanations	AI generated Planning for unmanned ground vehicles including tactical explanations regarding the plans in a defence context.
TAIRS	Facilitating a regulatory sandbox to explore explicit interpretations of relevant norms (laws, policies), dispute resolution, a usable normative model for AI behaviour, and understanding the compliance of AI behaviour.

11.7 Scientific Exploration and Collaborations

ERP Contacts: Johan Janssen (Operational manager)
Freek Bomhof/ Frans van Ette
Judith Dijk, Cor Veenman, Frank Benders (Lead Scientists)
Adelbert Bronkhorst – DSS, Omar Niamut – ISP, Marieke Martens – MBE (Science Directors)
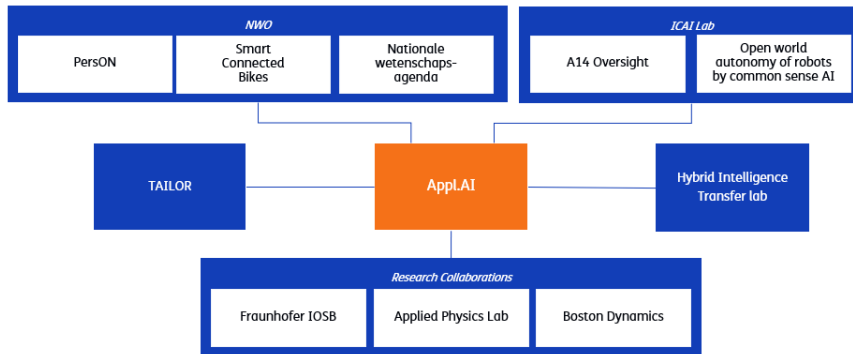
ERP Duration: 2023 – 2026

ERP Description
The objective of the scientific exploration within Appl.AI is to research concepts, methods and techniques that are needed to achieve the long-term Appl.AI goals. The activities are primarily conducted by (associate) professors and PhD researchers. The objective of the collaborations project is to identify, set up and work in national and international collaborations that strengthen the Appl.AI program.

Summary Result 2023
In 2023, six (associate) professors and four PhD students were financially supported. The relationships with universities is strengthened by close contact with the Scientific Advisory Board, and by initiating and participating in two ICAI labs together with universities and other stakeholders. ICAI labs are developed with different partners, including the Human Environment and Transport Inspectorate and the Royal Marechaussee. We continued the cooperation with the Zwaartekracht-programma HI and the partnership with APL (Johns Hopkins). The Appl.AI program also funds the TNO contribution to the Smart Connected Bikes NWO project and the PersOn NWO project. More than 40 papers are published on top of the papers reported in the Appl.AI flagships (reported in the previous sections of this chapter).

NWO-PersOn	1 PhD; Explainable, Maintainable, and Trustworthy Decision Support Systems for Personalised Care in Oncology
NWO-Smart Connected Bikes	1 PhD; Federated learning, secure multi-party computation and the Industrial data Spaces.
NWO-Nationale Wetenschapsagenda	Support NWA route AI and Big Data 2024
ICAI Lab -AI4Oversight	Coordination Lab and 1 Phd; Partners: Universiteit Leiden, Universiteit Utrecht, Wageningen University & Research, ILT(Inspectie Leefomgeving en Transport, NLA (Nederlandse Arbeidsinspectie), IvhO (Inspectie van het Onderwijs)
ICAI Lab - Open world autonomy of robots by common sense AI	Supervision of research and 1 PhD. Partners: Delft University of Technology, University of Amsterdam, Koninklijke Marechaussee
Hybrid Intelligence Transfer lab (HIT).	Collaboration between TNO Appl.AI and the HI Zwaartekrachtprogramma. Bringing fundamental results towards valorisation in use cases.
TAILOR (Trustworthy AI/ Learning, Optimization & Reasoning)	Roadmapping for large TAILOR EU consortium.
Fraunhofer IOSB	Collaborationon on application of AI for autonomous systems and medical decision support.
Applied Physics Lab	Collaboration between Appl.AI and the Applied Physics Lab of the Johns Hopkins university on autonomous systems
Boston Dynamics	Opportunity to demonstrate our work in the Boston Dynamics booth @ ICRA 2024. Discussions on potential market outlet of our stackable approach and modules.

Figure 11.1: Overview Scientific collaborations

Table 11.1: Overview Scientific positions enabled by Appl.AI

Function	Topic	University	Flagship
Professor	Communicative AI	Leiden University	MMAIS
Professor	Tangible User Interaction	University of Twente	SNOW
Full Professor	AI on Planning & Scheduling	Universidad Madrid	AutoADAPT, SNOW
Assistant Professor	Cooperative /Autonomous Vehicle Systems	Eindhoven University of Technology	SNOW
Lector	Data Science	Leiden Institute of Advance Computer Science	FATE, MMAIS
Research Fellow	Autonomous Vehicles	Radboud University	SEAMLESS, MMAIS, SNOW
PhD	Legal protection by design and applied cases in AI	University of Brussels	FATE
PhD	Deep Learning for long term video understanding	Delft University of Technology	SNOW
PhD	Person re-identification	University of Amsterdam	SNOW
PhD	Ethical framework for decision-making by automated vehicles	Utrecht University	MMAIS

12   ERP Next generation crypto

ERP Contacts:	Thijs Veugen (Lead Scientist) Sjoerd-Jan Wiarda (Program Lead) Adelbert Bronkhorst – DSS, Omar Niamut - ISP (Science Directors)
ERP Duration:	2023 – 2026

ERP Description

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.

Summary Result 2023

Due to academic partnerships with CWI and TU/e we were able to extend our Full ERP plan.
RL1: We designed distributed solutions for several image processing techniques and implemented measures to prevent reconstruction of the input data. We implemented several discrete optimization solutions for the energy and logistics domain.
RL2: Development of lattice-based (quantum safe) zero-knowledge proofs. Generalized security analysis of zero-knowledge proof systems. Development of a (slow) protocol analysis tool for homomorphic cryptography.
RL3: Two use cases (Health and Energy), co-created with relevant stakeholders; value propositions, first scan of ethical implications, relevant business model archetypes identified.
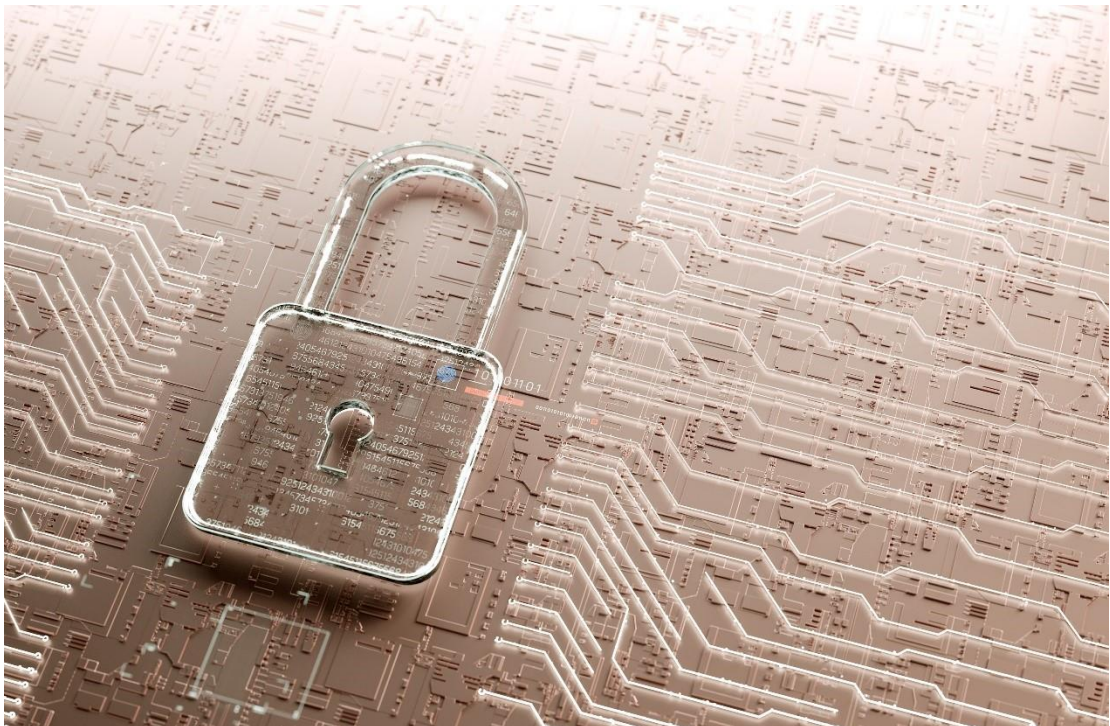
Result 2023 – ERP Next generation crypto

