EARTO Case Studies on Technology Infrastructures

11 May 2022

Technology infrastructures (TIs) are critical enablers for the European research, development and innovation ecosystems and are major building blocks for Europe to deliver on its ambitions of making successful transitions to a sustainable, digital and resilient industry and society. As European industry's innovation capacity, productivity and international competitiveness heavily depend on possibilities to develop, test, validate and upscale new technological solutions at an even-faster pace, TIs are crucial elements of building bridges between science and the market.

TIs are (physical or virtual) facilities and equipment, such as demonstrators, testbeds, piloting facilities and living labs, capable of building bridges between science and the market. They are mostly created, managed, maintained and upgraded by not-for-profit Research Performing Organisations (mainly Research and Technology Organisations – RTOs, and Technical Universities – TUs), which require dedicated and significant resources and competences. TIs are open to a wide range of public and private users, large and small, collaborating with TI managers to jointly develop and integrate innovative technologies into new products, processes, and services.

Current Policy Context

The EC Communication on a new ERA for Research and Innovation (2020) stresses that "Industry, and notably SMEs, require access to the right technology infrastructures to quickly develop and test their innovations and successfully enter the market." This EC Communication has been endorsed by the Council Conclusions on the New European Research Area (2020), which call for the development of an EU Strategy for Technology Infrastructures. The strategic importance of TIs in RD&I Ecosystems has also been highlighted in the EC Proposal for a Council Recommendation on a Pact for Research and Innovation in Europe (2021). This was the basis for the Council Recommendations on a Pact for R&I in Europe (2021), with a concrete Policy Agenda for the new ERA and a dedicated action plan for TIs over the next three years (i.e. ERA Action 12). Recently, the European Commission JRC & EARTO published a joint report on TIs 'Towards the Implementation of an EU Strategy for Technology Infrastructures: Insights for the implementation of the ERA Policy Agenda' to support TIs key positioning in policy-making in Europe. The report provides key policy recommendations to support the implementation of the ERA Policy Agenda towards an integrated European landscape for TIs in the next three years. More specifically, the report shed light on the common specificities of TIs across Europe, assessed the challenges they face over their whole lifecycle, and identified how their capacity could be further leveraged.

Currently, Member States and the European Commission are organising the discussion around the national commitments to ERA Actions, including on the ERA Action 12 looking at further ERA technology roadmaps and their technology infrastructures to support green transitions. To support Member States and the European Commission in their thinking on how to further develop the new EU strategy on technology Infrastructures envisioned in the ERA Policy Agenda, this booklet showcases various case studies on some key TIs created and managed by EARTO members. As such this booklet provides evidence on the wide variety of TIs that exists (different service delivery models, different users, different funding models, different topics/areas/focus, etc.). **This booklet particularly aims to exemplify what is a TI, hence serves as a reference for the ongoing discussions with the European Commission and Members States on TIs.**

Contents

CASE STUDY 1 – EURAC TECHNOLOGY INFRASTRUCTURE: TERRAXCUBE

Authors: Eva Maria Moar, Christian Steurer

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Introduction

Name of the Technology Infrastructure (TI): terraXcube

Name(s) or the organisations managing the TI: EURAC Research

Geographical location of the TI: Bolzano, South Tyrol, Italy

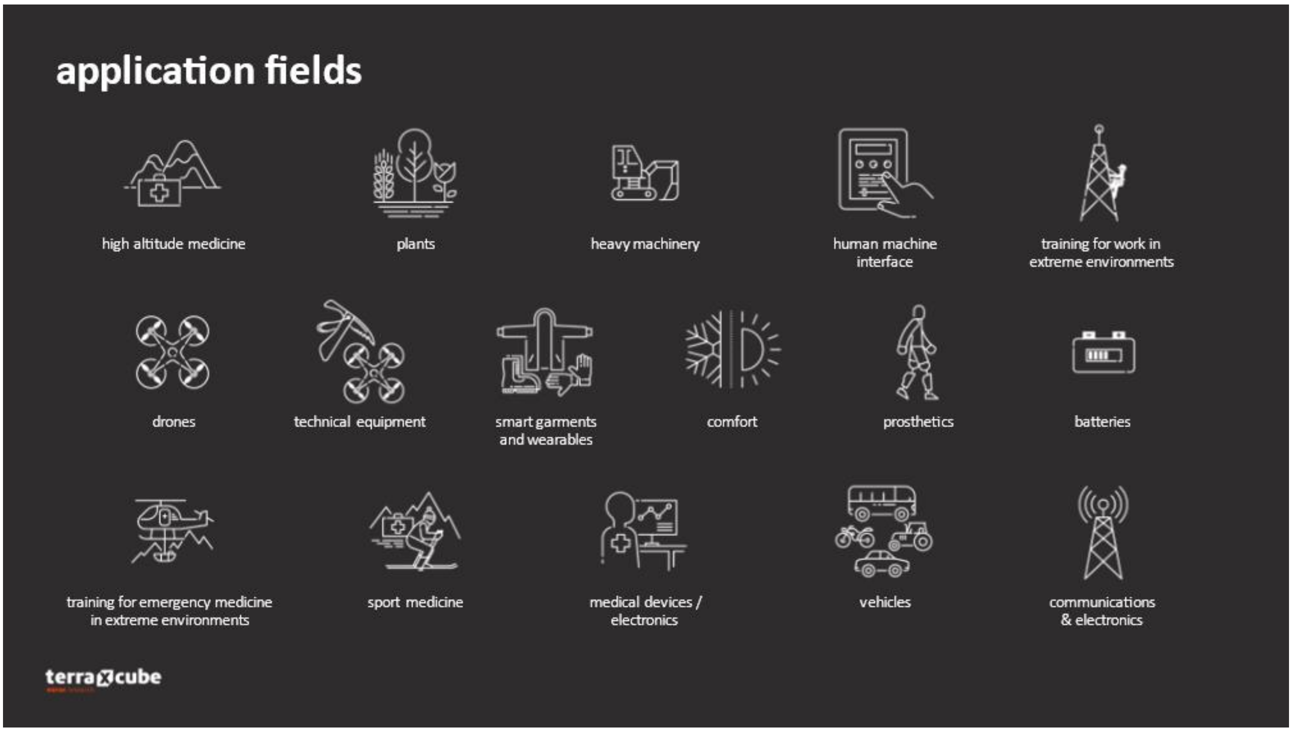
TI in national/European database of TIs: terraXcube is not listed in national/European database of TIs.

Focus of the TI activities: terraXcube is Eurac Research's Extreme climate simulation centre at the NOI Techpark in Bolzano (South Tyrol/ Italy) that simulates all the environmental conditions of our planet, up to extreme values. terraXcube combines hypobaric and altitude technology with state-of-the-art environmental simulation, aiming to investigate the effects of extreme climate conditions on humans, ecological processes and industrial products. The climate chambers differ in size and equipment. They can accommodate people, plants and other living organisms even over more extended periods and offer space also for huge machines and products.

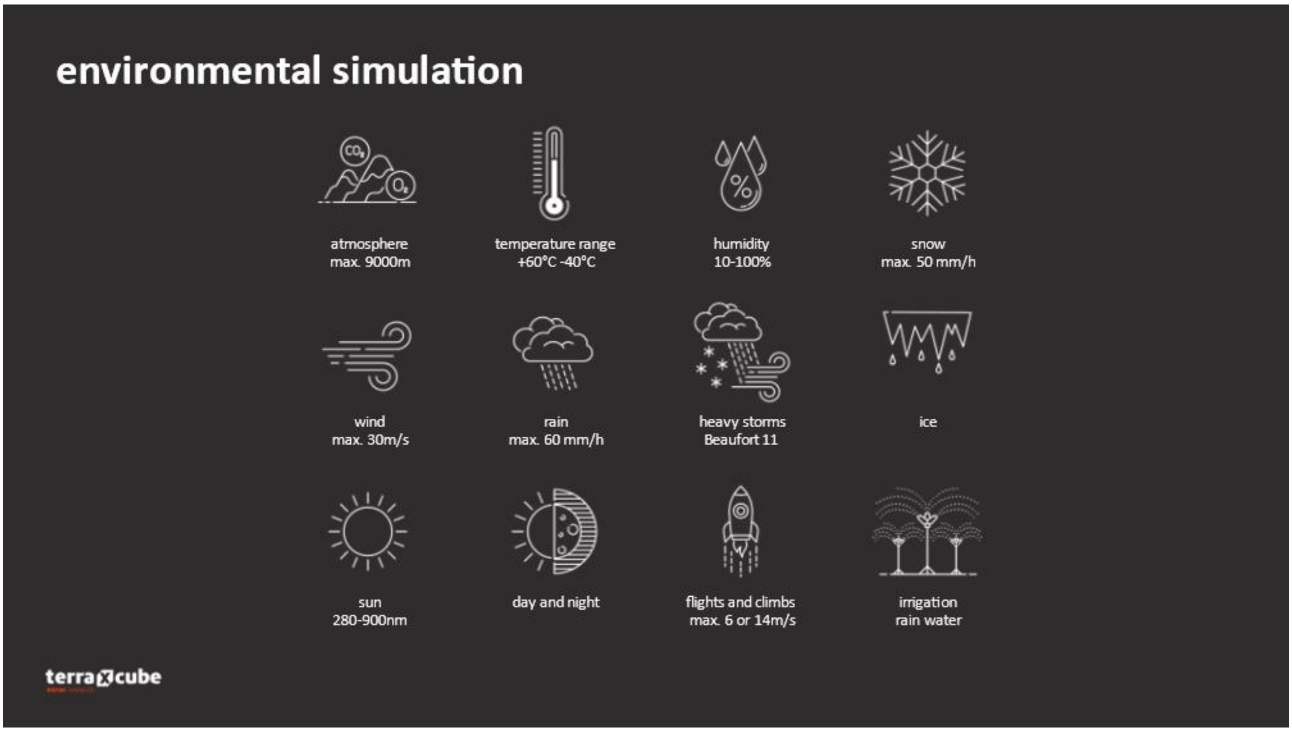
Technology fields:

terraXcube is focused on:

- product testing: terraXcube offers companies the possibility to carry out a wide range of tests and studies under extreme and at the same time, strictly controlled environmental conditions (tests of big machines and aggregates, vehicles, drones and single components, electrical devices, garments etc.). The lab can support the entire process of product development and testing, ranging from the technology development to the early-stage experimentation, upscaling, prototyping, validation and demonstration;
- medical research: the infrastructure allows scientists to study human physiological responses to challenging environmental conditions, in a safe and controllable lab, mainly for altitude medicine and emergency medicine research purposes;
- ecological research: the infrastructure can be used the whole year to investigate the impact of global climatic change on ecosystems in realistic environmental conditions while assuring the accuracy of a controlled lab;
- UAV research: remotely piloted aircraft (UAVs), commonly known as drones, are becoming ever more widespread in a variety of fields. In the world of aeronautics, one of the fastest growing and most highly invested in sectors is research & development. However, testing the performance and functionality of various types of UAVs under extreme climatic conditions is complicated as test conditions are uncontrollable and economic risks can be excessive. In the terraXcube, technical staff can simultaneously control multiple climate parameters and recreate perfectly reproducible test conditions;
- cognitive science: Over the years, scientific studies on the mind and brain have produced in-depth investigations and contributed to the advanced understanding of many processes underlying cognitive and brain functions. However, the majority of experiments in this field have been performed under highly artificial conditions. Thanks to terraXcube technology, high altitude and extreme environmental conditions can be simulated in the Large Cube to reproduce situations similar to everyday life, enabling scientists and researchers to bridge the gap between laboratory research and real-world studies. An important aspect is the study of perceived comfort, for example testing technical fabrics whilst performing sport or validating experimental models of theoretical prototypes.
  In the terraXcube, cognitive functions such as attention and memory can be investigated at the same time as training activities. Other projects can focus on perception of the body in relation to environmental conditions;
- training: this field covers three areas: 1) emergency medical care during rescue operations, 2) human-machine interfacing during work operations, 3) acclimatisation for operations at extreme heights. The terraXcube provides a safe training and preparatory environment for a variety of operations at extreme heights and under difficult conditions testing interactions with technology in controllable conditions enables human-machine interface optimisation.

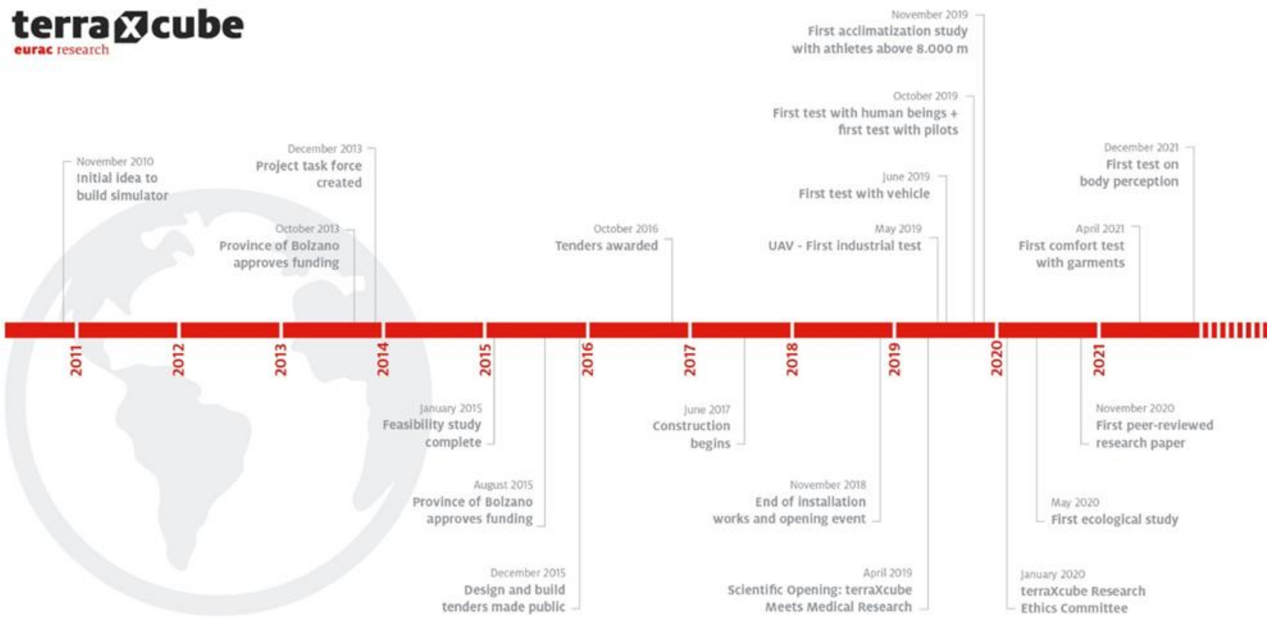


The following environmental parameters can be reproduced simultaneously in the infrastructure (with the possibility to combine all the parameters differently):



All terraXcube activities aim to acquire knowledge for the benefit of humankind and to primarily pursue civil objectives. terraXcube fundamentally rejects research and development and training activities in all areas of the weapons industry that directly contribute to the development of products, technologies and human skills that could harm other human beings, animals or the environment. Research that primarily concerns the weapons industry, e.g. research, development and testing of weapons or weapons systems, may not be carried out in the terraXcube. The **terraXcube Research Ethics Committee (REC),** formally created in January 2021, provides expert opinions in cases of research projects or tests of applications which have ethical implications for human dignity, life, health, liberty, property, the environment or peaceful coexistence.