Key results

Result 2023

New knowledge/technologies/methods/insights

- Privacy-preserving battery sharing in community reduces energy costs significantly
- Federated Learning for various computer-vision tasks at reasonable accuracy
- Analysis tool for protocols with homomorphic encryption not fast enough yet

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Partnership & Dissemination

Knowledge partners
Large academic network
- TU/e, RuG, UT, VU, ETH Zurich
- CWI

Stakeholder involvement
- 'remote patient monitoring' use case joined with 'ERP Digital health measurements'

Dissemination
- Four publications at high tier scientific venues

Valorisation

Actions towards valorisation
- Multiple year plan NBV (EZ) on Computer Aided Crypto, interest from Technolution, Compumatica and NXP

Achieved valorisation
- … first paid European projects on related topics
- LUMC box: Amgen, Erasmus MC, NICTIZ, Hogeschool Rotterdam, Health RI

13 ERP Plasma synthesis

ERP Contacts: Dirk van den Bekerom (Lead Scientist)
                  Hans Linden (Program Lead)
                  André Faaij – EMT, Christa Hooijer - HTI (Science Directors)

ERP Duration: 2023 – 2026

ERP Description

Electrification of chemical industry is crucial to reduce CO_2 emissions. Plasma synthesis is employed for electrically converting rest streams of methane to value added chemicals. The focus of the ERP is direct production of ethylene; an important large volume, high value chemical (HVC) for the polymer industry.

Summary Result 2023

During 2023, the modelling results established initial 0D-kinetics model for simulating reaction trajectories. With this 0D model, the hypothesized dominant reaction pathway of methane pyrolysis were confirmed. On the experimental side, a 10 kW reactor was realized as a first scale-up step. Significant insights into the importance of soot production were gained. A laser diagnostic for soot quantification was developed, to be used for model validation in the coming years. An improved understanding of what an engineering model should look like was established. The Life cycle analysis (LCA) was updated with a sensitivity analysis.

Result 2023 – ERP Plasma synthesis

Key results

Result 2023

New knowledge/technologies/methods/insights

- Established initial 0D-kinetics model for simulating reaction trajectories
- 0D model confirmed the hypothesized dominant reaction pathway of methane pyrolysis
- Gained insights into the importance of soot production and consequently the importance of including it in kinetic modelling
- Commissioned a laser diagnostic for soot quantification
- Improved understanding of what an engineering model for computer aided reactor optimization should look like
- Life cycle analysis (LCA) sensitivity analysis

Prototypes/demonstrators/models
- Realized 10 kW reactor as a first scale-up step (from 1kW → 10kW)

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Partnership & Dissemination

Knowledge partners
- *TNO internal:* CSI, NI, SSE
- *Brightsite core partners:* Maastricht University, Sitech services, Brightlands Chemelot Campus
- *Other knowledge partners:* DIFFER, University of Antwerp, Drexel university, University of Bolognia

Stakeholder involvement
- *Government:* RVO, Groeifonds, Prov Limburg, EZK
- *Chemical industry:* Shell, OCI,
- *High Tech Industry:* Demcon, MTSA, Vonk, QMicro, PinkRF

Dissemination
- Presentation at PlasmaTech 2023
- Poster at International Symposion on Plasma Chemistry (ISPC) 2023
- Initial patent filing on plasma spark volume enhancement

Valorisation

Actions towards valorisation
- Unique Brightsite partnership ensures development with partners across all TRL-levels
- Location at Chemelot Campus ensures connection with industrial partners and end-users
- Conceptual plan for valorization through licencing of IP established
- Founding of a B.V. to licence out IP i to the chemical industry

14 ERP Socio-economic impact of green transitions

ERP Contacts:	Peter Mulder (Lead Scientist)
	Caroline Schipper (Program Lead)
	Anne Fleur van Veenstra – ISP, André Faaij – EMT, Marieke Martens - MBE (Science Directors)
ERP Duration:	2023 – 2026

ERP Description

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.

Summary Result 2023

We developed two novel microsimulation modelling platforms: i) HESTIA-MIMOSI and ii) ORANGE-Urban Strategy. In addition, we developed several new Big Data sets with detailed socio-economic information at the household and firm level, combining a range of microdata sources from CBS. Finally, we developed several use cases around built environment, mobility and labour/skills. Together this led to a couple of published and unpublished novel calculations and insights on the distributional impact of the energy- and mobility transition on households.

Furthermore, we explored the state-of-the-art of the role of data, models and evidence on transitions in policy and decision making. Also, we developed a governance mapping approach to understand the governance of the knowledge ecosystem in the Dutch energy transition of the built environment – both in policy-making and policy implementation.

Socio-Economic Impact of Green Transitions

Result 2023 – ERP Socio-economic impact of green transitions

⚛ Key results

New knowledge/technologies/methods/insights

Built environment
- Successfully linked TNO HESTIA and CPB MIMOSI model. Both run in microenvironment CBS allowing 2 studies to be started and follow-up studies in 2024

Mobility
- Implemented, calibrated and validated a TNO version of VU ORANGE spatial equilibrium model. Also included heterogeneity (multiple education types) and agglomeration effects and developed a soft-link with modules in Urban Strategy

Labour
- Developed methodological basis for foreseen analyses byTNO WHL/EMT, Maastricht University/ROA and PBL by constructing new CBS microdata set
- Also set up baseline macroeconomic theoretical model that captures the adoption of fossil-energy-saving technology at the firm level

Governance
- Obtained insight into factors that negatively influence sustainability of homes

Result 2023

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🤝 Partnership & Dissemination

Knowledge partners
- CPB, CBS, PBL, VU University, University Utrecht, University Maastricht/ROA, Leiden University
- Started 4 PhD positions

Stakeholder involvement
- Collaboration with Rijkswaterstaat and PBL to explore how ORANGE-Urban Strategy can strengthen their Land use and Transportation models

Dissemination
- CPB-TNO study on income effects of large-scale home renovation -> draft academic paper
- TNO report "Evidence Based Policy Making in the Dutch Energy Transition: theory and practice".
- TNO report describing the combined ORANGE- Urban Strategy modelling platform
- Draft academic paper: 'Alleviating energy poverty as a governance issue in the built environment: bottlenecks for upscaling the insulation of the housing stock'.
- Academic paper on use of ESCO taxonomy to explain job changes in both tight jobs and sectors with a surplus of available personnel.
- Draft academic paper on macroeconomic model that captures adoption of fossil-energy-saving technology at firm level, impact of the supply/cost of fossil energy on the adoption decision, and how this decision can be affected by labor market tightness.
- Presentation at ECPR conference and International Conference on New Pathways for a Just and Inclusive Energy Transition

📊 Valorisation

Actions towards valorization
- Upcoming project with the Ministry of Infrastructure to explore how ORANGE-US can be applied to get insights in the spatial distribution effects of the Lelylijn
- About to secure additional budget from MRA

Achieved valorization
- CPB hired additional people and started 2nd study with us
- PBL has promised that they will co-invest concretely as of 1-1-24 (by providing people to work on further development of Hestia).
- CBS wants to cooperate more closely on microdata (wants to become part of this project)
- Established sounding board group for CPB studies with ministries (EZK/BZK/SZW/Fin) to help think about relevant topics

15 ERP Solar-2-hydrogen

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ERP Contacts:	Pascal Buskens (Lead Scientist)
	Nicole Meulendijks (Program Lead)
	Christa Hooijer – HTI, André Faaij – EMT, Paulien Bongers - HLW (Science Directors)
ERP Duration:	2023 – 2026

ERP Description

Based on commonly accepted scenarios for the energy transition in NL and EU, there will be a large demand for green hydrogen (H2). It is unlikely that this demand can be fully covered by large scale electrolysis. R&I activities on alternative technologies having the potential to produce green H2 at similar or lower costs are needed. The focus of ERP Solar-2-Hydrogen (S2H) is the development and demonstration of devices for water splitting that use sunlight as sustainable energy source and yield green H2 at a levelized cost of H2 (LCOH) $\leq$ 2€/kg (benchmark is green H2 from electrolysis).

Summary Result 2023

Activities in 2023 resulted in two 1st generation iPVE devices: one silicon based (ca. 196 cm²) and one 2T Per/Si based (>5 cm²) device, both with a STH efficiency $\geq$ 15%. Furthermore, an optimized design for PEC devices was delivered including a lab scale PEC device demonstrator consisting of a photocathode with a minimum STH efficiency of 2.1% under AEM conditions. Emphasis in 2023 was more on toolbox than on maximized demonstrator efficiency. The submitted Interreg project FOTON, with a.o. strategic partners IMEC and UHasseltis expected to start Q1 2024.
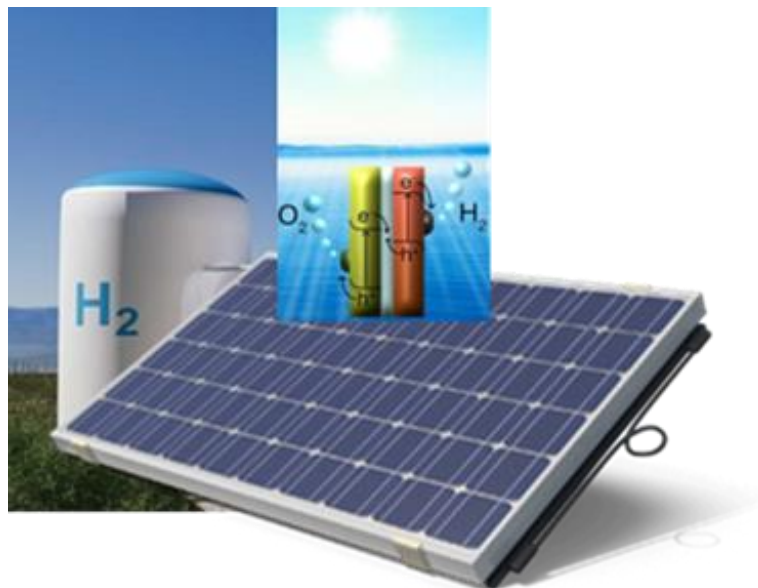
Result 2023 – ERP Solar-2-hydrogen

⚛ Key results

Result 2023

New knowledge/technologies/methods/insights
- User requirements (URS) set for iPVE devices established based on complete system analysis (not just single device analysis!).
- Economic analysis of system: iPVE panels need to be applied in large farms; otherwise, Balance of Plant costs dominate the levelized cost of H2 (LCOH).
- Most critical technical aspect for iPVE to check first: performance and stability under simulated real-life conditions. Performance and stability of electrolysers unknown. Tailored test set up established.
- URS for PEC: two options – improve efficiency of stable photoelectrodes or improve stability of efficient photoelectrodes ('submerged PV').
- PEC: to date, we mainly focused on increasing STH efficiency of stable photoelectrodes by material doping, use of co-catalysts, introducing porosity and light management.

Prototypes/demonstrators/models
- 1st generation (ca. 196 cm²) Si based (ca. 196 cm²) and 2T Pk/Si based (ca. 5 cm²) integrated iPVE devices with a STH efficiency ≥ 15%.
- Multiple lab scale demonstrators (>5 cm²) with stable photo-electrode materials

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🤝 Partnership & Dissemination

Knowledge partners
- TNO internal: RGs MAS, SSE (HTI); ETS, STA, STIP (EMT); RAPID (HLW).
- External knowledge partners: UHasselt, IMEC, UvA, UAntwerp.

Stakeholder involvement
- Government: Province N-Br, EZK, co-funding Interreg project FOTON.
- Companies: DCL, Soltech, Azteq involved via Interreg project FOTON.
- Member of WaterstofNet and Sunergy.

Dissemination
- First scientific publication: Facile Aqueous Solution-Gel Route toward Thin Film CuBi2O4 Photocathodes for Solar Hydrogen Production; B. Joos, K. Elen, J. van den Ham, N. Meulendijks, P. Buskens, A. Paulus, K. Wouters, J. Manca, J. D'Haen, S. Shukla, B. Vermang, M. Van Bael, and A. Hardy; Adv. Sustainable Syst. 2023, 2300083.
- Presentation: Techno-economics of solar fuels at Lorentz Workshop on Photocatalysis - Challenges and Future Perspectives, March 2023.
- No patents filed yet. First options for filing patents expected in 2024 related to porous photo-electrodes.
- Scientific symposium organized: Nano-technology Crossing Borders, with session focusing amongst others on green hydrogen

📊 Valorisation

Actions towards valorisation
- BD involvement, adoption by VPs: Involved VPs: EMT CO2 Neutral industry, Clean Hydrogen, HTI Smart Industry.
- Adjacent external knowledge investments: Interreg project FOTON (EFRO funding and additional funding expected from province N-Br and EZK).

Achieved valorisation
- Interreg project FOTON
- IEA Technology Collaboration Program "TRL assessment Photocatalytic water splitting"
- No other valorisation yet due to low TRL levels (3-4).

16 ERP Sustainable recycling of batteries and solar panels

ERP Contacts:	Mirjam Theelen, Devin Boom (Lead Scientist)
	Ahmed Fawzy (Program Lead)
	André Faaij (Science Director)
ERP Duration:	2023 – 2026

ERP Description

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 fromand to recycling. Focus will be on batteries and PV panels as primary use cases.

Summary Result 2023

The first year results per key technology are: 1) Selective delamination: a successful innovative process has been developed for delaminating the front glass sheet and encapsulant from the silicon wafer of commercial PV modules. 2) High grade silicon and silver recovery. The current purification method has achieved >95% purity level after a lot of optimization steps. 3) Strategic metal extraction and recovery:
reductor-free dissolution of battery cathode materials was successful for cathode active materials, but more challenging for black mass and therefore new ligands were tested for the metal extraction. First steps towards electrification of the recycling process were taken in the form of an in-house setup.
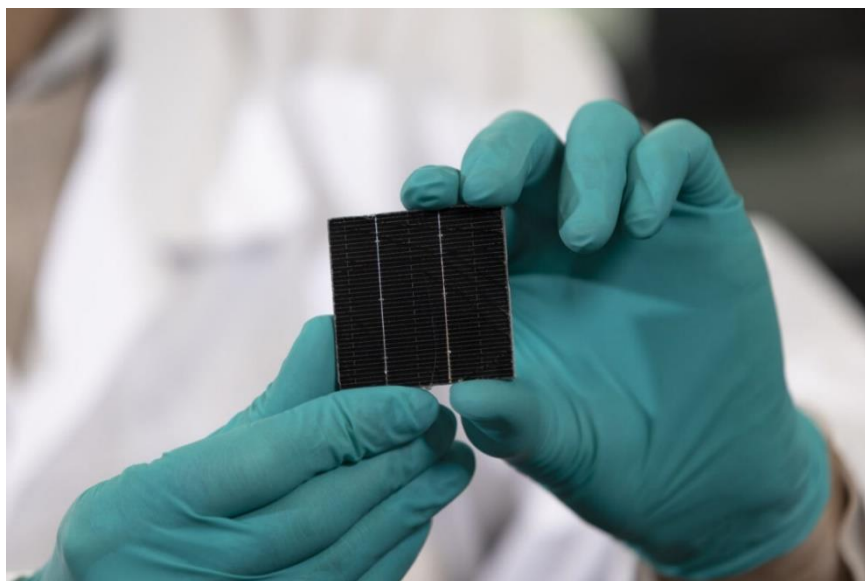
Result 2023 – ERP Sustainable recycling of batteries and solar panels

⚛ Key results

Result 2023

PV recycling
- Tool and method for the definition of required force for interface delamination
- Analysis of delamination forces vs encapsulation properties
- Very successful clean solar cell/encapsulation interface delamination
- Silicon wafer milling and first steps of purification
- Aluminium impurity ~1 %, in theory OK for Li battery application

Li-ion battery recycling
- High leaching rates for reductor-free dissolution of 4 different cathode types and black mass.
- New equipment for innovative metal separation installed and in use
- Successful separation of Co, Mn or Ni from lithium
- Insightful black mass analysis via XPS
- Setup build for ligand recovery
- Insights in environmental impact hotspots for battery recycling processes are obtained

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🤝 Partnership & Dissemination

Knowledge partners
- Process engineering (SPES, STIP), engineering (EfAM), life cycle assessment (CAS), polymer chemistry (MAS), safety assessments (RAPID) and technical economic analysis (SPES)
- TUD for detailed XPS analysis,
- TU/e for Lifecycle analysis