Short history of the TI:



1. Service-delivery model

1.1. Ownership/management

Eurac Research, a private research organisation, is the owner of the infrastructure (www.eurac.edu). The infrastructure is operated and developed by a dedicated organisational unit of Eurac Research, the multidisciplinary centre terraXcube. A board composed of main local stakeholder representatives (research, industry, university, public administration …) is supervising the strategic development of the infrastructure.

1.2. Users

Openness policy and access conditions: The infrastructure is open to research organisations, industry and rescue organisations at local/national/EU/international level. Research institutes at Eurac Research act as ambassadors in the academic sector. Sales agents expand the business in the commercial sector and the NOI Techpark provides marketing and access to global European networks. For the usage of the infrastructure a price model was developed, based on a daily fee system. Proposals for research projects are welcome and are evaluated for their quality.

Process to reach new users and/or foster SME access: terraXcube is located at the NOI Techpark, the South Tyrol's innovation district. The Techpark plays a key role in reaching new opportunities to terraXcube through engagement with companies and sector-specific networks (networking events, workshops, visits to terraXcube, access to EU opportunities and international projects, participation in international events etc.). terraXcube also benefits from stable relations with universities, research institutions and technopoles in Italy as well as abroad. terraXcube´s sales experts collaborate to promote the facility in the DACH region. Additionally, the work of terraXcube is communicated externally in occasion of scientific conferences and sector-specific trade-shows as well as through websites, different media and social channels and targeted mailing activities.

1.3. Users

Services provided by the managing RTO and skills needed: The service provided is a tailor-made service: from the feasibility study to the test-design, support in conducting the test, data acquisition and data delivery.
terraXcube is accredited by the Italian accreditation body Accredia and performs testing activities in accordance with the requirements of UNI ISO 17025. The list of accreditation certificate and accredited tests can be viewed here. The accreditation concerns all processes from the use of technical equipment to administrative aspects and test procedures. **terraXcube is the first climate simulator worldwide in which certified heat and cold tests involving organisms and plants can be carried out. The extreme climate simulator is a recognized Conformity Assessment Body (CAB).**

2. Funding model

2.1. Investments for the creation and upgrade of the TI

Initial investment: € 8.9 M€ over 7 years.

TerraXcube is just starting to get operational. No upgrade/upscale costs have been incurred so far. The following costs/investments are expected to ensure the long-term sustainability: 10% of total investment per year is foreseen for upgrade/upscale.

The concept and technical specification of terraXcube had been realized by collaborators of Eurac Research, whose costs are paid by the general Eurac Research budget. The construction of terraXcube has been funded by provincial (public) funds. The Province of Bolzano disposes of a special funding programme for capacity building, for which terraXcube had been selected. No private funds were involved in the construction of terraXcube. The total amount of investment costs comes up to 8.865.640€, covered by the Province of Bolzano.

The significant investment made so far has developed an ecosystem between research and industry that involves a strong acquisition of know-how in the field of extreme conditions, which is then transferred to the participating companies and to various applications in the industry sector. Ensuring a constant technology upgrade of the facility and enhancing it with additional functions (for example as a snow or ice test centre) guarantees a long-term use of the infrastructure and the extension of cooperation between companies and research.

2.2. Operational costs (usage/maintenance/depreciation)

The following turnover have been calculated for the running of the infrastructure

- 70 percent covered by Eurac Research basic funding
- 12 percent covered by incomes from industry projects
- 18 percent covered by research projects with public funding (incl. EU projects)

The following describes the main yearly cost division:

- Variable costs incl. cost of goods (energy...)	13.4%
- Personnel costs	57.4%
- Small investments	0.2%
- Repair and maintenance	7.4%
- Insurances	1.2%
- Office material	0.3%
- Advertising/trade shows/public relations	2.7%
- Training	2.1%
- Travel and costs and entertainment expenses	0.8%
- Rents and leases	9.6%
- Board and lodging	0.6%
- Other pers.costs/Recruiting	0.1%

3. Role in the RD&I ecosystem/innovation hub

terraXcube is a light tower project in the Euregio Region capable of reproducing all climate factors up to extreme values in a safe and controlled lab environment, acting as a bridge between science and industry. This infrastructure acts also as a demonstrator of a service-oriented lab facility in the context of the NOI Techpark.

Many different local companies and SMEs have been contacted to explore the possibility to test their products and services under harsh environmental conditions. As the performance of their products changes, the possibility to increase the robustness of different technological solutions seems to be an important added value in many application fields, in particular in the field of alpine technology, representing a pillar of the smart specialization strategy of the Autonomous Province of Bolzano/Bozen

3.1 Role of the TI in knowledge creation/technology transfer

Success story on the spotlight: Stories can be viewed here.

Connection with other TIs at regional/national/European level:

terraXcube is connected at regional level with the "Polo della Meccatronica" in Rovereto (Italy) and its Prototyping Mechatronics (ProM) Facility. The union of terraXcube, in delivering climatic testing, and ProM, in providing large scale prototyping, enables a wider service portfolio.
terraXcube is also partner of the MedTech-Cluster as well as of the Automobil Cluster in Austria.
Other links have been established at national level with Italian Universities (Politecnico di Torino e Politecnico di Milano), with the Italian Airforce unit and specifically with its hypobaric training facility for pilots in Pratica di Mare as well as with the Alpine Troops Command of the Italian Army.

Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

- Attracting small enterprises to use the facility: the daily price is market-oriented and for small companies this cost could be very high, particularly if the usage is for a long period. In this case, innovation grants (i.e. vouchers) would be appropriate to facilitate the usage of the infrastructure. Currently, terraXcube is also exploring the idea of approaching their industry and trade associations to reduce the usage price for their members.
- terraXcube investigated on the State Aid rules, since we sell services on the market. We are checking whether the internal rules are sufficiently clear to ensure that the economic activities performed by the infrastructure are considered as purely ancillary, not exceeding the 20% of the overall annual capacity of Eurac Research.
- The infrastructure was completely financed by regional funding, a programme which was thought to finance new infrastructure capacities in the region. No particular problems in accessing these funds have been encountered. Eurac Research did not investigate on national funds for infrastructures. Regarding European funds, it seems that only networks for running infrastructures are being financed.
- Regarding the financing and running of the infrastructure: if funded by public/structural funds, the problem is that the organisation running the infrastructure afterwards falls under state aid rules when offering the infrastructure for tests and similar on the market. This is contradictory: the public body is financing a research infrastructure (for public needs) but pretends that it should be self-sustaining (needs external income to keep it running). This is not even compatible with the idea that research/tech infrastructures should serve the following mission: "Research Infrastructures extend the frontiers of knowledge by providing state of the art services to research and innovation communities, thus contributing to the objectives of the clusters and missions supported in Horizon Europe." Hence, if the contribution to innovation is considered important, the risk for research organisations to cover the burden of state aid rules has to be minimised (e.g. through excluding structural funds contributions to infrastructures from the application field of state aid, as H2020). This would also allow a more flexible pricing system on local level, enabling smaller companies to access the services without problems.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

- It is important to provide small infrastructure with basic and effective tools for small projects also.

CASE STUDY 2 – EURECAT TECHNOLOGY INFRASTRUCTURE: REIMAGINE TEXTILE

Authors: Esther Hurtos Casals

Introduction

Name of the Technology Infrastructure (TI): Reimagine Textile - (Fablab)

Name(s) or the organisations managing the TI: Eurecat (50%) and Fundació Tecnocampus Mataró-Maresme (50%)

Geographical location of the TI: Mataró, SPAIN

Technology field: Advanced Materials and Manufacturing / Textile

Focus of the TI activities: The activities and services offered by Reimagine Textile are focused on Business Innovation by offering experimentation laboratories, Technological support, Competitive intelligence and Training. It brings together textile technology, innovation, talent, new business models, new skills, design and digitalisation.

Short history of the TI:

- Created in 2013 by Cetemmsa, one of the RTOs that merged to constitute Eurecat.
- 50% sharing with Fundació Tecnocampus Mataró-Maresme.
- 2018: Mataró Municipality engagement through PECT project (ERDF funding).

1. Service-delivery model

1.1 Ownership/management

The TI is co-owned by Eurecat and Fundació Tecnocampus Mataró-Maresme.

1.2 Users

Type of users: The 5 main concepts of Reimagine Textile are technology, industry, training, entrepreneurship and investment. As a result, it is made up of companies, entrepreneurs, technology centres, Fablabs, schools of design, investors, mentors, incubators, accelerators, consultants and associations from the Catalan region mainly.

Openness policy and access conditions: It is an ecosystem based on an open philosophy: its members cooperate, share, co-work, co-create, co-invest and connect.

Process to reach new users and/or foster SME access:
- Web platform: +14,000 users in 2018-2020 period.
- Organising thematic workshops: +150 attendants in 2018-2020 period.
- Organising inspirational tours of the facilities: 13 tours in 2018-2020 period.
- Network of dissemination collaborators: umbrella organisations: sectorial and SME associations: PIMEC, TEXFOR and AEQCT.

Projects:
- 15 experimental proof of concept projects in 2018-2020 period.
- 55 entrepreneurship pre-seed projects selected amongst 268 applications in 2018-2020 period.

1.3 Services provided by the managing RTO and skills needed

Technology-related services
- Creative labs to test innovations and to assess the technical viability and feasibility.
- Advanced prototyping laboratory.
- Company technological diagnosis to improve the productivity and to implement digital tools to increase efficiency.

Non-technological services:
- Competitive intelligence service including analytical information and trends in the textile sector.
- Entrepreneurship program.
- Corporate accelerator.
- Business incubation.
- Mentoring.
- Financing.
- Consulting on new business models.
- Networking events.
- Training: High level specialization program that includes masters, postgraduates and specialisation courses.
- Job board posting the job offers from companies in the textile sector.

2. Funding model

2.1 Initial investments for the creation of the TI

The creation of this TI was not included in national/regional strategic roadmaps/plans.

Size of initial investment: 1,500,000 € over the 2018-2021 period.

Sources of funding: 25% own RTO funding and 75% public funding from the regional ERDF PECT Program.

2.2 Upgrade/upscale investments (long-term sustainability)

The upgrade of this TI is not included in national/regional strategic roadmaps/plans.

Size of (past & foreseen) investments for upgrades/upscales (total & /year): Foreseen: 300,000 € per year.

Sources of funding for upgrades/upscales: 20% Public funding: local, regional and EU and 80% private co-funding for projects and annual subscription fees.

Key challenges faced to ensure the long-term sustainability: No mid-term stable public funding plans.

2.3 Operational costs (usage/maintenance/depreciation)

Average operational costs: Foreseen 210,000 €/year

Types of operational costs for running the TI:
- Dedicated staff: textile and consultancy experts - 54% of costs
- Use of infrastructures and equipment - 15% of costs
- Materials - 14% of costs
- Subcontracted external services - 12% of costs
- Maintenance - 2% of costs

- Marketing - 3% of costs

Operational costs coverage foreseen:

- 20% Public funding: local, regional and EU.
- 80% Private co-funding for projects and annual subscription fees.

Sources of private funding coming from:

- Subscription services: RT Passport for Start Ups; Tech radar, FabLab access, in company training for SMEs
- Direct contracts for SMEs projects for corporate accelerator, R&D and Tech transfer.
- Monthly fee, partially co-funded, for start-ups in the incubator program.
- Business council sponsorship: annual fee provided by the companies in the Council to participate in the strategic plans and dedicated tech radar.

Free services:

- Pre-seed entrepreneurs: Freemium.
- X hours free access to the FabLab for SMEs.

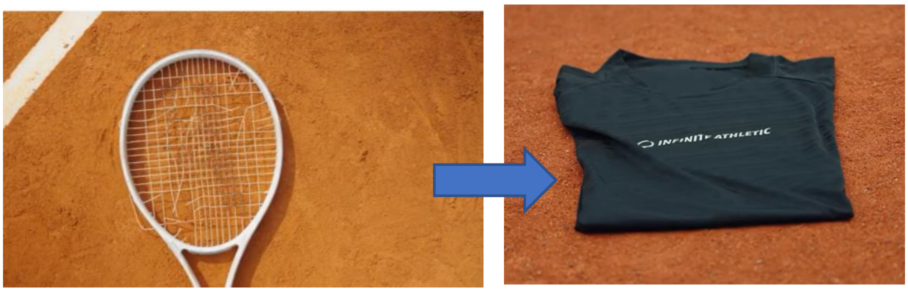
3. Role in the RD&I ecosystem/innovation hub

Role of the TI in the RD&I ecosystem: Reimagine Textile aims to promote a textile ecosystem of innovation and entrepreneurship. The textile sector is identified as one of the 14 industrial ecosystems of the new EC Industrial Strategy and has a key role in addressing the Circular Economy challenges towards the EU Green Deal. There is also a plan for networking with other EU textile incubators.

3.1 Role of the TI in knowledge creation/technology transfer

- 30 adhoc technology roadmaps for companies in 2018-2020.
- 31 spin-offs created thanks to this TI in total in 2018-2020.
- 63 jobs created in 2018-2020.

Success story on the spotlight: Infinite Athletic converts used tennis racket strings into fully recyclable tennis shirts. It is an entrepreneurship initiative from textile engineers that have benefited from the Reimagine Textile Incubator and fab lab services. First time ever that racquet strings are recycled. 60 tonnes per year are wasted in Spain, about 400 tonnes in Europe. They have now their first production batch of 1,000 units. It is a 100% Polyester monofilament with great tenacity that provides high durability to the clothes. By recycling and adding color during the extrusion of the yarn, there is a reduction in water consumption by 80%, energy consumption by 60% and CO2 emissions by 70%, when compared to a conventional polyester.



Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

- Short to midterm financial sustainability.
- Uncertainty on the availability of the necessary funding to invest in keeping it updated.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

- To implement the tools for supporting with funding what already exists, such as our Reimagine Textile and to map and support the creation of new Tis, when there is a market need.
- We now have nice infrastructures, we can prove an impact and value to the textile sector, but, without financial sustainability, the risk is that the TIs fails to remain up to date and becomes obsolete.
- To promote the collaboration amongst TIs at EU level.

CASE STUDY 3 – JSI TECHNOLOGY INFRASTRUCTURE: RESEARCH REACTOR TRIGA MARK II

Authors: Leon Cizelj, Igor Jenčič, Romana Jordan, Jan Malec, Marja Mali, Borut Smodiš, Luka Snoj. Špela Stres

Photo Jan Malec

Introduction

Name of the Technology Infrastructure (TI): Research Reactor TRIGA MARK II (https://ric.ijs.si/en//)

Name(s) or the organisations managing the TI: Institute Jozef Stefan (https://www.ijs.si/ijsw/V001/JSI)

Geographical location of the TI: The Jožef Stefan Institute Reactor Center is nicely placed in the environment in the middle of fields and meadows on the northern bank of the Sava river, about 12 km northeast of Ljubljana. It is surrounded by the settlements Šentjakob, Podgorica, Pšata, Bišče and Brinje.

TI in national/European database of TIs: The reactor is listed in the following national and European databases of technology infrastructures:

- IAEA Research Reactor Database (RRDB)
- Brief description of the research infrastructures relevant for the Euratom programmes of Horizon2020 and beyond, prepared by the Euratom Scientific and Technical Committee in 2016
- Advanced European Infrastructures for Detectors at Accelerators
- TRIGA critical experiments were thoroughly analysed and included in ICSBEP (International Criticality Safety Benchmark Evaluation) handbook.