Stakeholder involvement
- Growth funds
- Various companies across the value chain

Dissemination (in preparation)
- Aninat et al., PV module delamination (in prep)
- Geerligs et al., Cleanliness demands for recycled silicon, (in prep)
- Yilmaz et al., Detailed XPS analysis on black mass for recycling (in prep)
- Van Berkum et al., TEA on SotA Li-ion recycling processes (in prep)
- Battery recycling demo at Netwerkfestival IenW, RWS en TNO

📊 Valorisation

Actions towards valorisation
- Results in two national growth funds:
  1. Circulaire geïntegreerde hoog- rendements zonnepanelen (Circularity as core target)
  2. Material Independence & Circular Batteries (WP battery recycling mainly written by this ERP battery team and aligns with ERP goals)
- Two proposals on PV Circularity and sustainability in preparation
- Exploration of reuse options by visit to recycling company and network

Achieved valorisation
- B2B assignments for two companies

17 ERP Synthetic biochemistry

ERP Contacts:	Wouter Vaes (Lead Scientist)
	Dide Reijmer (Program Lead)
	Paulien Bongers – HLW, André Faaij - EMT (Science Directors)
ERP Duration:	2023 – 2026

ERP Description
Our 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.

Summary Result 2023
This ERP has identified the main impact drivers and specific requirements for the production of therapeutic proteins and bulk chemicals and energy carriers. Generic strategies developed in 2023 have been successfully applied in the synthesis of two types of quantifiable products.
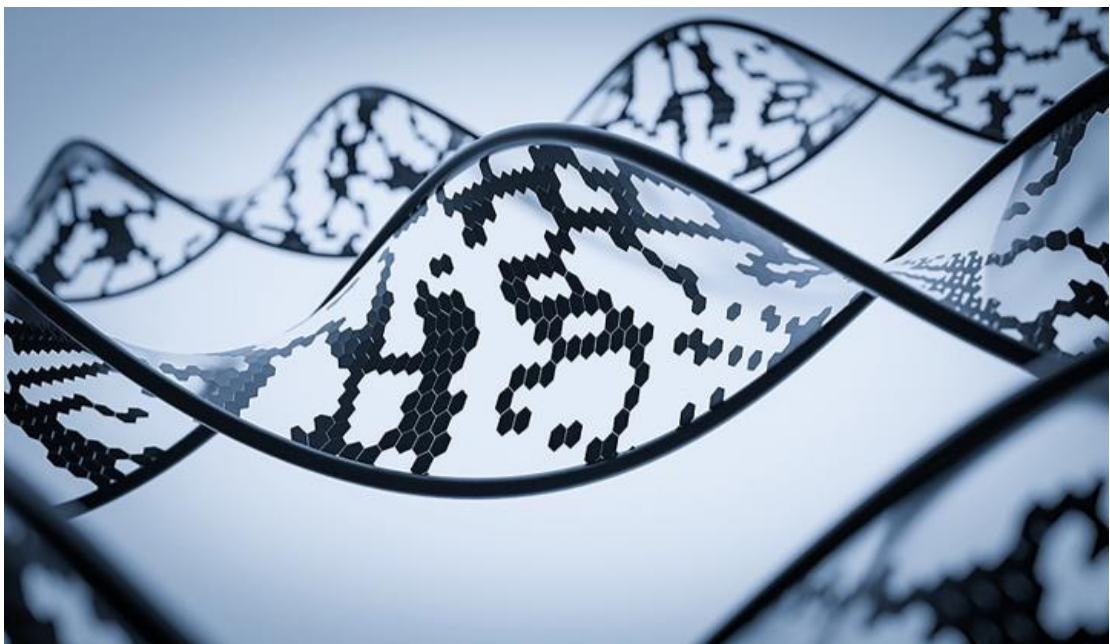
Result 2023 – ERP Synthetic biochemistry

Key results

New knowledge/technologies/methods/insights

Successful production of Therapeutic Proteins (TPs)
- Yield realization comparable to commercial kits
- Successful regeneration of energy carriers
- Improved stability of one key biomolecule
- Achieved satisfactory results in preliminary scale-up
- Ongoing establishment of materials sourcing agreements and purification capabilities for further scale-up

Knowledge build-up in bioproduction of Bulk Chemicals & Energy Carriers (BCECs)
- >90 potential biobased chemicals and fuels assessed
- Selected test candidates based on identified impact drivers
- Defined synthetic requirements for production of a first bulk chemical product
- Ongoing development of analytical methods for product quantification and process performance assessment

Result 2023

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Partnership & Dissemination

Ongoing expansion of the knowledge partner network
- Academic collaborations set via the creation of 1 joint PhD and Master student positions within the TPs use case
- New research programs are being established within the network

Increasing stakeholder interest
- Additional internal investment allocated to support development of the TPs use case

Prudent dissemination strategy
- External dissemination remains limited until IP protection is secured

Valorisation

Valorisation strategy regarding TPs in place
- Business plan with valorisation strategy designed

Execution of the IP strategy in progress
- IP protection strategy defined for the TPs use case
- Patent search revealed first promising BCECs results

Promising market interest
- Two types of pilot projects in scope (pending TRL), based on follow-up discussions with targeted clients

18 Seed ERP Asphalt rejuvenation using micro-algae

ERP Contacts: Greet Leegwater (Lead Scientist)
Tim Dijkmans (Program Lead)
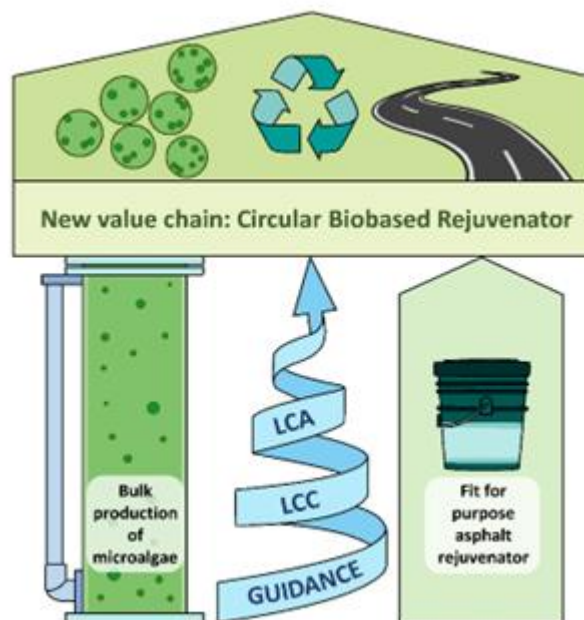Arjen Adriaanse – MBE, André Faaij - EMT (Science Directors)

ERP Duration: 2023 → Full ERP 2024 – 2027

ERP Description

The proposal aims to develop a circular and fit for purpose asphalt recycling agent based on waste water grown micro-algae at an industrial scale to keep the Dutch road network operational in a new circular value chain.

Summary Result 2023

The aim of the Seed ERP was to provide a proof of principle that lipids extracted from microalgae could serve as a rejuvenator for asphalt. Next to this, economic and environmental impacts of the different processes needed for this solution were studied and possible partnerships were explored.

Result 2023 – Seed ERP Asphalt rejuvenation using micro-algae

⚛ Key results	Result 2023

New knowledge/technologies/methods/insights
- An estimated initial cost, performance target, environmental risks and opportunities of the rejuvenator developed in this ERP
- Inventory of other potential suitable side streams (biobased) for rejuvenator production
- Concept validation method for evaluating rejuvenator effect
- Design of the tilting point tool for circular products

Prototypes/demonstrators/models
- Proof of concept for the extraction/isolation procedure of lipids from micro-algae

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- Collaboration with WUR established and formalized

Stakeholder involvement
- Rijkswaterstaat has been informed

Dissemination
- Patent application proposed
- TNO-internal report

Actions towards valorisation
- Full ERP plan (incl. valorisation plan) → Full ERP 2024

Achieved valorisation
- NA

19 Seed ERP Atmospheric models for optical solutions

ERP Contacts: Lex van Eijk, Niek Doelman, Bas Henzing (Lead Scientists)
Heather Young (Program Lead)
Adelbert Bronkhorst – DSS, Christa Hooijer – HTI, André Faaij – EMT (Science Directors)

ERP Duration: 2023 → Full ERP 2024 – 2027

ERP Description

This ERP Atmospheric Models for Optical Solutions (ATMOS) creates a leading position for TNO in mastering the impact of the Atmospheric State on the technologies Adaptive Optics, Optical Communication Terminals and Earth Observation. This will strengthen our market position for Laser Satellite Communication, High-Energy Lasers and Monitoring Atmospheric Pollutants and result in effective communication, successful military operations and accurate monitoring of climate and pollution.

Summary Result 2023

We found that current estimates for laser satcom link signal loss due to atmospheric turbulance can be improved by a factor of about three. This shows the importance of new models that provide the turbulence over specific ground station locations. For Earth Observation, we found that estimates of nitrogen dioxide (NO2) concentrations from TROPOMI satellite data can be significantly improved with new knowledge about aerosols and clouds. Similar conclusions may apply to other pollutants and climate gases (HCHO, SO2, CO2, CH4), illustrating the importance of upgrading atmospheric models (LOTUS-EUROS) in combination with data from upcoming satellite missions.
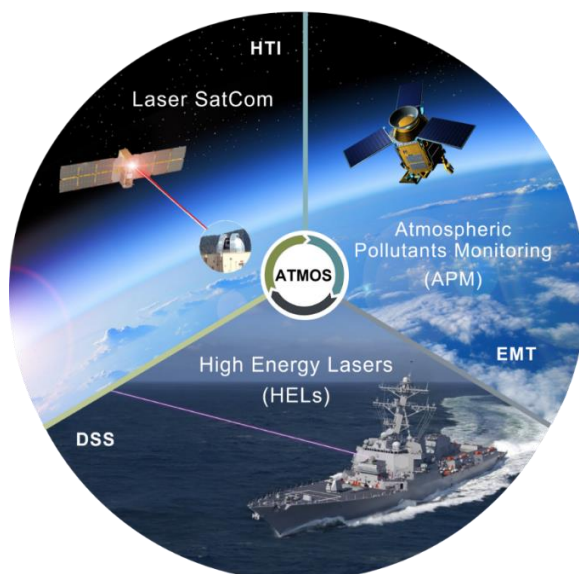
Result 2023 – Seed ERP Atmospheric models for optical solutions

⚛ Key results	Result 2023

New knowledge/technologies/methods/insights
- Review the impact (order of magnitude) of atmospheric effects on the leading SatCom use case (selected for the Seed ERP phase) based on new insights on propagation fundamentals
- Novel model of the Satellite Communication link behaviour based on new insights on the atmospheric state. Improved insight into the performance and reliability of a SatCom link based on the novel model.
- Review how the retrieval of NO2 concentrations from TROPOMI satellite data depends on atmospheric state effects related to aerosols and clouds
- Assess the percentage gains expected for the accuracy of the concentrations of various pollution and climate change tracer gases using new models and satellite data

Prototypes/demonstrators/models
- Novel model of the Satellite Communication link behaviour based on new insights on the atmospheric state.

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- VU Amsterdam
- WUR
- Fraunhofer IOSB
- Universidad de los Andes
- Laboratoire d'Optique Atmosphérique (LOA)

Stakeholder involvement
- Contact with FSO Instruments
- Airbus
- KNMI
- NL Ministry of Defence
- Ministry of EZK

Dissemination
- Actively reached out to knowledge partners and potential stakeholders on Full ERP plan.

Actions towards valorisation
- Full ERP Plan → Full ERP 2024

Achieved valorisation
- N.A.

20 Seed ERP Empowering citizen collectives

ERP Contacts:	Pepijn Van Empelen, Wessel Kraaij, Geiske Bouma (Lead Scientists)
	Ellian Lebbink (Program Lead)
	Paulien Bongers – HLW, Anne Fleur van Veenstra – ISP, André Faaij - EMT (Science Directors)
ERP Duration:	2023 → Full ERP 2024 – 2027

ERP Description

This ERP will develop 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. This will lead to improved trust, social cohesion and support for governmental decisions, essential for every transition.

Summary Result 2023

In 2023 we engaged in various activities to obtain a proof-of-concept of Key Enabling Methodologies for (data-) empowered citizen collectives.

Result 2023 – Seed ERP Empowering citizen collectives

Key results	Result 2023

New knowledge/technologies/methods/insights
- Inventory of community engagement/learning methodologies
- Inventory of governmental transformational methodologies
- Inventory of useful complimentary existing data sets on local health, social index and liveability indicators
- Data infrastructure for a monitoring and planning tool for collectives, including prototype for secure citizen data analytics
- Client journey map
- Inventory of potential use cases and living labs for Full ERP

Prototypes/demonstrators/models
- Prototype methodology for community development and government dialogue
- Pilot evaluation of a community and government engagement methodology (application in pilot Viteylingen)

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Partnership & Dissemination

Knowledge partners
- Erasmus University Rotterdam (Vital Cities & Citizens)
- Leiden University

Stakeholder involvement
- Advisory board meetings with ministries, municipalities, network organisations and private partners
- Letters of Support from municipalities, network organisations and private partners for the Full ERP phase
- Stakeholder consultation (Heijmans, Univé, Health~Holland)
- Pilot with the HLT municipalities (Viteylingen)
- Community consultation (Rotterdam Afrikaanderwijk, ZutphenEnergie)

Dissemination
- Website better-together.dev Launch of the Better Together coalition

Valorisation

Actions towards valorisation
- Full ERP plan (incl. valorisation section) → Full ERP 2024
- NWA ORC proposal
- NWO Perspectief proposal

Achieved valorisation
- N.A.

21 Seed ERP Polymer design by machine learning

ERP Contacts:	Jan Harm Urbanus (Lead Scientist)
	Judith Kessens (Program Lead)
	André Faaij – EMT, Christa Hooijer – HTI, Omar Niamut - ISP (Science Directors)
ERP Duration:	2023 → Full ERP 2024 – 2027

ERP Description
To develop and validate a Polymer Informatics engine that realistically captures the complexity of polymers to design novel candidates that match with requirements for safe & circular plastics.

Summary Result 2023
Using a promising machine learning approach and a corresponding large synthetic data set from literature, it was demonstrated that polymer properties could be predicted with reasonable accuracy with data sets of around a thousand points. Substantially smaller data sets sufficed to extend the model for prediction of additional related properties through so-called transfer learning.

A classical 'nearest-neighbour' method was used to identify the most suitable materials for a desired combination of polymer properties, thus allowing prediction of likely candidate materials for a given application.

The main operational challenge remains identification and high quality data collection for crucial application properties.

Result 2023 – Seed ERP Polymer design by machine learning

⚛ Key results

New knowledge/technologies/methods/insights
- Descriptors (~3-5), database (as much information as possible) and ML architecture (generic framework applied to use case) for polymers in biodegradable textile fibre applications
- Insight: generic models exist, value is in adding specific properties to the model, based on high-quality data input
- A methodology for high-throughput screening (HTS) is conceptually developed and an inventory is completed for tools/equipment that can support this HTS-method

Prototypes/demonstrators/models
- Prototype of working ML-model for predicting the structure-property-function relationship of polymers in textile fibre
- Prototype of working ML-model for inverse design of polymers, based on a generative approach combined with a Nearest Neighbour method
- Samples (10-100 gram) of selected bio-based polymers (max 30) synthesized and/or gathered. The selection is based on properties beneficial for the specified use case

Result 2023

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🤝 Partnership & Dissemination

Knowledge partners
- WUR
- RUG
- NHL Stenden

Stakeholder involvement
- Involved Senbis Sustainable Products B.V.
- Involved Senbis Polymer Innovations B.V.

Dissemination
- Press release on BIOTTEK-project (a.o. via LinkedIn)
- First steps towards the establishment of a consortia (incl. BIOTTEK, BIOPOLAIM and bio-PHAC)

📊 Valorisation

Actions towards valorisation
- Full ERP plan (incl. valorisation section) → Full ERP 2024
- Multiple discussions with companies on potential collaboration (e.g. B4Plastics)
- Brought in as potential topic for the Global Impact Coalition (for which we currently host the R&D Hub on Plastic Waste Processing for 7 major chemical corporates)

Achieved valorisation
- Granting of BIOTTEK project, collaboration with a.o. Senbis to further develop and validate the ML-model

22 Seed ERP Sustainable ICT

ERP Contacts: Hans Stokking, Ton Bastein, Mark Huijbregts (Lead Scientist)
Joris van Diemen (Program Lead)
Omar Niamut – ISP, André Faaij – EMT, Anne Fleur van Veenstra - ISP (Science Directors)

ERP Duration: 2023 → Full ERP 2024 – 2027

ERP Description

The ERP Sustainable ICT will develop actions and methods to enable 1) policy makers to get a grip on GHG emissions in the ICT sector and 2) ICT companies to react to such policies, based on providing clear insight in all emissions and in impacts of policies on market forces and demand drivers.