Technology field: nuclear technology, nuclear energy

Focus of the TI activities: The 250 kW_{th} TRIGA Mark II research reactor is a light water reactor, with solid fuel elements in which zirconium hydride moderator is homogeneously distributed between 20% enriched uranium. The reactor core yields the maximum neutron flux in the central thimble of 10^{13} n cm^{-1} s^{-1}. A 40-position rotary specimen rack (located around the fuel elements), two pneumatic tube transfer rabbit systems, as well as central thimble and three extra positions in the core are used for irradiation of samples. Additional experimental facilities include two radial and two tangential beam tubes, a graphite thermal column and a thermalizing column. In 1991 the reactor underwent major reconstruction, which involved the installation of a pulse rod so that it can be operated also in a pulse mode, achieving up to 1 GW for a few 10 ms.

As the abbreviation TRIGA implies, the reactor has been mainly utilized (apart from “GA”, abbreviation for the producer **G**eneral **A**tomics) for **T**raining, **R**esearch and **I**sotopes production.

Education and training activities comprise regular experimental exercises for graduate and postgraduate students from several national and foreign universities, training of reactor operators, courses organized by the JSI Nuclear Training Centre, as well as visits for general population. International collaborations include participation in two networks coordinated by the International Atomic Energy agency (IAEA): the East European Research Reactor Initiative and the Advisory Safety Committee for Research Reactors in Eastern Europe. In addition, the reactor staff acts as IAEA external experts and train IAEA fellows upon request. Neutron activation analysis has represented one of the most important utilizations of the reactor since its commissioning. Other research applications comprise irradiation of various materials, radiation hardness studies, verification and validation of computer codes and nuclear data, and development of a digital reactivity meter. Although the production of medical and industrial isotopes discontinued, there are still some short-lived isotopes produced for mostly on-site users.

Short history of the TI: The decision for a research reactor in Slovenia was taken in late 1950s and is strongly connected with the activities of Jožef Stefan Institute (JSI) for peaceful use of nuclear energy and the needs of energy sector. The preliminary agreement on reactor delivery was signed in the year 1960, the final contract in 1961, construction started in 1963. The TRIGA MARK II research reactor has been in operation since 1966, it achieved the first criticality on 31st May 1966. In 1991, it was reconstructed and equipped for pulse operation. The reactor has accumulated 54 years of continuous operation without any failure of major equipment or any event violating safety standards. It will operate at least until 2026, when the next periodic safety review will have been completed.

1. Service-delivery model

1.1. Ownership/management

The reactor is owned and operated by the Jožef Stefan Institute (JSI), Ljubljana. The main national stakeholders are:

- The Slovenian Nuclear Safety Administration (SNSA) carries out at least two inspections per year, including the review of documentation, periodic safety reviews and reviews each new modification at the reactor that can have an impact on nuclear safety.
- The Slovenian Research Agency (SRA) is the funding agency for the reactor staff and maintenance according to the national research programme.

1.2. Users

The main national beneficiaries receiving free of charge services are:

- The Agency for Radwaste Management (ARAO) is hiring the Hot Cells Facility.
- The Krško Nuclear Power Plant through the training courses for their staff organized by the JSI Nuclear Training Centre (ICJT). This training includes exercises in nuclear and reactor physics on TRIGA research reactor. Future NPP operators also obtain a “junior reactor operator” license on TRIGA reactor.
- The University of Ljubljana – Faculty of Mathematics and Physics: there are two subjects, where students alternately perform exercises once a week.
- The University of Ljubljana – Faculty of Electrical Engineering: once a year, a group of students performs the basic exercises to get some experience in reactor physics.
- The University of Maribor – Faculty for Energy: once a year, a group of students visit the reactor.

Other national customers now comprise two SMEs, making radiation resistant electronics. The components are tested by well-characterised irradiations, involving gamma rays and/or neutrons.

In general, the reactor staff supports public visits to the reactor, organised both, for general public and the professional trainees. There are about 40 group visits yearly, comprising over 1,000 primary and high school students. About 30 trainees, working with radioactive materials, are toured through the facility yearly, and about three short courses are organised for firefighters and police officers, to be trained in work with radioactive materials in practice.

The main international stakeholders are:

- International Atomic Energy Agency (IAEA): Slovenia is under the IAEA safeguards agreement, thus the reactor staff provides assistance regarding technical issues and provides training courses for IAEA trainees and fellows.

- Euratom: Fissile material balance is reported to Euratom monthly and yearly. Every year, Euratom (usually in collaboration with IAEA) performs an inspection.
- Irradiation of samples with highly thermalized neutron spectra is provided to a number of international customers, based on either bilateral or multilateral cooperation. Various equipment can be placed either in irradiation channels or inside measurement positions among fuel elements. The customers usually reserve the whole reactor time for a week at a time. The main international customers are the European Organization for Nuclear Research (CERN) and French Alternative Energies and Atomic Energy Commission (CEA).

In 2018, the research reactor was included in 11 bilateral projects with 118.346 EUR of income and in one H2020 project.

2. Funding model

2.1. Investments for the creation and upgrade of the TI

Initial funding comprised federal and national funds, as well as international aid. The existing specific financial support includes:

- 200.000 $ (17.548,55 EUR) from USA government funds (14,4 %) in year 1960,
- 33.000 $ (28.955,11 EUR) from USA funds for nuclear fuel (2,4 %) in year 1963,
- 1 billion DIN (1.333.333,33 $ or 1.169.903,60 EUR) from federal funds (exchange rates: 1 USD = 750 din, 1 USD = 0,877427 €) in year 1963,
- national funds.

Upgrade to pulsing capability was done in years 1990 and 1991, the total investment is estimated to a few 100.000 € and was covered by the Slovenian government, specifically by the Ministry of Defence.

2.2. Operational costs (usage/maintenance/depreciation)

Approximate average yearly budget for basic reactor operation is 600.000 €. Types of costs and their yearly amount for 2018 are as follows:

Operating costs:

- Dedicated staff 187.000 €
- Electricity - 26.600 €
- Security - 3.100 €
- Water - 600 €
- Heating - 11.000 €
- Cleaning - 4.500 €
- Duty for urban land - 2.500 €
- Maintenance - 57.000 €
- Other running costs - 60.000 €
- Administration costs - 23.000 €
- Material costs - 7.500 €
- Other services costs - 48.000 €
- Radiological examinations and supervision - 103.200 €

Depreciation costs:

- Depreciation costs of building 24.500 €
- Depreciation costs of small equipment 36.500 €

The assessment of the operating costs is not based on the exact running costs, but is calculated according to the allocation keys of the JSI's for research departments and centres.

Most of the above costs are covered through the national financing by the Slovenian Research Agency and a smaller part through the national market by customers of the reactor services.

2.3. Services provided by the managing RTO and skills needed

Support and services for the industry:

- The infrastructure provided by the reactor enabled JSI to develop and validate core design package CORD-2, simulation software LoadF and a digital reactivity meter DMR043, which allowed the Krško NPP to be more independent than commercial companies, such as Westinghouse, and to thereby

have a better negotiation position, greatly reduced the time needed to perform start-up tests, leading to significant savings.
- Design, development and testing of radiation hard products, such as LED lighting and processing electronics and nuclear radiation detectors.
- Research of proton therapy options in Slovenia.

Only in 2019 the Reactor was used for the following research activities:

- Reactor physics and neutronics;
- Activation analysis;
- Research on radiation damage of semiconductors;
- Neutron dosimetry and spectrometry;
- Activation of materials, nuclear waste and decommissioning;
- Radiation hardness studies;
- Irradiation of materials for fusion reactors;
- Irradiation of electronic and medical components;
- Development and testing of new detectors;
- Development of new methods for measuring power profiles, neutron spectra, etc.;
- Verification and validation of methods for calculating the transport of neutrons, photons and electrons;
- Development of educational tools in reactor physics.

These research activities of the Reactor resulted in several established and/or continued collaborations in 2019 with domestic and international organizations. On the field of irradiations and tests several activities were performed. Sample irradiation was done with the French Alternative Energies and Atomic Energy Commission (CEA), irradiations of boron nitride nano powder in collaboration with the Institute of Radiation Problems of Azerbaijan National Academy of Sciences, semiconductor samples were irradiated for the CERN and for the Department of Environmental Sciences at the Jožef Stefan Institute, while with the Department of Experimental Particle Physics at the Jožef Stefan Institute and Turkish Nuclear Radiation Detectors Application and Research Centre tests of semiconductor radiation detectors were performed. Additionally, radiation hardness tests on samples of special rubbers were completed for the company MK-TEAM, tests on Rolls Royce Civil Nuclear SAS nuclear-acquisition system, ultrasound detectors were exposed to high neutron and gamma radiation with online test of detectors' survivability, the latter with the companies Acoustics, IONIX and TWI. Equipment tests were also performed for the Reactor Physics department at the Jožef Stefan Institute.

Cooperation with companies included also replacement of radiation source Kr-85 for the company Papirnica Vevče and the development of radiation-resistant lights with the companies DITO d. o. o. and Nanocut d. o. o.

Support was provided to research programmes and projects between Jožef Stefan Institute, the Faculty of Mathematics and Physics (University of Ljubljana), the Faculty of Electrical Engineering (University of Ljubljana) and the Faculty of Energy Technology (University of Maribor). Moreover, the Reactor is engaged in activities in projects AIDA (Advanced Infrastructures for Detectors and Accelerators) as a reference centre for neutron irradiation in the development of ATLAS detectors.

To exchange knowledge, practical exercises and courses were hosted for the Faculty of Mathematics and Physics, the Uppsala University, University of Milan and EERRI ''Group fellowship training course program'' with the International Atomic Energy Agency, while also accepting organized group visits to the Reactor from foreign scientists, students and schoolchildren.

3. Role in the RD&I ecosystem/innovation hub

The reactor's mission is to provide neutron and gamma-ray irradiation for research and development purposes in the interested institutions within the region and beyond. The vision and motto is to achieve and maintain the highest scientific level in a nuclear safe and working hospitable environment. Since its commissioning the reactor has been playing an important role in developing nuclear technology and safety culture in Slovenia being one of a few centres of modern technology in the country. Its international scientific cooperation and recognized reputation are important for promotion of JSI and the Slovenian science as well.

The main strength are the reactor's well characterised neutron spectra and gamma dose rates inside its irradiation channels, which is advantageous for accurate dosimetry measurements. The access to the reactor is easy and prompt, and therefore favourable for domestic and foreign researchers. Furthermore, it is favourable for trainees, as they can get familiar with a number of research reactor utilisation opportunities. The reactor offers many opportunities for regional research activities, including educating new human resources, either nuclear scientists or other professionals.

3.1. Role of the TI in knowledge creation/technology transfer

Main achievements in training and education:

- Practically all nuclear professionals in Slovenia started their career or attended practical training courses at the TRIGA reactor (including all professors of nuclear engineering and reactor physics at universities in Ljubljana and Maribor, as well as key personnel of the Krško Nuclear Power Plant (NEK), Slovenian Nuclear Safety Administration and Agency for Radioactive Waste.
- All NEK reactor operators and other technical staff have been, in part, trained on the TRIGA reactor.
- The reactor is used in regular laboratory exercises for graduate and post graduate students of physics and nuclear engineering at the Faculty of Mathematics and Physics, University of Ljubljana.
- On-the-job training for IAEA trainees from developing countries, on average twice per year.
- The reactor has been used in numerous international training courses.
- The reactor is open to the visitors, more than 1,000 per year, mainly schools.

Main achievements in research activities:

- Reactor has been used in research work published in approximately 300 scientific papers and more than 600 published conference reports.
- More than 20 PhD research works, more than 30 MSc degree works and more than 100 Diploma works have been performed using the reactor.
- In 2018, the reactor supported five research programmes funded by the Slovenian Research Agency and over 20 R&D national and international programmes and projects.
- In 2018, about 40 reactor-related scientific papers were published in international scientific journals, and six young researchers were performing their scientific work.
- Main areas of research connected to the reactor are fission reactor physics, nuclear instrumentation improvement of nuclear data, neutron activation analysis, radiation hardness studies and various fusion and medical physics related applications.
- TRIGA critical experiments were thoroughly analyzed and included in ICSBEP (International Criticality Safety Benchmark Evaluation) handbook.

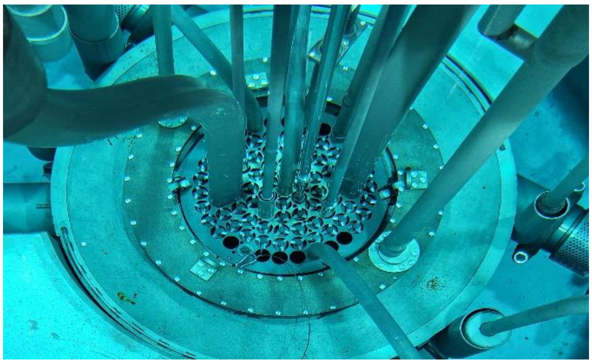
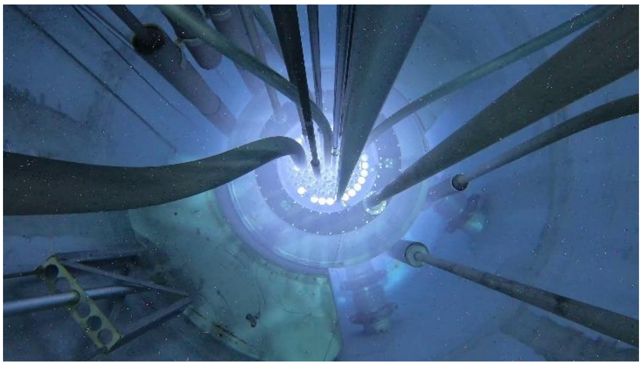
Isotope production

- Total number of patients treated with radio-isotopes produced in the reactor is more than 100.000 (mainly radioactive technetium).
- 10 - 20 industrial sealed sources per year (mainly cobalt), in total several hundred.
- Several special radioactive sources (e.g. radioactive sodium) in soluble compound for turbine testing in NEK.

3.2. Connection with other TIs at regional/national/European level:

Participation in international infrastructure networks:

- Eastern European Research Reactor Initiative (EERRI), supported by the IAEA,
- Europe Advisory Safety Committee for Research Reactors (EURASC), supported by IAEA,
- Horizon 2020 AIDA-2020 project on Advanced European Infrastructures for Detectors and Accelerators,
- European Atomic Energy Society Research Reactor Operators Group (EAES/RROG).