Summary Result 2023

In 2023, a thorough state-of-the-art analysis has been conducted on the sustainability of digital systems, proof-of-concept energy measurements have been performed as well as optimisation modelling on two use cases. Furthermore, the team has explored the future directions wherein TNO can have the most impact, including assessments of business strategy, policy directions and user behaviour. Current state and future directions have been discussed with various outside stakeholders. The projected has resulted in a report on the topics mentioned above, as well as a full plan for an Early Research Program, which was granted to start as a Full ERP in 2024.

Result 2023 – Seed ERP Sustainable ICT

⚛ Key results	Result 2023

New knowledge/technologies/methods/insights
- Analysis of the current state of the sector's environmental impact resulted in the following insight: 1) a lack of good data and an overall picture of intransparency and lack of insight 2) many companies are reporting on their sustainability, but often incomplete or, in our opinion, at least somewhat misleading ("greenwashing").
- Analysing state of the art and interaction with outside stakeholders has taught us that many ideas for improving efficiency are being picked up by industry, currently focussing mostly on smart shutdown & standby strategies.
- After deliberation internally and with The Ministry of Economic Affairs and Climate, our conclusion is the ERP should not engage in developing such efficiency measures, but will focus on options to assess (both for companies and policymakers) the impact of proposed measures.
- The value of TNO is more inter- or trans-disciplinary here: combining our knowledge on ICT systems and value chains with our efforts on sustainability, user behaviour, transitions, economic and policy analysis allow us to really contribute to a more sustainable ICT sector within Europe, resulting in the specifics of this ERP plan.
- Concept vision paper on how to approach sustainability efforts of digital services

Prototypes/demonstrators/models
- Proof of concept measurements on the energy usage of digital streaming services

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- Nationale Coalitie Duurzame Digitalisering

Stakeholder involvement
- Intended users involved: KPN, Vodafone, DDA and Leafcloud, Ministry of EZK

Dissemination
- Speaker at the BEHAVE 2023 conference on scaling up behaviour change in the light of the energy and climate crises.
- Parallel to the actual project work, we started a lecture series @TNO with external speakers. In 2023, we had Orange/Soft at Home (Ben Schwarz) the SDIA (Max Schulze), KPN (Jeroen Cox), ABN AMRO (Wiebren van der Zee) and KU Leuve (Prof. Liesbet van der Perre)

Actions towards valorisation
- Full ERP plan (incl. valorisation section) → Full ERP 2024
- Commitments for a bi-annual advisory board from: EZK, Orange, E&Y, Norigin Media, Lancaster University and Consumentenbond

Adjacent projects startin Jan 2024
- Exigence, a Horizon/SNS project with European partners on measuring and optimising energy use in future mobile networks;
- MISD, an IPCEI-CIS project with Dutch partners on distributed en federated cloud computing with a focus on high sustainability and a flexible interaction with the energy grid;
- Future Networks and Services, a Dutch 'groeifonds' program on the development of smart components and smart networks for 6G mobile networks, with sustainability through 'smart/AI based optimisation' one of the goals

Achieved valorisation
- N.A.

23 Seed ERP Ammonia: a future proof commodity

ERP Contacts: Jurriaan Boon, Lawien Zuurbier (Lead Scientists)
Marija Saric (Program Lead)
André Faaij - EMT (Science Director)

ERP Duration: 2023

ERP Description

The objectives of this ERP project are to map the global picture and identify opportunities and technology gaps for the Dutch economy and the right to play for TNO. Specifically, this see-ERP focused on the cost and energy efficient reforming of ammonia to high purity hydrogen and direct ammonia utilisation to syngas and fuels eg. dimethyl ether.

Summary Result 2023

The Seed ERP showed Proof-of-Principle for the three research lines with respect to demonstration of the separation enhanced reaction technologies and to the performance of the catalytic materials under non-standard reaction condition. Calculated potential energy savings compared to benchmark technologies were 15% for NH3-SEDMES (direct utilization of NH_3 and CO_2 to DME is sorption enhanced reactor) and 30% for MEMA (NH3 reforming to H_2 in Pd membrane reactor) and CLARA technology (syngas production from NH_3 and CO_2 by chemical looping) .
The LCA analysis of the NH_3 supply chain revealed that the location of electricity and ammonia production is essential for the overall enviromental impact and will determine (next to geopolitical considerations) the choice of geographical location of various process steps.

Result 2023 – Seed ERP Ammonia: a future proof commodity

⚛ Key results

New knowledge/technologies/methods/insights
- Proof of principle Clara technology (produce syngas from pure NH_3 reforming and in-situ utilization of the formed H_2 for CO_2 reduction using chemical looping)
- Proof of principle MEMA technology (The H_2 separation experiments showed an optimal performance at 450 °C and 30 bar, at which no NH_3 adsorption at the membrane surface was observed)
- Proof of principle NH3-SEDMES technology (For the SEDMES technology the first tests in the adapted unit proved the activity and stability of the Ru/Al_2O_3 NH_3 reforming catalyst under SEDMES temperatures and pressure)

Prototypes/demonstrators/models
- Adapted infrastructure for membrane reactor characterisation to work with up to 10vol% of NH_3
- Adapted installation for catalyst/sorbent characterization to work with up to 10vol% of NH_3
- Adapted installation for chemical looping tests to work with pure NH_3

Result 2023

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🤝 Partnership & Dissemination

Knowledge partners
- University of Utrecht, TU Delft, and TU Eindhoven

Stakeholder involvement
- Port of Rotterdam, Stamicarbon, OCI Nitrogen, Duiker, Proton ventures

Dissemination
- Presentation on Sustainability assessment of utilizing green ammonia in three converting technologies for the production of hydrogen, dimethyl ether and syngas
- Student report on renewable ammonia value chain analysis
- Presentation at NH3 event EU

📊 Valorisation

Actions towards valorisation
- Visibility: presence at the relevant conferences, symposiums
- Engagement with relevant knowledge partners and stakeholders
- Acquisition for TSE call

Achieved valorisation
- N.A.

24 Seed ERP Responsible hyper-nudging

|	
ERP Contacts:	Stefan Raaijmakers, Marc Schuilenburg, Pepijn van Empelen (Lead Scientists)
	José Kerstholt (Program Lead)
	Adelbert Bronkhorst - DSS, Omar Niamut - ISP (Science Directors)
ERP Duration:	2023

ERP Description

Hyper-nudging is a data-driven influencing technique that allows for large-scale online automatised and personalised behaviour steering. Hyper-nudging is currently insufficiently used for beneficial purposes, but mostly in ways that threaten people's agency and choice autonomy. This seed-ERP investigated how effective digital nudges can be created to influence people's behaviours for beneficial purposes, while considering social/societal, ethics, legal and privacy/data protection requirements. In addition, it investigated how to support user awareness of current hyper-nudging techniques and value-based decision making.