Conclusion: Challenges faced & Recommendations to policy makers

- **Regulatory challenges:** Nuclear activities are subject to very strict national and European regulations. Therefore, it is often hard to fulfil the industry needs when designing new types of experiments. Slovenia currently does not have a vision, strategy and action plan on energy research policy, including nuclear research and education. Regulatory solution for decommissioning of the reactor does not specify the financial resources.
- **Challenges connected with funding:** The national public funding is not sufficient for covering full costs of reactor operation, therefore the JSI contributes the missing funds. Consequently, international networking at regional and European level, involving stable long-term funding, is of upmost importance. The TRIGA Mark II reactor of JSI, although being a small and relatively old research reactor, can effectively support education and research in various fields and thus be valuable contributes at EU level. The reactor is over 50 years old and additional activities are required to preserve operating licence. Additional funds are needed to maintain safe reactor operation.
- **Shared and coordinated access for education and training:** Research reactors are part of the critical infrastructures indispensable for excellent building and transfer of competences including "know why (education)" and "know how (training)" to the future generations of nuclear graduates, postgraduates and professionals to be active in nuclear industrial and research facilities, as has been pointed out by the International Group on Research Reactors (http://www.igorr.com/). Currently, 36 research reactors are operational in EU, one (Jules Horowitz Reactor, JHR) is in construction and two (MYRRHA, PALLAS) are planned. They are complemented by approximately 150 research reactors in various stages of decommissioning. This is a clear indication that the retirement of the research reactors in EU is taking place at a much faster pace than construction of new ones. Even Member States (MS) with active plans to expand use of nuclear power (e.g., UK and Finland) do not poses an operating research reactor. This clearly calls for a joint action, possibly lead by the EC (already identified for example EC in the H2020 EURATOM call in 2018 and by ENEN, www.enen.eu) to create more opportunities for related research and competence building through coordinated and long term planning.
- **Existing nuclear infrastructures as potential for hosting diverse innovative research infrastructures:** Operation of a research reactor requires basic infrastructure, which can enable hosting innovative and diverse research infrastructures, e.g. in medical physics, radiation biology, or for example research or demonstration equipment for future small and modular reactors. Not many such sites exist in EU, thus joint national and EU investments in sustaining and further developing them as enablers of new approaches could create a high European added value.

Case Study 4 – Imec Technology Infrastructure: 300mm Cleanrooms

Authors: Anne Van den Bosch

Introduction

Name of the Technology Infrastructure (TI): 3 state-of-the-art cleanrooms with leading semiconductor industry relevant equipment (https://www.imec-int.com/en): FAB1 cleanroom, FAB2 cleanroom, FAB3 cleanroom.

Name(s) or the organisations managing the TI: imec

Geographical location of the TI: Leuven, Belgium

TI in national/European database of TIs:

- DIH database available at
- EUROPRACTICE list
- Imec is also part of a large research infrastructure project for starting communities ASCENT (funded under H2020) where the 300mm cleanroom services are opened to the academic world worldwide. Information about the access to infrastructure can be found using the following link

Technology field: Nano and Digital technology, semiconductors

Focus of the TI activities: FAB2 opened in June 2004 as a 300 mm ballroom cleanroom. FAB2 extension (ready in 2010) and FAB3 (ready beginning of 2016) are both EUV compatible. The FAB2&FAB3 infrastructure allows imec to perform R&D at the most advanced technology nodes and this for logic as well as memory applications. Build around the most advanced Lithography clusters (immersion as well as EUV) our ability to perform R&D as well as to offer advanced vehicles (short loop as well as full CMOS processing) at aggressive cycle times attracts a broad set of partners from all over the world. Started with the Advanced Patterning Centre (collaboration with ASML) extended towards the Supplier hub since late 2013 an attractive offering towards equipment and material suppliers became available. The very advanced litho and patterning infrastructure as well as in-line metrology makes it attractive for equipment suppliers to place their tools and validate their solutions making use of the running imec vehicles (short loop up to full CMOS). This also results in the fact that the amount of process tools installed keeps on increasing, which triggered the extension of FAB2 and the construction of FAB3.

FAB 2 (300mm):

- A 3,200m2 ballroom type, class 1,000 cleanroom area (wafer sorter and microenvironments up to class 1); with 2,200m² resting on a vibration-controlled waffle table

- Silicon pilot line for sub-7nm CMOS processing on the most advanced industrial toolset, covering the entire process flow
- Semi-industrial operation (24/7; process monitoring; short cycle time)
- Highly advanced equipment, with preproduction tools
- Unique lithography cluster centered on ASML equipment (hyper-NA immersion scanner and EUV scanner etc.)
- A range of atomic-layer and metal-organic CVD tools, etc.
- Advanced etch and ultra-clean processing equipment, etc.
- Ultra-thin magnetic film and multilayer deposition tools for nano-magnetic and spintronic applications

FAB 3 (300mm) - 3-level fab with cleanroom, clean sub fab and dirty sub fab level:

- A 4,000m2 ballroom type, class 1000 cleanroom area (wafer sorter and micro-environments up to class 1); resting on a vibration-controlled waffle table
- Silicon pilot line for sub-7nm CMOS processing on industrial size wafers, covering the entire process flow Semi-industrial operation (24/7; process monitoring; short cycle time)
- Highly advanced equipment, with preproduction tools
- Unique lithography cluster centred on ASML equipment (hyper-NA immersion scanner and EUV scanner etc.
- A range of atomic-layer and metal-organic CVD tools, etc.
- Advanced tech and ultra-clean processing equipment, etc.

Short history of the TI:

- FAB3 cleanroom – 300mm processing: operational from Q1, 2016: Engineering started early 2012, 60 % design was completed end 2013. Construction started June 2014
- FAB2 cleanroom – 300mm processing: R&D towards (sub-)2nm device architectures and process R&D: FAB2 opened 2004, and extension opened in 2010
- FAB1 cleanroom – 200mm processing: R&D, prototyping and low volume manufacturing on more-than-Moore technologies: was built in 1986-1987 as a partly class 1 partly class 1000 5" facility, extended in 1998 with 1000 m2 and went through several wafer size migrations from 5" over 6" till today 200 mm

1. Service-delivery model

1.1 Ownership/management

The cleanrooms are run by imec employees only. So, a totally open and dedicated physical access to the infrastructure is not a standard option. A resident model is in place where under well-defined conditions and subject to training certification, students, academic researchers and industry residents can access the facility.

Imec has a group of business development and funded managers that interact with potential users of the infrastructure on a daily base. Access conditions are depending on the needs of the users and is tailored accordingly.

1.2 Users

Openness policy and access conditions: Access to the infrastructure can go through different routes

- Through EUROPRACTICE. Imec supports academic institutions, research institutions and medium-sized companies with IC prototyping services, system integration solutions, training activities and possibilities for small volume production. In addition, we provide universities and research institutes with access to CAD tools.
- Through dedicated work for any of the industrial, start-up, academic partners looking for a specific solution within scope and competence of imec's facilities and expertise
- Through participation in the IIAP (see next paragraph)
- Through funded projects where imec co-develops together with the consortium partners

Process to reach new users and/or foster SME access: To enable imec's growth a variety of flexible business models have been put in place to answer to imec partners needs and challenges. The models can be split into industry-oriented partnership models and public-private-partnership funding models. The most relevant models are described below:

- Imec Industry Affiliation Program model (IIAP) has been the traditional imec model for a long time across several of our research offerings. It started with our nanoelectronics CMOS scaling research and has over the past 15 years expanded into other research offerings. The IIAP model is characterized by longer-term precompetitive activities where imec defines the research along a roadmap of phases of innovation and continuous progress. In general, each program addresses next generation technologies in all relevant semiconductor technology fields (Lithography, Logic, Memory, Optical I/O etc.) in a multi-partner context, where often market competitors work together on precompetitive items, sharing cost and risk, and creating critical mass. In its most general form partners can come from various angles across the full stack of the semiconductor ecosystem: system or design houses, software and EDA players, IDM's and Fabless companies, equipment and material suppliers.

- Joint Development Programs (JDP): Whereas the IIAP is essentially multi-partner oriented, the business model for different market segments may be distinctly different. As such, many of the IIAP programs build on various collaborative R&D engagements, many of which with the supplier community, on topics like equipment, materials, software, masks etc. The nature of a JDP is a topically focused collaboration, with two-way contributions, in areas of interest of the specific supplier in the broader context of a program, and as such building to the ecosystem of such program.
- Venture activities: Imec supports innovation in a number of ways (each program has its own focus and mission:
    - Imec.istart is the tech accelerator program that aims to boost digital innovation and entrepreneurship in Flanders. Imec.istart was recognized as one of the world's best university-linked business accelerators. Through the program, the start-ups become part of the imec ecosystem, which helps them to expand their network and find potential investors more easily.
    - Innovation is an integral part of imec's organizational culture and throughout the years, our employees have frequently leveraged their experience to set up successful imec spin-offs, supported by our investment fund Fidimec NV, mostly in partnership with other investors.
    - Imec.xpand is an early stage and growth fund that aims to turn hardware driven nanotechnology innovation into commercial success. Unlike imec.istart, imec.xpand only focuses on ventures in which imec's intellectual property, technology and expertise are determining factors for success. So even if the deep-tech venture idea was conceived externally, the targets are those benefiting greatly from imec technology.
- Interaction with the academic partners: Imec invests in activities that are critical to longstanding and high-quality interactions with academic teams. Historically there have been strong interactions with the Flemish universities – with the associated labs in pole position, and this remains a stronghold in imec's innovation engine. Besides these, imec continues to strengthen and build up strategically important interactions with universities worldwide. The role of academic relations in the imec strategy can be summarized as follows.
    - Joint research in the frame of joint research programs in key strategic research areas and disciplines. Imec is continuously looking for structural collaborations as well as for funding of such joint research.
    - Teaching: imec is contributing in educating students in the imec research disciplines at master, PhD and postdoctoral level.
- Interactions with the Flemish government, and the governments where imec has international presence (e.g. The Netherlands, US, etc): The continuous support of the Flemish government was and still is crucial for imec to reach and maintain leading position in nanoelectronics technology. The structural local funding allows imec to start new research domains, to keep its independency and leadership position and therefore to attract international money. This allows imec to support innovation in Flemish companies in terms of technology, people, competences, knowledge, infrastructure, eco-system.

Use in multi-stakeholder competitive projects: EU funded programs (including ESA) based on research projects represented in 2018 about 6% of the total revenue of imec. Imec's research infrastructure and expertise is the base for participation in various public funded projects. In H2020 projects, the participation of imec is mainly in the Information and Communication Technologies programme (ICT) for the low TRL research although imec is also present in the Excellent Science and Societal Challenge pillars. Imec is also very active in projects from the ECSEL Joint Undertaking - the Public-Private Partnership for Electronic Components and Systems – which are targeting high TRL research, equipment development and pilot lines across Europe.

1.3 Services provided by the managing RTO and skills needed

The infrastructure and expertise that is built up in imec over the past decades are a very fertile ground for driving breakthrough results to industrial innovation and impact. Imec has many collaborations with partners where such ambition is the focus of the project. Examples are, as mentioned earlier, in the area of equipment and materials suppliers where options for new component integration are fleshed out, others are on the circuit and (sub-)system level where innovation is validated by virtual system prototyping and calibration of new experimental demonstrators. This is extremely valuable for e.g., start-ups, system innovation partners that do not have the specific microelectronics know-how (health, automotive, pharma) etc.

Next to the R&D offering imec also offers services in the following areas:

- Materials and Components Analysis: Imec supports and drives the development and implementation of tomorrows materials characterization techniques. This is accomplished through a careful balance between service work and fundamental research. More information on the available equipment and expertise can be found at https://www.imec-int.com/en/semiconductor-technology-and-systems/materials-and-components-analysis
- Imec.IC-link, whose core mission is to provide access and support to SMEs. It comprises the following services/ units:
    - ASIC services, providing foundry access support, prototyping, test and packaging
    - Design services, providing analog/ digital design and implementation
    - Center for Electronic Design and Manufacturing, providing support for the manufacturing of printed circuit boards and printed board assemblies

  More information can be found at https://www.imec-int.com/en/innovation

2. Funding model

2.1 Investments for the creation and upgrade of the TI

Today imec FAB cleanrooms and equipment can be estimated to have a value of about 3 billion EUR. The initial investment for the building infrastructure was supported by the Flemish government while the running costs and investment budget is leveraged by the JDPs.
As an illustration, in 2016 FAB3 cleanroom comprised a total investment (building and equipment) of more than 1 billion euro of which 100 million EUR funding from the Flemish Government and more than 900 million EUR investments from joint R&D with the leading players from the entire semiconductor industry, totalling more than 90 industrial partners.
Given the fast pace of technology development, it is imperative that the imec researchers always have access to state-of-the-art tools in the cleanroom. As a consequence, the tools in the cleanroom are being replaced on a continuous basis requiring a huge yearly investment.

2.2 Operational costs (usage/maintenance/depreciation)

In Horizon 2020 projects, imec is using the LRI scheme to claim the costs of the infrastructure. One of the major cost carriers is the lotturn cost. This cost includes f.e. the use of consumables, the depreciation of the tools and the operator costs This cost however does not include all costs such as but not limited to maintenance, staff to maintain the cleanroom, cleaning costs, insurance building and taxes. The lotturn cost funded by the European Commission covers around 80% of the real cost of a lotturn. Imec is therefore only participating in projects requiring a high processing cost if these projects are of the highest strategical value since not all costs are covered. It is expected that in Horizon Europe this issue will be addressed.

3. Role in the RD&I ecosystem/innovation hub

Imec's international exposure strengthens the organisation as an attraction pole for inward investments and/or related knowledge-creating activities. This is an asset that allows Flanders to attract R&D from industry leading companies worldwide to the region. The revenues from collaborations in Flanders, from collaborations with international sites of companies having a site in Flanders and from collaborations with companies who set up a R&D activity in Flanders related to the collaboration with imec are expected to increase in the years to come.

3.1 Role of the TI in knowledge creation/technology transfer

Publications, patents, spin-offs, PhD students are historically part of imec's Key Performance Indicators (KPIs). Detailed numbers for these for **2018** are given below. An estimation is made which portion of the KPI is linked to the use of the described infrastructure.

Key Performance Indicator for the year 2018	Total for imec	Related to the use of advanced infrastructure
Publications	1850	785
Patents filed	174	113
Spin-offs	8	3
PhD students	874	192

Success story on the spotlight:

Highlights of imec deep-tech startups and ventures created last year:

- **Axelera AI** joined forces with imec to develop groundbreaking computing architecture for high-performance AI, and successfully closed a seed investment round of $12 million joined by imec and imec.xpand
- **Azalea Vision** was incorporated with a seed investment round of 6.3M€. The company is developing smart vision solutions inside a contact lens offering a non-invasive solution for people who suffer from iris deficiencies and light sensitivity

Going forward, a few imec-backed startups followed up on their success story last year.
Spectricity, for example, an imec spin-off and leading provider of hyperspectral sensing solutions for mobile and consumer devices, secured a second financing round of €14 million to further accelerate the development and mass production of hyperspectral sensors and imagers for high-volume, low-cost applications from wearables to smartphones and IoT devices.
MICLEDI Microdisplays, a leading technology company in the field of microLED displays for high-end Augmented Reality (AR) glasses demonstrated the industry's first microLED arrays-for-AR built on a 300mm CMOS manufacturing platform. They successfully closed a second financing round of 7M€ to accelerate the commercialization of their technology.
Pulsify Medical, an imec spinoff developing a non-obtrusive ultrasound patch system for continuous monitoring of stroke volume & cardiac output in the ICU and home setting announced the second closing of their Series A financing round, bringing the total capital increase of the financing round to a value of 6.35M€

3.2 Connection with other TIs at regional/national/European level:

Imec is closely collaborating with other RTOs in the area of nano-electronics and digital technologies where advanced technology infrastructure is available. Among these are CEA-Leti, Fraunhofer, TNO, Tyndall etc. These interactions are either bilateral and/or in the frame of EU and interreg projects. Examples are:

- ASCENT (H2020 – www.ascent.network);
- TEMPO (ECSEL 2018);
- MadeIn4 (ECSEL 2018);
- EUROPRACTICE (H2020 – www.europractice-ic.com/),
- Flexlines (https://www.flexlines.be/about-flexlines).

Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

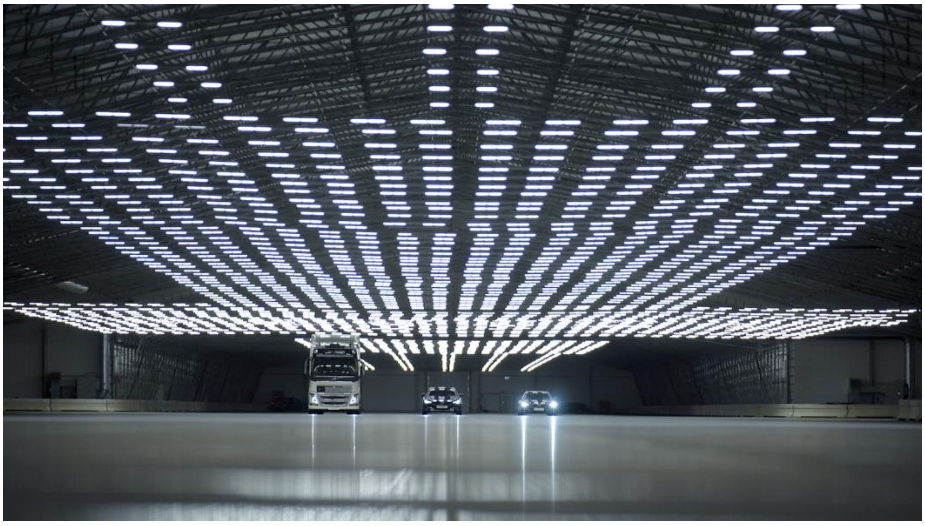
- The challenges when it comes to collaboration and providing access to SMEs are mostly related to the high R&D cost which is rarely affordable for them. The main tool to do this remains public funding via projects like EUROPRACTICE, ASCENT, MIRPHAB, PIX4LIFE, ACTPHAST as well as through IC-link services. The existing SME funding instrument of H2020 is a good initiative but it aims to support the entire SME community in Europe which results in low success rates. SMEs also often need fast "cash-in-flow" which is difficult in case of EU projects considering that the time from idea to budget and full process from submission, evaluation, start to generation of results takes too long.
- Building and offering advanced research infrastructure depends on the availability of new generations of advanced tools. There is an entire ecosystem of semiconductor equipment suppliers in Europe which is actively looking for funding for the high TRL development and pre-production assessment of their tools in semi-industrial conditions. Under FP7, this could be done via the "Semiconductor Equipment Assessment" type of projects in the ICT program. In H2020 this was no longer an option.
- Since state aid ruling applies to projects supported with regional funds, this adds to the administrative burden since additional information is asked to prove compliance with these rules. On top of that the financial auditing of some of these type of projects (f.e. interreg) is extremely time consuming.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

- The EU Chips act aims at European Technology and Innovation leadership and should foster the alliance between leading edge RTOs creating new next generation infrastructure platforms in strategic economic fields with huge impact on society and sovereignty by a strong support from the European Union. More precisely, increasing the demand in Europe for advanced and leading-edge technology is paramount for Europe's position and the development of and access to hardware for the next generation technologies is a clear priority for Europe. The opportunity of new concept demonstration and early development coming from an extended and world-leading technology and design ecosystem is large for Europe, because it is at the centre of most of today's innovations in healthcare, industry, mobility etc. where technologies for artificial intelligence, high-performance computing and cybersecurity become indispensable. Since these initiatives are aimed at cross-border collaboration, EU funds should be foreseen to support this.
- Regional, national and European public funding programmes and instruments to support the creation and upgrade of advanced infrastructures are essential and should be strengthened. Imec's advanced cleanrooms (300mm) were built with the support of the Flemish Government. The Hercules program (under FWO - Fonds Wetenschappelijk Onderzoek) provides structural funding for equipment enabling fundamental and strategic research. The budget for this program is rather low and only aimed at one specific tool and the Flemish ecosystem. For imec that would be more used for characterisation type of tools. In the frame of the Digital Europe Program, some calls have/will become available on regional/national level to support Flemish/Belgian participation
- With increased cost of R&D it is absolutely mandatory to respond to global challenges and/or foster combining skills, data and efforts of the world's best scientists.

CASE STUDY 5 – RISE TECHNOLOGY INFRASTRUCTURE: ASTAZERO

Author: Peter Janevik



Introduction

Name of the Technology Infrastructure (TI): ASTAZERO

Name(s) or the organisations managing the TI: RISE and Chalmers University

Geographical location of the TI: Sandhult, SWEDEN

Technology field: Automotive, telecom, transport system

Focus of the TI activities: The activities and services offered by ASTAZERO are focused on TRL 2-5, from early concept phase to verification and product performance follow-up of, for instance, performance in series production of vehicles. Also, it is possible to conduct transportation system level research and testing, e.g. cybersecurity testing for automated vehicles on site level, research on connectivity needs of automated vehicles etc.

Short history of the TI:

- Planning start: 2008 (Approx)
- Company founded: 2011
- Proving Ground Inauguration: 2014
- Upgrades: Continuous since 2016

1. Service-delivery model

1.1 Ownership/management

AstaZero has two owners, RISE Research Institute of Sweden and Chalmers University of Technology. AstaZero is a company that does not pay profits to the owners, so all financial surplus is reinvested into the proving ground.

1.2 Users

Type of users: Vehicle industry in Sweden and EU: Original Equipment Manufacturers (OEMs), Tier 1s suppliers, public research organisations. Transport Administrations. Telecom system suppliers and operators. Policy makers.

Openness policy and access conditions: Neutral and open access for all relevant customers. Confidentiality conditions sometimes restricts customer and users being at the proving ground at the same time. In that case customers can be separated using exclusive time slots. Customer and user info/data normally kept secret unless explicitly stated. Research projects are generally disseminated in the normal way.

Projects:
- About 10 projects including use of the TI in competitive public funding programmes.
- Small share of contracts with SMEs.

1.3 Services provided by the managing RTO and skills needed

Technology-related services: Special expertise regarding non-critical but project-specific competence such as measurement technology competence, EMC competence, AI and Cyber Security competence etc.

Non-technological services: Business support, communication, grants office etc.

2 Funding model

2.1 Initial investments for the creation of the TI

The creation of this TI was partially included in national/regional strategic roadmaps/plans.

Size of initial investment: SEK 500M in 2014

Sources of funding: Original setup: Public funding ~50% and Bank ~50%.

2.2 Upgrade/upscale investments (long-term sustainability)

The upgrade of this TI is currently not included in national/regional strategic roadmaps/plans.

Size of (past & foreseen) investments for upgrades/upscales (total & /year): Continuous and significant but not disclosed.

Sources of funding for upgrades/upscales: Varies from case to case, including both public and private sources. Percentage undisclosed.

Key challenges faced to ensure the long-term sustainability: The most important challenge is the lack of support for TIs in the research grant system. For instance, proving ground use of TIs in research projects is massively underfunded, which acts as a strong barrier.

2.3 Operational costs (usage/maintenance/depreciation)

Average operational costs: Approx. 80MSEK/year.

Types of operational costs for running the TI: Maintenance of equipment and facility, traffic management, handling of permits etc., calibration of equipment, road keeping such as snow ploughing, test preparations, fuel handling, waste handling etc.

Operational costs coverage foreseen: Not disclosed

Sources of private funding coming from: the Nordic Investment Bank, Handelsbanken.

Success story on the spotlight: In general, the establishing of AstaZero, both from a research and commercial point of view is the greatest success story. In a very short time, AstaZero established itself as a successful test bed, helping accelerate both research and development activities. Initial focus was on the vehicles, but soon the transportation level became the targeted system level. Since 2017, a major addition to the proving ground infrastructure has been made each year, the 700m long and 40m wide test environment called the "DryZone" being the latest new environment added.
Research and development projects have been conducted on multiple topics and a few examples include some key results such as Ericsson and Volvo Cars first successful test handover of connected cars between two national mobile 5G networks and tests carried out within the KRABAT project to test fully autonomous Volvo Bus.

AstaZero is not diverting any profit towards it´s owners but rather reinvests all surplus funds, in effect being a not-for-profit organization. Other activities at AstaZero have been directed towards contributing to rating test protocols in Euro NCAP working groups, test target standardization through ISO and participation in legal requirement working groups.

3 Role in the RD&I ecosystem/innovation hub

Role of the TI in the RD&I ecosystem:

- National: A neutral and open site where multi-disciplinary research and development projects can be conducted. Simplifies tests and demonstrations for SME as well as collaboration between SME and other organisations such as policy labs, authorities, OEMs and Tier 1-2s. Makes possible for SME to do test and development that would otherwise be very hard to conduct. Einride, a Swedish startup within logistics is a good example. Makes possible for OEMs and Tier 1s to accelerate rate of development of automated vehicles. The neutral and open system level profile generally facilitates acceleration of the pace of innovation across the transportation system as well as transportation system level research.
- EU level: Similar to the national level but with more emphasis on Tier 1s.

3.1 Role of the TI in knowledge creation/technology transfer

As a test bed, AstaZero makes knowledge creation possible that could otherwise not be done. As a test bed, AstaZero is generally a place where knowledge creation and technology transfer can happen. In most cases however, the main tech transfer and knowledge creation happens within the customer organizations and research collaboration, made possible by the proving ground.

3.2 Connection with other TIs at regional/national/European level:

Safety collaboration with other proving grounds in Europe- ESPGA. International collaboration with proving grounds in the US and South Korea- IFACT. Compatibility collaboration with other TIs in RISE: e.g. EMC/ AWITAR- test bed chain.

Conclusion: Challenges faced & Recommendations to policy makers

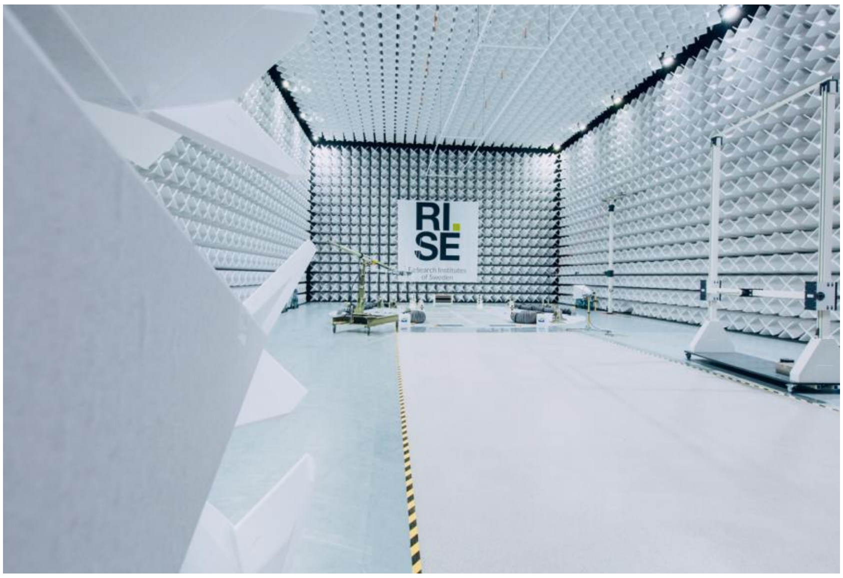
Main challenges faced for the creation and running of this TI: Secure early investments as well as navigation of the funding system for research. The financial and organization classification rules in the funding system for research in combination with the rules for governmental support creates too creates too big challenges for TIs when it comes to participating in publicly research in an economically sustainable manner. In our view, the TIs in Europe are under-used in comparison with both Asia (China, Korea and Japan) as well as the US (Michigan as well as California), resulting in a lower progress rate in applied research phases. Due to the potentially disruptive effects of automation of the transportation in combination with electrification of vehicles and taking into account Europe's current reliance on the Automotive Industry in the economy, this is very serious indeed. The lagging behind of Europe in critical branches like the electronics industry, battery manufacturing and others make these challenges even more grave. In the current situation, having the rules for classification and financing of TIs in research projects work against them is very unfortunate. Policy makers need to understand this vicious problem and take action to solve it, not in the typical pace of the EU policy makers but in the benchmarking pace of their Chinese and American counterparts.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:
Support is needed in e.g., the following categories:

- Massively simplifying the governmental support policy, rules, and funding instruments. Make it possible to do what is intended and what is right without having the rules stopping sound initiatives.
- Evaluating and adjusting the funding mechanics so that all costs of a TI can be covered in a publicly funded research and development project.
- Make sure that Tis generally are included into the definition of research organisations in a way so that the TIs can fully participate in publicly funded research, development and innovation projects.
- Integrate a TI perspective, and financial support to TI, in the European funding landscape (e.g., within Horizon, Digital Europe) – link TI support to successful and efficient European initatives so that the bureaucratic process of establishing new financial support models is shortened. It is very important to act fast and make room for more direct TI support also in Europe, this to be able to compete with the development in the US and China.

CASE STUDY 6 – RISE TECHNOLOGY INFRASTRUCTURE: AWITAR

Author: Monika Fuller



Introduction

Name of the Technology Infrastructure (TI): AWITAR - Automotive Wireless Test and Research Facility

Name(s) or the organisations managing the TI: RISE Research Institutes of Sweden

Geographical location of the TI: Borås, SWEDEN

Technology field: EMC and Wireless communications for Automotive, transport system, telecom and Industry

Focus of the TI activities: The activities and services offered by AWITAR range from early R&D phase to commercial, accredited EMC/radio testing and research within wireless communications, automotive, telecoms and industry. Test and Research facility for autonomous vehicles.

Short history of the TI:

- Feasibility study 2014
- Planning started in 2015
- Launched in January 2018
- Upgrades made 2020

1. Service-delivery model

1.1 Ownership/management

AWITAR is 100% owned by RISE.

1.2 Users

Type of users: Variety of National/EU/international manufacturers within vehicle component and complete vehicles as well as telecom and various industry manufacturers. National/EU/international research projects.

Openness policy and access conditions: open to all partners and customers.

Projects:

- About 2 projects including use of the TI in competitive public funding programmes.
- Other data: not disclosed

1.3 Services provided by the managing RTO and skills needed

Technology-related services: Measurement methods development, test and validation, competence development.

Non-technological services: Business support, project management, adherence to regulations, providing training.

2. Funding model

2.1 Initial investments for the creation of the TI

The creation of this TI was not included in national/regional strategic roadmaps/plans.

Size of initial investment: SEK 100M

Sources of funding: 100% funded by RISE

The investment was in its total made from profits from RISE economic activities. The TI was also intended to be predominantly used for economic activities although it is a vital resource for research activities.

2.2 Upgrade/upscale investments (long-term sustainability)

The upgrade of this TI is not included in national/regional strategic roadmaps/plans.

Size of (past & foreseen) investments for upgrades/upscales (total & /year): Continuous but not disclosed.

Sources of funding for upgrades/upscales: Varies from case to case, including both public and private sources. Percentage undisclosed.

Key challenges faced to ensure the long-term sustainability: The current funding setup of this TI in research projects reduces the possibility for TI to be used in research projects compared to commercial testing.

2.3 Operational costs (usage/maintenance/depreciation)

As the TI is predominantly used for economic activities with commercial customers, we cannot disclose operational cost. These commercial activities are performed in an open market and our operational cost are not disclosed to either customers or competitors.

Average operational costs: Not disclosed

Types of operational costs for running the TI: Not disclosed

Operational costs coverage foreseen: Not disclosed

Sources of private funding coming from: Not disclosed

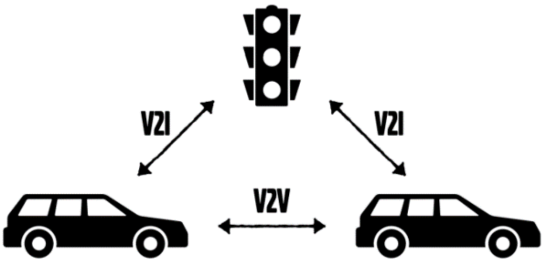
Success story on the spotlight:

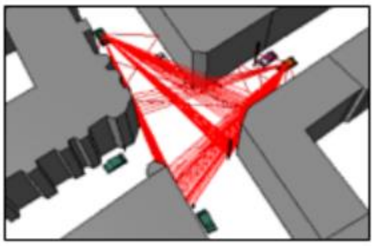
The SIVERT project - Simulation and verification of wireless technologies (www.ri.se)

Wireless connection (connectivity) is standard when it comes to entertainment in vehicles. In modern, intelligent vehicles, more and more functions are connected wirelessly.

Connectivity is also needed for advanced driver assistance systems (ADAS) as traffic alerts. It is also expected to play a greater role in both ADAS and autonomous driving (AD) with the introduction of car-to-car communication (V2V). To develop and ensure the performance and reliability of the wireless links that enable this type of advanced system, simulation and testing is a prerequisite.

The purpose was to ensure the performance and quality of the wireless communication as early as possible in the development project and thus reduce the amount of field tests.





3. Role in the RD&I ecosystem/innovation hub

Role of the TI in the RD&I ecosystem: An open test site where research and development projects as well as commercial testing can be conducted.

3.1 Role of the TI in knowledge creation/technology transfer

Awitar is mainly an EMC chamber, designed to meet techniques and requirements for commercial testing and research projects of autonomous vehicles and active safety systems and is also designed to support the charging challenges in the electrification change of the transport system. The TI is used in open research projects together with industry partners where the results are shared within the consortium and to some extent also public.

3.2 Connection with other TIs at regional/national/European level:

The TI has close connection and collaboration with other TIs within RISE, for example with AstaZero for different research projects related to testing and validation of autonomous driving and advanced safety systems and their functions.

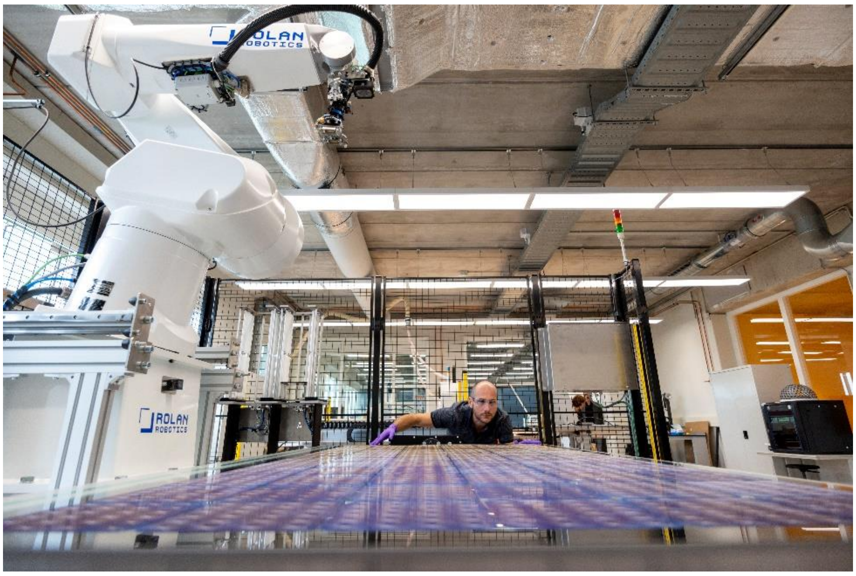
Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI: Secure early investments, navigate the funding system for research. The combination of the funding system for research in combination with the rules for governmental support leaves very few possibilities for TIs to be used for research.
The TI is predominantly used for commercial testing purposes within RISE economic activities. It is used in research projects to some extent, but to increase this part, the rules from the funding agencies on how to get cost coverage for the TI need to be improved. The cost is from the funding agencies today expected to be included in the overhead on man-hours.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:
The funding setup of test sites need to be adjusted in order to accelerate the usage of TI in various research projects. See above

CASE STUDY 7 – TNO TECHNOLOGY INFRASTRUCTURE: SOLAR LAB

Authors: Bart Geerligs, Arthur Weeber, Patrick Darphorn, Henny Welleman



Introduction

Name of the Technology Infrastructure (TI): TNO Solar Lab / Custom and high-efficiency-tandem photovoltaic (https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/renewable-electricity/solar-energy/solar-panel-efficiency/solar-lab/)

Name(s) or the organisations managing the TI: TNO

Geographical location of the TI: Petten, The Netherlands

TI in national/European database of TIs: part of the Solar Cell cluster of the NWO National Roadmap for Large-Scale Scientific Infrastructure (https://www.nwo.nl/en/researchprogrammes/national-roadmap-large-scale-research-facilities), and the SolarLab NL plan in the NWO National Roadmap for Large-Scale Scientific Infrastructure 2021-2025.

Technology field: Solar photovoltaic technology

Focus of the TI activities: The focus of the TI activities is on tech maturation, upscaling, prototyping, and validation, in most of the cases in cooperation with or contracted by commercial R&D partners.

Short history of the TI:

- 1994 large-scale cleanrooms and facilities at ECN Solar Energy
- 2000 solar cell pilot line operational
- 2007 solar module pilot line operational
- 2012 establishing the Silicon Competence Centre for collaboration and coordination on infrastructure, between TNO/ECN and academic and industrial partners
- 2016 part of the Solar Cell cluster in the NWO National Roadmap for Large-Scale Scientific Infrastructure
- 2021 new building and equipment investments for Solar Energy research at TNO Petten, resulting in the new 2200 m2 “Solar Lab”, including an Application and Safety Lab
- 2021 part of the SolarLab NL plan in the NWO National Roadmap for Large-Scale Scientific Infrastructure 2021-2025

1. Service-delivery model

1.1 Ownership/management

TNO owns and manages the TI. The TI is used to help companies to develop and manufacture innovative products, to improve existing products or processes, and to enter new markets. In the lab TNO can develop, research and test innovations with companies, making and evaluating prototypes of new module and cell concepts. More advanced innovations are often pursued in collaboration with academic partners in government-subsidized projects.

1.2 Users

Type of users:

- Commercial work for small and large companies, of which several multinationals, government organizations, private organizations, other technology institutes, academia. Both inside and outside EU.
- Academic collaborations with most universities in the Netherlands, and several universities abroad, involving use of the Solar Lab facilities
- Competitive public funded projects

Openness policy and access conditions: Access is open, in principle, to commercial customers and academic/RTD partners of all origins. TNO has clear export conditions for its research. For example, projects are checked on potential military use of results.

Process to reach new users and/or foster SME access: The TI is visible via key roles of employees in national consortia with partners from public and private sector, as well as in international forums. Employees are also visible in the media, participate in organisation of conferences and specialist workshops, have part-time professorships, and provide expert input for national and international innovation programs and roadmaps. The collaboration with other units of TNO (such as building, infrastructure and maritime, datascience, traffic and transport, etc.) result in additional routes for users to be aware of the TI.

Projects:

- More than 55 business-to-business projects in 2020.
- About 1.000 kEUR income from business-to-business projects in 2020.
- About 20% share of contracts with SMEs.
- More than 30 projects including use of the TI in competitive public funding programmes.

1.3 Services provided by the managing RTO and skills needed

Technology-related services

- IEC level testing, as well as advanced diagnostics.
- Prototyping (including aesthetics toolbox), in particular new PV module concepts including 3D shapes. Support for materials developments.
- Outdoor test facilities. Electrical system safety. Modeling.
- Wafer to cell processing, thin functional coatings.
- Technology transfer, training, production line audit.

Non-technological services:

- Technology roadmapping. Support for national market analyses.

2. Funding model

2.1 Initial investments for the creation of the TI

The investments for the Solar Lab were funded by the Dutch Ministry of Economic Affairs and Climate, the province of North-Holland, and TNO.

Size of initial investment: 23 MEUR.

Sources of funding:

- TNO: 971 kEUR
- Government: 7.902 kEUR (Dutch Ministry for Economic Affairs and Climate)
- Province of North-Holland 14.000 kEUR
- Private: none

2.2 Upgrade/upscale investments (long-term sustainability)

Size of (past & foreseen) investments for upgrades/upscales (total & /year): 925 kEUR/year (depreciation).

Sources of funding for upgrades/upscales: TNO's own funding.

2.3 Operational costs (usage/maintenance/depreciation)

Average operational costs: 1420 kEUR/year

Types of operational costs for running the TI: Facilities (electricity, consumables), maintenance staff, building maintenance, etc.

Operational costs coverage foreseen: Included in project costs and RTO basic funding.

40% of these operational costs are covered in competitive publicly-funded projects

3. Role in the RD&I ecosystem/innovation hub

3.1 Role of the TI in RD&I ecosystem

- Regional: the Solar Lab is located on the Energy and Health Campus. The Solar Lab stimulates innovation of local companies in joint R&D projects.
- National: the Solar Lab is the only facility in the Netherlands providing access to industrial full size solar cell and module technology, testing facilities, and specialist know-how.
- EU: within the EU, TNO's Solar Lab is a RTD facility that is well known for its developments for industrial low-cost PV mass manufacturing, and well known for "PV integration in X" (i.e., free-form, aesthetic PV, vehicle integrated PV, PV on infrastructure, facades, etc.). TNO is active in the Solar Manufacturing Accelerator, to bring back high-volume manufacturing to Europe.

3.2 Role of the TI in knowledge creation/technology transfer

- 32 active patent families - no first filings in 2020
- About 15 peer-review publications/year, about 20 oral conference presentations/year, about 10 invited scientific presentations/year, about 10 scientific outreach presentations (non-scientific)/year
- 3 spin-offs between 2016 and 2019. No spin-off in 2020.

Success story on the spotlight:

- Multi-junction (tandem) photovoltaics: TNO has achieved multi-junction solar modules by stacking low-cost perovskite solar cells and crystalline silicon (cSi) solar cells, an R&D activity which combines R&D efforts and facilities of the Solar Lab with the laboratories of TNO in Eindhoven and Solliance partners. A world record efficiency was achieved both for small tandem cells (29.7%), as well as tandem modules of 100 cm^2 aperture area (22.0 %), with this novel technology. The Solar Lab is developing module technologies, and performing outdoor tests and monitoring, to achieve reliable and high-performance tandem modules. All technologies that were used for the 100 cm2 module are scalable to mass production. According to the international PV roadmap, tandem PV is expected to enter the mass manufacturing market by 2023. It can be an important part of European technology leadership in PV, and is very valuable to increase power production from constrained areas.
- Mass customization: Together with the company Atlas Technologies, better known by their trademark Lightyear, TNO has developed a solution for a commercially available solar electric car in which more than 50% of the power needed for driving can be produced by an integrated solar panel on the car body surface. We have worked with a new set of materials in order to allow 3D curvature of cSi solar cells. Based on TNO's conductive back contact foil technology for interconnection of the solar cells, the result is a mechanically stable, electronically smart, aesthetic, and manufacturable solution for the mobile market. Together with TNO Traffic and Transport, the Solar Lab is addressing the issues of automotive safety and road compliance throughout the design process. The Lightyear One car is planned to become commercially available in 2022 with this TNO technology. The development and prototyping of the solar car roof and feasibility of vehicle-integrated PV will result in the accelerated adoption of truly zero-emissions electric vehicles, and reduce the demand on the electricity grid.

These two success stories, high efficiency tandem PV, and customization, are likely to merge and strengthen each other in the future.

3.3 Connection with other TIs at regional/national/European level

- The Solar Lab in Petten and the TNO facilities for Solar Technology and Applications in Eindhoven work under joint scientific management and joint roadmaps. TNO is one of the key partners in Solliance, an international consortium for thin film PV research. Another key partner in Solliance is imec.
- At the national level, the TNO facilities are part of the Solar Cell cluster in the NWO National Roadmap for Large-Scale Scientific Infrastructure (NWO is the Netherlands organization for scientific research).
- The Solar Lab collaborates with several large technological institutes in The Netherlands, which maintain TIs in very different fields (Deltares, Marin, WUR, etc.)
- TNO and the Fraunhofer-Gesellschaft have recently concluded a framework agreement. This is in an early phase, and practical implementation is to be worked out.
- TNO and other foreign TIs are partner in EERA-PV, and the principal scientist of the Solar Lab is vice chairman of ETIP-PV (European Technology and Innovation Platform for PV).

Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

- Having a thriving ecosystem of national and EU industrial activity, leading in innovative technologies, and with a competitive edge on at least local (Dutch and EU) PV markets. This translates into partners/customers which are essential for long-term sustainability of the lab. Of course the Solar Lab itself will play a role in enhancing such an ecosystem.
- Play a role in know-how for bringing large scale PV manufacturing back to Europe. The focus on customized PV and novel high efficiency PV technologies such as tandems has this ambition to be more competitive than 'made in China'.
- Attracting talented employees and R&D projects in which to create the innovations. Only the infrastructure is not enough.
- Secure high quality R&D with competitive public funding, especially on European level.
- Secure investments for timely upgrades and additions, to create innovations for novel PV products beyond 2025.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

- At a European level, allow duplicates of TIs when needed.
- In support programs for TIs, include a component for funding of actual innovative R&D (at low TRL).