Summary Result 2023

Insight into (underlying mechanisms of) hyper-nudging was attained through a literature search and two studies; a questionnaire study on drivers for protection motivation and a qualitative study (interviews) on online fuelled public disorder. Regarding SELP, we developed a preliminary framework, to support the design of such responsible hyper-nudging solutions. A Smart Sister demonstrator was develop that showed users how online profiling takes place (using a recipe recommendation application), and to provide them with insight into their migration over time to certain personas. Lastly, we held a series of 14 conversations with various stakeholders and partners.
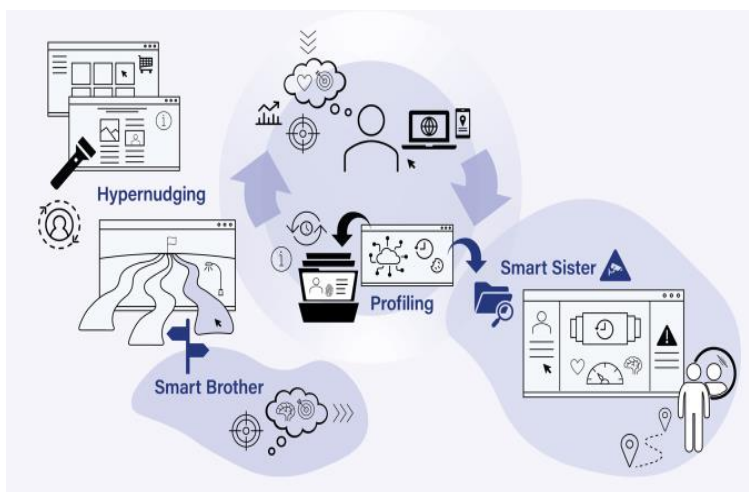
Result 2023 – Seed ERP Responsible hyper-nudging

Key results

New knowledge/technologies/methods/insights
- Memo TNO. Kox, E., Cadet, B & Broderick-Hale, J (2023). A short introduction to hyper-nudging: its mechanisms, the psychological consequences and applications.
- Master thesis Vrije Universiteit Amsterdam (VU). Beentjes, G. (2023). Hyper-nudging tegen online aangejaagde ordeverstoringen: Kansen en risico's. (supervised by Marc Schuilenburg)
- Master thesis Univeristy of Utrecht. Cabral Litowsky, Y (2023). Hyper-nudging and Protection Motivation Theory: Investigating Awareness, Previous Protective Behaviour, and Protection Motivation. (supervised by José Kerstholt)
- TNO report Bodea, G. (2023). Social, ethics, legal and privacy/data protection (SELP) aspects of hyper-nudging.

Prototypes/demonstrators/models
- A short film, demonstrating Smart Sister. Vos, D., Bekkers, E., Excel, C. & Raaijmakers, S. (2023). Smart Sister: a web app to increase awareness and informed choice in the context of hyper-nudging
- Slide deck. Vos, D., Bekkers, E., Excel, C. & Raaijmakers, S. (2023). Smart Sister: a web app to increase awareness and informed choice in the context of hyper-nudging.
- Working code. Vos, D., Bekkers, E., Excel, C. & Raaijmakers, S. (2023). Smart Sister: a web app to increase awareness and informed choice in the context of hyper-nudging.

Result 2023

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Partnership & Dissemination

Knowledge partners
- University of Utrecht, Erasmus University Rotterdam

Stakeholder involvement
- National Police

Dissemination
- Article Marc Schuilenburg in NRC-Handelsblad https://www.nrc.nl/nieuws/2023/06/23/na-het-lichaam-pakt-ai-nu-uw-ziela4167991
- The thesis of Yanna Cabral Litowsky (a questionnaire study on drivers underlying protection motivation) is currently rewritten to be submitted to a scientific journal.

Valorisation

Actions towards valorisation
- Full ERP proposal
- Call KIC Cybersecurity for digital resilience (NOW)

Achieved valorisation
- N.A.

25 Seed ERP Sustainable printed electronics

ERP Contacts:	Stephan Harkema (Lead Scientists)
	Gerwin Gelinck (Program Lead)
	Christa Hooijer - HTI, André Faaij - EMT (Science Directors)
ERP Duration:	2023

ERP Description

Hybrid and Printed Electronics reduce the carbon footprint by 30-35% in comparison to conventional electronics based on Printed Circuitry Boards (PCBs). This is a good start, but we need to do much better than that to reach 55% less emissions by 2030 and near carbon neutrality by 2050. Especially now, with the global environmental crisis and the transition to a circular economy, it is necessary to step up and make a change. TNO has filed a unique patent on a method to manufacture encapsulated electronic devices that can be disassembled at end-of-life. This may change how electronics are made and integrated into consumer products in any domain.

Summary Result 2023

A route towards preventing future e-waste from in-plastics encapsulated printed electronics was established using design-for-recycling principles that greatly enhance the recyclability of materials. Dedicated disassembly layers incorporated into electronic devices facilitate efficient recycling of (printed) metal, recovery of pure plastics at high yield (>85%) and full recollection of all semiconductor components. Our right-to-play was established by 4 patents, convincing experiments, supporting life cycle assessment (LCA) and demonstrators.

Result 2023 – Seed ERP Sustainable printed electronics

⚛ Key results | Result 2023

New knowledge/technologies/methods/insights
- Design-for-recycling principles applied to flexible and rigid Hybrid & Printed Electronics (H&PE)
- Low TRL recycling performed to recollect > 80% of bulk plastics, 100% of semiconductor components
- Novel method for high speed dismantling
- Environmental impact assessed using ReCiPe 2016 LCA methodology, including preliminary assessment of end-of-life recycling following disassembly

Prototypes/demonstrators/models
- Flexible and rigid H&PE demonstrators, both intact and fully functional and disassembled for recycling, shown at several national and international events

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🤝 Partnership & Dissemination

Knowledge partners
- Business unit EMT departments CSI, SPES; HTI Holst Centre

Stakeholder involvement
- Printed Electronics community
- EU policy offers: sustainable design
- Automotive tier suppliers/OEMs

Dissemination
- Various industry events: Innovation Day, TechBlick, Folien&Fahrzeug, IMSE days
- TechBlick white paper
- Submission of peer review paper (positive evaluation, reviewer comments being addressed)
- Joint development agreement with Dutch design studio to explore and envision future sustainable products

📊 Valorisation

Actions towards valorisation
- 4 patents filed or in filing
- Contract negotiations with printed electronics companies
- Proposal submission for JTF project
  1st stage proposal submission for EU project

Achieved valorisation
- Dutch KIA-CE project funded

26 Seed ERP Robot orchestration

ERP Contacts: Yori Kamphuis, Frank ter Haar, Frank Benders, Relja Djapic (Lead Scientists)
Marcel van Sambeek, Sylvia Dijkstra (Program Lead)
Adelbert Bronkhorst – DSS, Omar Niamut – ISP, Marieke Martens - MBE (Science Directors)

ERP Duration: 2023

ERP Description
This Seed ERP focused on developing and implementing orchestration mechnisms for collaborative networked robots, enabling secure and efficient coordination, seamless task allocation and replanning, and reliable real-time communication among diverse robots.

Summary Result 2023
In 2023 three main acitivies were performed to explore beyond state-of-the-art of robot orchestration with future network and cloud technologies.

1. **Inventory and research:** The main conclusion of the inventory and research phase is that the ERP should focus on orchestration of heterogeneous teams of robots in distinct application domains of Defence, automotive, and agriculture, with a focus on concept development & evaluation of heterogeneous robot teams in dynamic environments with both unrestricted 5G/6G communication and edge/cloud processing capabilities, as with restricted capabilities in the Defence domain.

2. **Architecture and design:** Based on the inventory & research analysis an initial architectural design of the multi-robot orchestration capabilities was developed. The team also developed a first PoC in the TNO lab environment of a use case on public safety (fire detection and extinguishing) via a hierarchical centralized approach of a heterogeneous robot team of drones and unmanned ground vehicles.

3. **Project Management & dissemination:** In this activity the future collaborations with universities and industry were investigated and aligned for the start of the ERP RO project. A poster on RO was presented by the project team on ICRA'23. Discussion with stakeholders and partners led to an initial advisory board with point of contacts from Demcon, VDL, MINDbase, and optionally Delft Dynamics, KPN, and others.

Result 2023 – Seed ERP Robot orchestration

⚛ Key results		Result 2023
New knowledge/technologies/methods/insights ◼ Overview of use cases and requirements in line with unit/stakeholder interests ◼ State-of-the-Art document based on literature review and IP/Patent scan ◼ Initial reference architecture for a reference platform for real-time resource orchestration in networked cooperative multi-robotic systems. **Prototypes/demonstrators/models** Proof-of-concept of use case on public safety (fire detection and extinguishing) via a hierarchical centralized approach of a heterogeneous robot team of drones and unmanned ground vehicles in a dynamic (new fires) and open environment and with 5G and cloud technology. In this PoC a (parameterized ICTUS6) plan is autonomously created to facilitate the orchestrated execution of the mission, leveraging the technology that is developed at TNO for autonomous (military) operations with unmanned systems.		🎓 0 🎖 0 📄 0 💡 0

🤝 Partnership & Dissemination	📊 Valorisation
Knowledge partners / targeted partnership for full ERP ◼ Academia, research organisations, and field labs: TUD, UT, TU/e, DoIoT, Unmanned Valley, TomatoWorld, Intelligent Robotics Lab, North Sea Field lab, Marin. **Stakeholder involvement** ◼ Governmental organisations: ministries of Defence, JenV, I&W, and Dutch Authority for Digital Infrastructure, COMMIT Mindbase, RWS. ◼ Commercial and non-governmental organisations: Demcon DSS, S&T, Reeq, Milrem, Avular, Delft Dynamics, Nedinsco, Avalor.AI, Demcon unmanned systems, CaptainAI, KPN, VDL, AnyBotics, DAF, High Tech NL Robotics, Port of Rotterdam, Shell Energy & Innovation. ◼ EU consortia: foreseen participation in Horizon calls and EDF/EDA. In particular for the Agriculture, Inspection, and Logistics use cases it helps to partner-up with High Tech NL Robotics. **Dissemination** ◼ Poster presentation on conference ICRA 2023 ◼ Paper on concepts of resource orchestration for networked multi-robotic systems submitted to ICRA 2024	**Actions towards valorisation** ◼ Full ERP plan (incl. section on valorisation) ◼ Discussion with stakeholders and partners led to an initial advisory board with point of contacts from Demcon, VDL, MINDbase, and optionally Delft Dynamics and KPN. **Achieved valorisation** ◼ Continuation with stakeholders and partners on unmanned systems and UAVs in partnerships in future DSS projects.