CASE STUDY 8 – VITO TECHNOLOGY INFRASTRUCTURE: DEEP GEOTHERMAL FACILITY

Authors: Steven Van Meensel, Ben Laenen & Roger Dijkmans

Introduction

Name of the Technology Infrastructure (TI): Balmatt Deep Geothermal Facility

Name(s) or the organisations managing the TI: VITO (https://vito.be/en)

Geographical location of the TI: Mol, Belgium

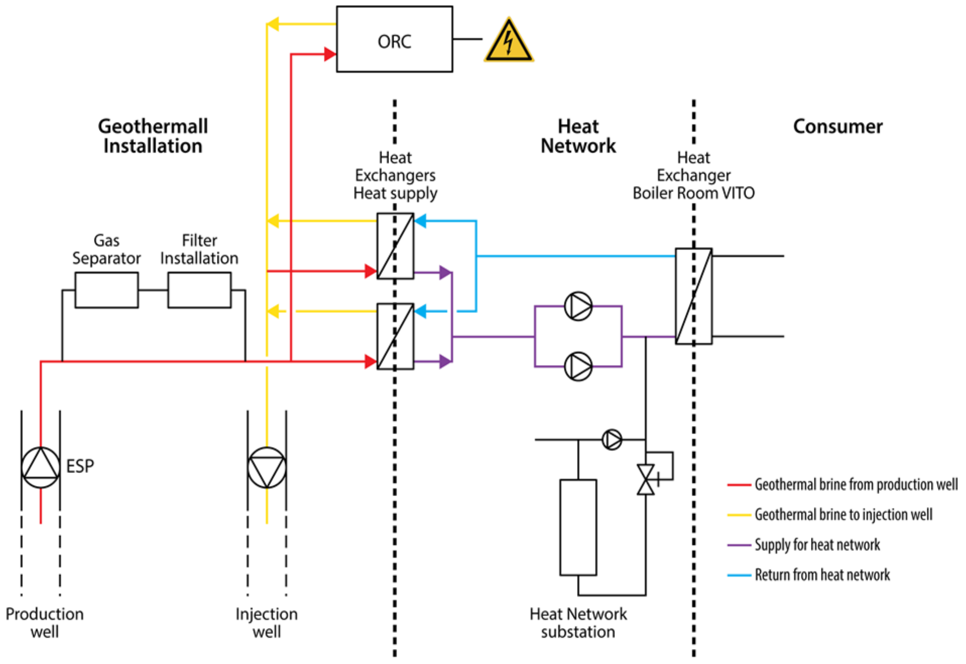
Technology field: geothermal energy, applied geology

Focus of the TI activities: This case study shows the geothermal facility constructed by VITO in Mol, Belgium. This pilot project started in November 2009 with as aim to evaluate the viability of deep geothermal heat as a source for local and sustainable energy. With the project, VITO wanted to give a new impulse to the development of deep geothermal energy in the northern part of Belgium. This objective was met: the geothermal plant and the related research acted as a catalysator for the development of deep geothermal in the northern part of Belgium and neighbouring regions.
The initial development part of the project is finished, and the geothermal plant is currently in operation. While delivering heat to VITO premises, the geothermal plant is being optimized and being employed as a research lab. VITO has identified a series of research topics, such as reservoir engineering, induced seismicity and brine disposal.
The project is considered a "technology Infrastructure" in the sense that it *consists of facilities, equipment, capabilities and support services required to develop, test and upscale technology to advance to competitive market entry. Its main users are industrial players which want to develop geothermal solutions, whilst ensuring feasibility and regulatory compliance*.
Deep geothermal energy is the natural heat found beneath the earth's surface. It comes from the hot core of our planet, the friction between rocks and the decay of radioactive elements on the earth's surface. Deep geothermal energy has therefore been around for billions of years and will also remain permanently available in the future. Furthermore, it is always available, independent of the weather, at a constant rate.

In the Flanders region of Belgium, and many other European regions, exploitable geothermal resources are not found directly at the surface but located deep in the subsoil. To reach water of a sufficiently high temperature wells must be drilled to well below 2 km. VITO was not the first to look for deep geothermal energy in Flanders. The first exploration dates from the 1950's. Since then, several projects were launched to extract heat from deep geological layers in the Campine region, but none of them resulted in the development of a geothermal plant. Unique to Balmatt project was the target depth of 3 – 3.5 km, which should provide water that is hot enough for co-generation of heat and electricity, and the link of geothermal with district heating. The project is the first of its kind in Belgium and the surrounding regions. If successful, it will contribute significantly to the transition towards sustainable and renewable energy production.

The infrastructure and the related research aim at:

- Execution of a pilot project consisting of deep well drilling and the realization of a geothermal installation.
- Finding and sharing solutions for problems encountered with deep geothermal drilling, reservoir development, and the construction and operation of geothermal installations, such as corrosion, reservoir stimulation, induced seismicity and brine disposal.
- Helping industrial stakeholders to successfully explore this form of energy and technology.
- Helping industrial stakeholders to develop new technologies to reduce the risks and improve the efficacity of geothermal projects.
- Assisting governments in establishing or adapting regional legislation for deep geothermal energy in the domains of exploration (including appropriate insurance schemes), exploitation, environmental impact above and below ground, and in defining appropriate support schemes.
- Creating new industrial enterprises / start-ups for the roll-out of geothermal energy in e.g. Belgium.
- Creating general awareness and support for technological solutions in general, and geothermal energy, for the energy and climate challenges.
- Geological exploration of Lower Carboniferous Limestone Group. This geological layer is recognized to host significant geothermal resources in Belgium, Netherlands, North Rhine-Westphalia, northern France, Ireland and the UK.



Overview of the main parts of the surface installations of the Balmatt geothermal plant

The VITO technology infrastructure consists of:

- Three deep geothermal wells : one vertical production well (depth 3610 m) and two deviated wells (depth 4341 m and 4905 m, one of which is equipped and used as an injection well and the other one as a monitoring well (Table)
- A geothermal heat and electricity generation pilot installation & building, including (**Error! Reference source not found.**):
    - A loop to extract heat from the geothermal fluid;
    - A branch of the geothermal loop to perform corrosion and performance tests on pipelines or prototypes by exposing them to the geothermal fluid;

- A substation and piping system to connect the geothermal plant with the district heating network;
  - An organic Rankine cycle unit;
  - A collector to distribute the produced heat over different applications (branch towards the substation for district heating and a branch towards a section that included the ORC and that can be used to test other heat-driven technologies);
  - Adiabatic coolers;
- A district heating network for delivering heat to buildings and laboratories of VITO and neighbouring companies, and to a residential area;
- A seismic monitoring network consisting of 16 seismometers: 4 at surface, 9 at a depth of 30 to 500 m and four on the 'bed rock' between 600 and 2052 m (Figure 1).

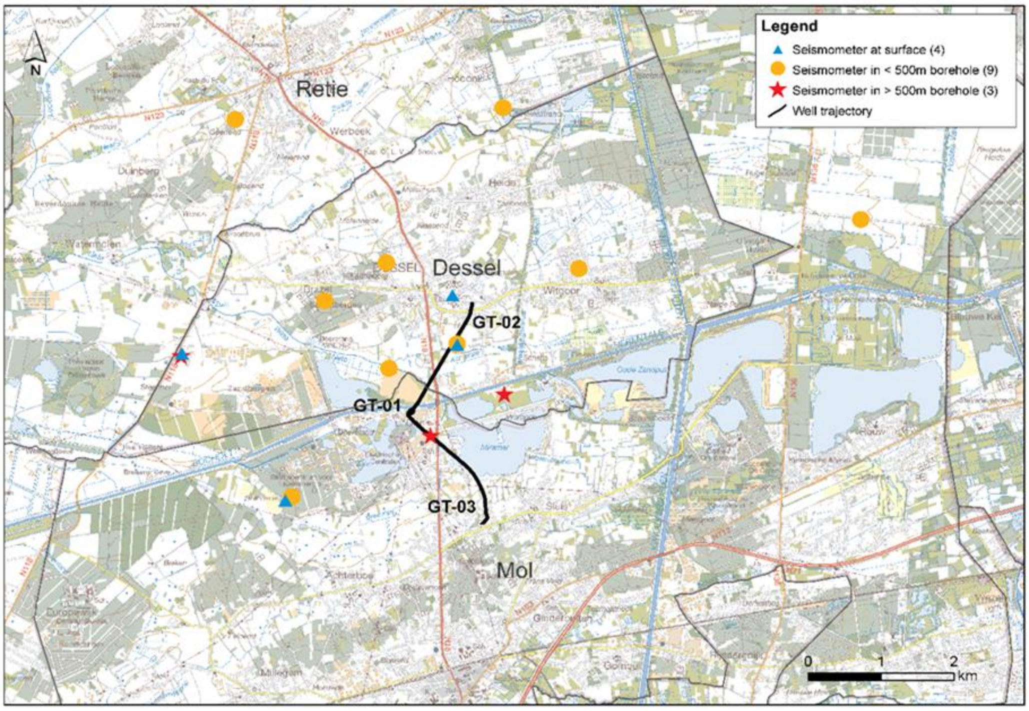


Figure 1: Location of the seismometers installed near the Balmatt geothermal plant

		Well 1 MOL-GT-01(-S1)	Well 2 MOL-GT-02	Well 3 MOL-GT-03(-S1)
Total depth (TD)	m	3610	4341	4905
Vertical depth (TVD)	m	3610	3830.2	4235.7
Side track	m	2700 - 3610		4308 - 4905
Top *Kolenkalk* Grp.	m	3175.5	3787.5	3643
Base *Kolenkalk* Grp.	m	-	-	4747.5
Maximal temperature	°C	139	147	142
Maximal flow during test	m^3/h	150 (p)	240 (i)	dry well

Table: Technical specifications of the thee deep wells drilled at Balmatt (p: production test, i: injection test)

Short history of the TI:

VITO started the Balmatt geothermal project in November 2009. An overview of the main phases of the Balmatt project is given in Figure. The project was organized as a standard deep geothermal exploration and development project. After a process of preliminary studies and a 2D seismic exploration campaign, the first drilling was spudded on 15 September 2015. Well MOL-GT-01 hit hot water at a depth of 3200 to 3400 m in the limestones of the Lower Carboniferous Limestone Group. In the following years two more deep wells were completed: MOL-GT-02 which serves as an injection well, and MOL-GT-03 which was carried out as a second production well, but ultimately turned out to be 'dry' (Table).

In January 2017, VITO started the procedures for the procurement of the construction of the geothermal power plant and the above-ground installations. In the spring of 2017, the connecting pipeline between the Balmatt site and the boiler room of the heat network on the research campus of VITO – SCK•CEN was installed. The works for the above-ground installations started in the first quarter of 2017. The geothermal plant was completed in November 2018. During the construction of the plant, several technical issues arose that needed solving. Major issues were:

- The presence of Naturally Occurring Radioactive Materials in the brine taking for the definition of protocols to replace filters, to remove scaling and to deal with non-injected brine;
- Proper material selection to reduce the impact of corrosion;
- Measuring the bubble point and defining a proper operational pressure to avoid degassing and minimize scaling;
- Induced seismicity.

In the period December 2018 – June 2019, a series of production tests were carried out with the aim to start-up stable heat production. The start-up of the plant proved to be difficult: the main reason for this is the high pressure that is required to inject the pumped water back into the subsoil. The start-up was suspended after an earthquake that was felt in Dessel and Mol on 23 June 2019. The earthquake resulted in a red-light situation within the traffic light protocol.

From July 2019 to December 2020, further studies were conducted into the seismic hazard and risks associated with geothermal energy extraction from the Lower Carboniferous limestones. These studies resulted in a new research program that aims to determine to what extent deep geothermal energy in the Mol – Dessel region is technically and economically feasible from a seismological point of view. Production was restarted in April 2021 to conduct additional measurements in the context of the seismological research program. Since then, several production cycles were performed to investigate the impact of production on the seismic response of the reservoir. Next to the seismological research, VITO is developing an installation for brine disposal.

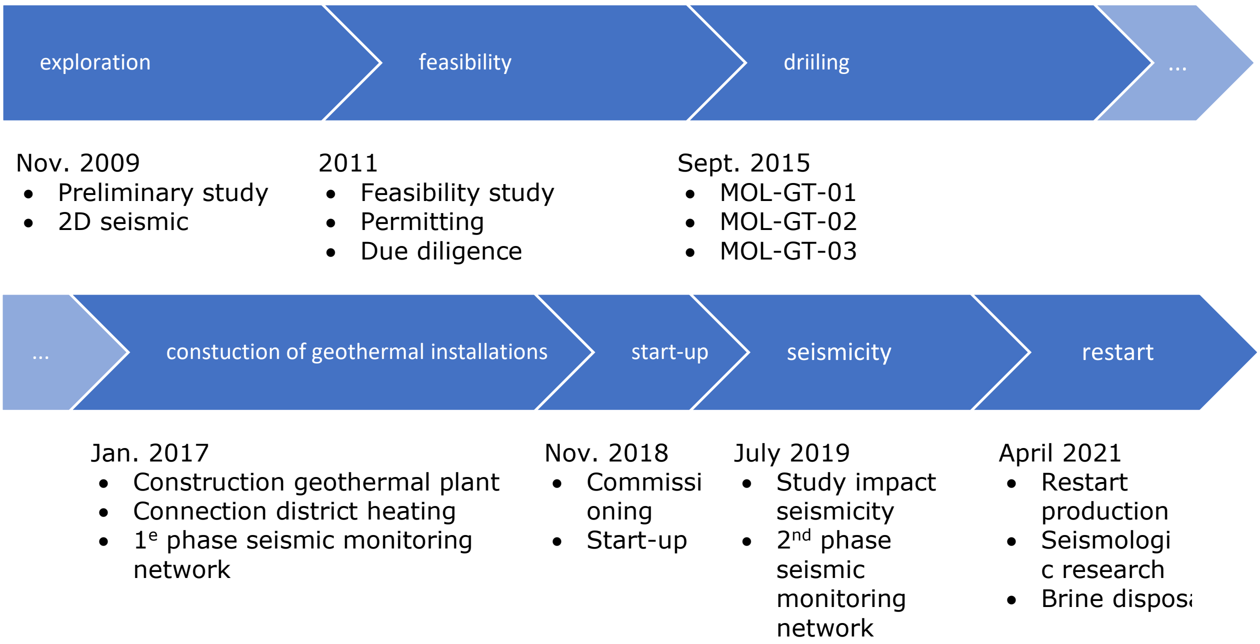


Figure: Overview of the main phases of the Balmatt project

1. Service-delivery model

1.1 Ownership/management

As an RTO VITO has the following mission: "*We accelerate the transition to a sustainable world. We reduce the risk of innovation for companies and strengthen the economic and social fabric of Flanders with interdisciplinary research and large-scale demonstrators*".

VITO took the initiative to start the deep geothermal project in framework of its sustainable energy techno-logy program. With the initiative VITO wants to a-pave the road for the development of deep geothermal in Flanders and the surrounding regions. Extracting geothermal heat from the deep subsoil is very complex and comes with many uncertainties and risks. This makes it hard to start project, especially in a greenfield like Flanders, or targeting poorly known reservoirs like the Lower Carboniferous limestones. The VITO infrastructure and project aims to reduce these risks for industry, other energy users and governments.

VITO operates and maintains the geothermal pilot installation. Investment has been almost entirely funded by internal VITO budget. VITO is the owner of three deep wells, the geothermal plant, the boiler house of the district heating network and the seismometer network. VITO operates the district heating network and has a long-term rental contract for the pipeline that connects the geothermal plant with boiler house. VITO is also owner of the data generated in the context of the Balmatt geothermal project.

In the operational phase VITO is continuing to investigate how risks can be further reduced. One domain is reservoir engineering, i.e. understanding the geological behaviour of the Lower Carboniferous limestone reservoir during geothermal operations. Secondly, induced seismicity has proved to be an issue at the VITO site, and, because of the political impact, it is currently the focus of VITO's geothermal research. Finally, the brine, that has been collected during the production tests and which must be considered as Naturally Occurring Radioactive Material (NORM), needs to be disposed of in an environmentally acceptable manner.

1.2 Users

Openness policy and access conditions:

In the current early stage of the project the installation is run by VITO and its contractors. Geological research results are published in in scientific papers and papers for the general public (see e.g. VITO seismometer network investigates earthquakes | VITO, Radioactivity and deep geothermal energy | VITO). It is VITO's policy to make detailed data from the wells, the geothermal plant and the seismic monitoring available for research upon request. The terms and conditions for the utilisation of the data will be laid down in an agreement between the requesting party and VITO.

The installation is ready to incorporate and/or to test installation from third parties. Third parties can contact VITO to rent (part) of the infrastructure for testing, or the define a joint development program. In the former case, VITO will negotiate a loan agreement taking into account the costs and practical arrangements (e.g., work program, time schedule, safety measures, permits) of the test, as well as the liability of all parties involved with respect to risks for the installations, the personnel and the surroundings. In the latter case, a collaboration agreement will be negotiated.