27 Seed ERP Atmospheric CO$_2$ removal

ERP Contacts:	Jurriaan Boon, Mark Rolands (Lead Scientists) Marco Linders (Program Lead) André Faaij - EMT (Science Director)
ERP Duration:	2023

ERP Description

To limit Global Warming to no more than +1.5 degrees, it has become essential that technology for atmospheric CO$_2$ removal (CDR) is developed. This Seed ERP aimed to establish technology for atmospheric CO$_2$ removal for a sustainable society, including proof of principle(s), strengthening IP positions, developing the basis for the evaluation framework, and generating a full ERP plan. Various TNO departments worked closely together, connecting also with relevant experts in and outside of TNO. The following research questions were addressed: 1) How to evaluate technologies for atmospheric CO$_2$ removal in a common framework? 2) How to make techniques for CO$_2$ capture from sea water and air applicable and (cost)efficient? 3) What are the best options to do with the captured CO$_2$?

Summary Result 2023

For air capture, experiments were done to test field enhanced heating in the form of induction and photonics to release captured CO$_2$ from sorbent materials and further conversion of released CO$_2$ to products; both heating methods showed promising initial results. For enhanced sea water absorption an inventory was made of technologies that electrochemically change the pH of the sea water. The route to transfer natural alkalinity from igneous rock to sea water was seen as advantageous over the routes that remove dissolved CO$_2$ gas by stripping out or precipitating out; modelling showed this route may also have less environmental impact.

Result 2023 – Seed ERP Atmospheric CO_2 removal

⚛ Key results		Result 2023

New knowledge/technologies/methods/insights
- Roadmap for climate positive technologies indicating the way forward with respect to technology development for direct air capture and enhanced sea water absorption, focusing on both process intensification and process integration to lower process cost and hence accelerating large scale deployment,
- Impact and sustainability assessment.

Prototypes/demonstrators/models
- Experimental facilities for advanced sorbent regeneration (induction, solar irradiation)

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
Potential knowledge partners were approached
- UTwente (Brilman): air capture technology,
- TU/e (Van Sint Annaland): inductive heating, reactor technology,
- TUDelft (Urukawa): integrated capture and conversion, materials, (Vermaas): electrochemical cell design,
- a PhD at Radboud University/Utrecht University: macro-scale modelling of atmospheric CO2 removal technology, biomass-based alternatives,
- GEOMAR Helmholtz Centre for Ocean Research Kiel (Fuhr): enhanced weathering of silicates in seawater,
- NIOZ (Humphreys): modelling of ocean carbonate system,
- Carbyon (De Neve): direct air capture technology, SeaO2 (Shafirian),
- Captura USA (Sant): enhanced sea water absorption technology ,
- Ebb Carbon USA: membrane development, Co2urage 6) consortium (NWO Perspectief): integrated capture and conversion, reactors,
- Arrhenius consortium (UT Keurentjes): integrated capture and mineralization,
- Hasselt University (Buskens) plasmonic/photonic heating and plasmon catalysis

Stakeholder involvement
- See knowledge partners

Dissemination
- N.A.

Actions towards valorisation
- Full ERP plan (incl. section on valorisation)

Achieved valorisation
- N.A.

28 Seed ERP Accelerating orchestrated innovation

ERP Contacts:	Angela Greco (Lead Scientists)
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	Anne Fleur van Veenstra - ISP, Christa Hooijer - HTI, Arjen Adriaanse - BME (Science Directors)
ERP Duration:	2023

ERP Description

The aim of the Seed ERP was twofold: 1. To test the basic assumption that orchestrators can (learn to) classify problems and as a result design better orchestrations; 2. To prepare for the full ERP by lining up the empirical evidence needed to begin this multi-year study.

Summary Result 2023

i) Understanding Problems: Is There Hope? We piloted a quantitative concrete choice experiment in collaboration with a cognitive psychologists from the University of Groningen. Participants were drawn from three distinct groups: Experienced orchestrators, TNO *internal* orchestrating innovation course attendees, and *external* course attendees. We received responses to 137 problem classification questions. Before the lecture, 29% of participants classified innovation problems correctly. After the lecture, 41% of participants did. While further data is required to establish the effectiveness of our learning approach for problem classification, initial findings are encouraging. **ii) Prototype Problem-Classification Method (Acceleration Compass).** We conducted an in-depth literature review (see v below) and interviewed orchestrators to develop a preliminary problem-classification method, the Acceleration Compass. **iii) Compilation of TNO Orchestration Initiatives.** We began compiling a long list of TNO orchestration initiatives that will be analysed retrospectively in the coming years allowing for a thorough failure and success pattern identification. **iv) Exploring Innovation Failures.** Through explorative interviews, we gathered insights into TNO's innovation failures. Notable examples included 'solar road,' the 'LAMP test,' the 'Doe-het-zelf raam,' and the 'Torwash for nitrogen.' Identifying common themes among these examples is the first step in understanding if we could have either prevented or accelerated failure. Initial red threads include: lack of clear problem-scope, clients' pressure, pursuing a dead-end strategy for too long.

Result 2023 – Seed ERP Accelerating orchestrated innovation

⚛ Key results	Result 2023

New knowledge/technologies/methods/insights
- We demonstrated that the lack of collaborative problem understanding leads to longer innovation cycles.
- We identify best practices of orchestrating innovation to classify innovation problems at the start of a project.
- We clustered innovation problems by their level of complexity
- We created a framework to match the innovation approach to the level of complexity of the problem orchestration attempts to solve.

Prototypes/demonstrators/models
- Prototype Problem-Classification Method (Acceleration Compass).

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🤝 Partnership & Dissemination	📊 Valorisation

Knowledge partners
- TUDelft | One of TNO Vector employees was successfully granted a PhD position at TU Delft
- RUG | Lecture on problem classification for entrepreneurship students at University of Groningen
- Invited keynote at the Sustainable Society Network event at the Green Village Field Lab

Stakeholder involvement
- The community of alumni's from both the TNO internal course as the course of TNO together with Erasmus Centre for Entrepreneurship was participated in validation of the acceleration compass

Dissemination
- Abstract for the RENT conference 2024: "Accelerating innovation though problem collectivization: the role of goal specificity and interdependence".
- Abstract for the EGOS Conference 2024: "Is it tame or is it wicked? The effect of problem differentiation on innovation strategies."
- Workshop at RSD Conference. An external stakeholder workshop was given at the RSD12 (Relating Systems Thinking and Design) – Conference in October 2023, providing an excellent opportunity to share our research progress with a broader audience and gather valuable feedback from a community of systems innovation experts to sharpen our work for the full ERP.

Actions towards valorisation
- **Use-cases and orchestration strategies**: We organized collaborative problem-solving exercises[1] through three use-case focus groups, around innovation challenges on energy-label for building (led by MBE) and laser satellite communication (led by HTI).
- 2-stages NWO-KIC Mission-driven innovation proposal "Future-proof retrofits with Integral Quality Assurance" submitted to test the Acceleration Compass Longitudinally in the next 5 years.

Achieved valorisation
- N.A.

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[1] The collaborative problem solving exercise is a method developed by Harvard University to generate a large number of in-depth solutions to problems and sketch actionable strategies a in a short-time.