Process to reach new users and/or foster SME access:

VITO uses the Balmatt Deep Geothermal Facility to advance the development of deep geothermal energy in two ways:

- To show interested parties how a deep geothermal plant works: VITO welcome all interested parties to visit the geothermal plant. Companies and other stakeholders can contact VITO for individual visits. Besides, VITO organizes events at Balmatt for (local) policy makers and associations like the local Chamber of Commerce. School visits are organized in the context of STEM with the support of the province of Antwerp.
- VITO offers technology developers the possibility to test new technologies at the Balmatt Deep Geothermal Facility or to set-up joint development projects. As for the latter, VITO has nearby research facilities to conduct laboratory experiments on new materials (Sustainable Materials | VITO) and in the field of sustainable chemistry (Sustainable Chemistry | VITO). For the development of energy applications and the integration of geothermal in the future energy landscape, VITO works together with academic partners and imec in EnergyVille (Research into sustainable energy and intelligent energy systems | EnergyVille). For research on NORM-related issues, VITO collaborates with the nuclear research centre in Mol (Belgian Nuclear Research Centre | SCK CEN).

Use in multi-stakeholder competitive projects:

The Balmatt Deep Geothermal Facility meets the European call for the provision of infrastructure for the testing and monitoring of low-carbon energy systems. Balmatt is used in several multi-stakeholder project for the data obtained during development and exploitation of the facility, as well as that for fact it offers an environment to test new technologies and acts as a living lab to test innovative solution for the utilization of geothermal energy. Following EU-projects are connected:

- GEOENVI (Horizon 2020 - https://www.egec.org/h2020-geoenvi-project)
- MATCHING (Horizon 2020 – http://matching-project.eu/)
- CHPM2030 (Horizon 2020 - https://www.chpm2030.eu/)
- GeoSmart (Horizon 2020 – https://www.geosmartproject.eu/#)
- REFLECT Redefining geothermal fluid properties at extreme conditions (H2020: https://www.reflect-h2020.eu/)
- Heatstore (GEOTHERMICA – https://www.heatstore.eu/project.html)
- CAGE (GEOTHERMICA – http://www.geothermica.eu/projects/cage)
- DGE-ROLLOUT (INTERREG NEW – www.nweurope.eu/projects/project-search/dge-rollout-roll-out-of-deep-geothermal-energy-in-nwe),

- GEOHEAT.APP (INTERREG Vlaanderen – Nederland - https://vito.be/en/geoheat-app),
- GEOTHERMIE 2020 (EFRO - https://vito.be/en/geothermal-energy-boosts-employmentà
- Study on 'Geothermal plants' and applications' emissions (EC DG for Research and Innovation - Study on 'Geothermal plants' and applications' emissions - Publications Office of the EU (europa.eu))

Besides these EU projects, data from Balmatt is used in other multi-stakeholder projects including:
- Decision Support under Uncertainty for Geothermal Applications (BRAIN-Be 2.0 - https://www.belspo.be/belspo/brain2-be/projects/DESIGNATE_E.pdf)
- Seismicity potential Dinantian geothermal reservoirs – implications of case study Balmatt for projects in the Netherlands (TKI Nieuw Gas Projecten | Topsector Energie)
- The Dutch program for the development of deep geothermal 'Scan Dinantien' (Duurzame energie in Nederland - SCAN aardwarmte)
- KEM-06 Hazard and risk assessment for Ultra Deep Geothermal Energy (UDG) and inventory of preventive and mitigation measures (Knowledge Programme on Effects of Mining (SSM NL - KEM-06 Hazard and risk assessment for Ultra Deep Geothermal Energy (UDG) and inventory of preventive and mitigation measures (finished) · kem programma)
- Minimizing the risk of induced seismicity associated with geothermal energy in fractured reservoirs (NOW NL - NWO project on minimizing the risk of induced seismicity associated with geothermal energy granted (tudelft.nl)
- Chemical and radiological assessment of deep brine-type geothermal groundwaters (PhD J. Pauwels, KU Leuven & SCK•CEN - https://lirias.kuleuven.be/3550744?limo=0)
- Geothermal reservoir evaluation of the lower carboniferous carbonates in the Campine Basin in northern Belgium, and its analogues (PhD E. van der Voet, KU Leuven - https://ees.kuleuven.be/geology/projects/index.html?project_id=545)

1.3 Services provided by the managing RTO and skills needed

VITO is a leading European independent RTO in the areas of clean tech and sustainable development, elaborating solutions for the large societal challenges of today. VITO provides innovative and high-quality solutions, whereby large and small companies can gain a competitive advantage, and advises industry and governments on determining their policy for the future. VITO focuses on five different research programmes: sustainable chemistry, energy, health, materials and land use.

In the field of deep geothermal, VITO is active as a project developer and client-representative for geophysical exploration campaigns and helps project developers in the design of both subsurface and surface installations. Moreover, VITO assists authorities in defining regulation that is adjusted for deep geothermal and provides knowledge to (local) authorities about available resources and the integration of geothermal in energy and climate plans.

The technology infrastructure was built in support of these activities. It aims at:
- Learning by doing by drilling three deep wells and the realization of a geothermal installation VITO gained practical experience and became aware of the main technical and non-technical challenges for the development of (green field) geothermal projects;
- Finding and sharing solutions for challenges encountered during deep geothermal drilling, and the design and operation of geothermal installations;
- Helping industrial stakeholders to successfully explore this form of energy and technology;
- Assisting governments in establishing or adapting regional legislation for deep geothermal energy in the domains of exploration (including appropriate insurance schemes), exploitation, environmental impact above and below ground, and in finding potential investors;
- Creating new industrial enterprises / start-ups for the roll-out of geothermal energy in e.g. Belgium;
- Creating general awareness and support for technological solutions in general, and geothermal energy in particular, for the climate challenge;
- Exploring the geothermal potential of the Lower Carboniferous limestones in Flanders and the surrounding regions.

2. Funding model

2.1 Investments for the creation and upgrade of the TI

Geothermal projects have high investment costs associated with drilling wells deep into the subsoil. At this point the technology facility is built and commissioned. Roughly 48 million euros have been invested

(Table). Of the total financing cost approximately 85% came from internal VITO funds (including loans) and approximately 10% from government subsidies.

Table: Overview of investment costs

Description	Investment cost
Seismic exploration	0,7 MEUR
Feasibility study	1 MEUR
Drilling of 3 wells	30 MEUR
Seismic monitoring	1 MEUR
Geothermal plant	15 MEUR
ORC & adiabatic cooling	2 MEUR

Part of the VITO self-financing includes a bank loan of 10 million euros. This loan was used to supplement the high drilling costs at the beginning of the project. The repayment of the loan will be covered by the income from the sale of heat in the local heat network (SCK•CEN, VITO [avoiding the purchase of natural gas] the 'Atoomwijk' residential area and Belgoprocess.

VITO evaluates additional investments to upgrade and extend the facilities (ca. 2,5 MEUR). The additional investments will improve the knowledge of the Lower Carboniferous limestone reservoir and increase the operational flexibility of the geothermal installations. The former investments will help to reduce the risks related to testing of new equipment and drilling tools in the deep wells. The latter will make it easier to organise

2.2 Operational costs (usage/maintenance/depreciation)

The annual operational costs are estimated at ca. 1 MEUR/year:

Because of the uncertainties on seismic events, VITO has decided to initially operate the plant at a low intensity, i.e. operating at a low flow rate. This implies that less heat is currently being delivered than planned, although with current fossil energy prices VITO remains on track in terms of the original business plan. Once the impact of above ground parameters such as pumped volume, flow rate and/or injection pressure on the induced seismicity is better understood, VITO believes it will be possible to move back to nominal intensity operations.

3. Role in the RD&I ecosystem/innovation hub

3.1 Connection with ecosystem partners

The following ecosystem partners have a crucial role in the geothermal energy pilot:

- General outreach: In 2013, the Chamber of Commerce of the Campine region, the intercommunal company IOK and VITO started ERDF-project 910 – GEOTHERMIE 2020 to initiate the discussion about the possible role of deep geothermal. The project created momentum for the construction of the Balmatt geothermal plant. Moreover, deep geothermal was selected as one of the spear points for the development of the Campine region and Balmatt was labelled to become a test and learning site for the development of the technology (RES15-003-dynak (streekplatformkempen.be)).
- Industry: VITO closely worked together with industry to create the geothermal technology infra-structure. The most important contracts awarded were those for the drilling of the wells (JV SMET-DALDRUP), the design and building of the Organic Ranking Cycle ORC (Atlas Copco) and the building of the geothermal plant itself (ENGIE). The connection with the heat network was installed by Fluvius. VITO collaborated with the Belgian nuclear research institute SCK•CEN and BelgoProcess to define protocols to deal with NORM-containing waste streams. For seismic monitoring and the evaluation of the seismic risk, VITO contracted DMT (GE), specialized in the exploitation of seismic networks, as well as by an independent third-party consultant, INERIS (FR).

Figure: Circuit for testing of heat conversion technologies at the Balmatt facility

- In the fall of 2021, the company Radial Drilling Europe B.V. (moreheat.nl) performed a field tests with a new tools to jet an drill small diameter lateral holes in the third well MOL-GT-03. The field operations were designed to test the operability of the tools at large depth (+/- 4000 m), and to evaluate the jetability of a hard limestone reservoir where slow progress of the jetting process is expected.

Figure: Preparation of the field test on radial drilling by RDE in the fall of 2021.

- Start-ups: In May 2016, the spin-off company Kempens Warmtebedrijf was created. The company forms the link between the heat supplier and producer of deep geothermal heat at one side and the customer at the other. As such, it communicates and examines new developments in the field. In June 2019, a second spin-off company HITA was founded based on the knowledge gained by the VITO technology infrastructure and its projects. Over the next ten years, the company intends to develop and market 10 geothermal power stations, representing a total investment of 230 million EUR (not including the heat network). Private investors from the Campine region have raised 3,8 million EUR in venture capital to provide HITA with the necessary initial working capital. HITA is currently developing three locations for geothermal exploitation in the Campine region. New seismic campaigns have been executed, well design is ongoing, and the necessary permits are being acquired. In parallel, HITA is looking for local private investors for executing new projects.
- In 2019, J&J - Janssen Pharmaceutica started drilling a geothermal doublet at their site in Beerse. The project originated in 2014, in the context of INTERREG GEOHEAT.APP and profited from the experience gained at Balmatt. The geothermal system is connected to a new heating network. Once the system is in full operation, it can save up to 30% of CO_2 emissions at the site (see: Geothermal Energy: ecological innovation | Janssen Belgium).
- Authorities: The pilot project shows local and regional authorities to what extent geothermal heat could be used as a source of local and sustainable energy throughout the region. Initially there was no strong policy context or legal framework in place regarding geothermal projects in the deep subsoil of Flanders. Throughout the operational phase, VITO maintained constant dialogue with the governmental authorities responsible for the subsurface, surface installations and induced seismicity. Local governments (e.g. of Dessel and Mol) found inspiration in the project and took first steps in investing in local heating networks (Belgium has only few examples of district heating yet). VITO has also made closer partnerships with government parties in the neighbouring countries, e.g. VITO is a partner in the Dutch Green Deal Ultradeep Geothermal energy.

- Research community: The geothermal project is a source of data and expertise for various geothermal projects across Europe. VITO's unique combination between a research site and a pilot geothermal plant make the facility an ideal development and test site, and a source of operational data. Further research and development on following subjects is planned: occurrence of vibration during the injection of cooled water, treatment of naturally occurring radioactive material or controlling the gasses present in the water, new materials and/or additives to better control corrosion and scaling, alternative drilling technologies, …

Figure: Branch of the geothermal loop for corrosion test on pipes at the Balmatt facility

- General public: To create general awareness and support for technological solutions for societal challenges and geothermal energy as an alternative energy form, VITO has organized numerous visits to the drilling location and the geothermal plant. Neighbours, local citizens, (international) specialized interest groups, (international) university students, (international) political and industrial decision makers have been hosted by VITO and received briefings and guided tours. In cooperation with the local school association KOGECA, campus KOGEKA, Campus Het Spoor, TISP, VOKA Kempen and GoodPlanet Belgium, VITO organizes a specific Science-Technology-Engineering-Mathematics program (STEM) for the youth (Figure). In the context of this program children and adolescents receive a half-day educational program focusses on alternative energy in general, geothermal energy in particular. The initiative gets financial support from the province of Antwerp, the Flemish government and Eandis.

Figure: Education about geothermal and alternative energy in the context of the 'Geothermie voor STEM' program.

3.2 Role of the TI in knowledge creation/technology transfer

Success story on the spotlight

The development and the construction of the Balmatt Deep Geothermal Facility offered a unique situation to create an environment that is supportive to the development of deep geothermal projects in Flanders. It also resulted in an ecosystem of people that believe in the potential of geothermal and district heating.

- The discussion of opportunities and challenges with the competent authorities and policy makers allowed them to create a legal and financial landscape that is supportive for the development of deep geothermal projects. This encompasses a legal basis for the extraction and utilisation of

geothermal heat, a legal basis for the distribution of heat and electricity, an adapted regulation with respect to energy efficiency and renewable energy, a scheme to reduce the investment risks, upfront support for investments in capital intensive renewable energy sources, a scheme for operational support to bridge the gap between the costs for the renewable energy relative to conventional sources of heat and electricity.
- The progress line shows the importance to engage with a broad group of (local) stakeholders to create momentum for far-field exploration and to realize a transition in the energy landscape. The agora approach, the design research projects and the incorporation of geothermal in the local energy and climate plans in the spatial planning and design of new (real estate) projects proved to be crucial to build the Balmatt geothermal plant.
- From the Balmatt project and the related INTERREG and ERDF projects an expanding ecosystem emerged that is carrying forward the development of deep geothermal and geothermal district heating the Campine region. Economic actors started to build new business cases that strengthened the momentum for geothermal and district heating (i.e., the Beerse geothermal project of J&J - Janssen Pharmaceutica, Kempens Warmtebedrijf, HITA, warmte@vlaanderen and IOK – Wartme-makelaar Kempen). In addition, new research was started to that should result in a more efficient development and exploitation of deep geothermal projects, a reduction of the risks and impact of deep geothermal, an effective integration of geothermal (district heating) in the future energy landscape and a socially accepted and justified rollout of deep geothermal and collective heating.

The Balmatt geothermal project was initiated as a research and exploration project. From the start, it is however the ambition of VITO to use it as a pivot in the Flemish energy transition as well. With the project, VITO wanted to give a new impulse to the development of deep geothermal energy in Belgium. This objective has been achieved. Rollout of the technology is now taken over private companies like J J&J - Janssen Pharmaceutica and HITA. This role of VITO in the emerging geothermal landscape is to conduct further research to better characterise the geothermal resources, and to improve the efficiency and reduce the impact of deep geothermal. In addition, VITO will assist companies in the development of innovative technologies by offering them expertise and facilities to conduct tests in a relevant, operational environment. The Balmatt Deep Geothermal facility hence extends to research and development capabilities of VITO. With the facility we can now assist technology developers from basic, low TRL research up to TRL9.

3.3 Connection with other TIs at regional/national/European level

VITO is one of the partners of Energyville. EnergyVille is a collaboration between the Belgian research partners KU Leuven, VITO, imec and UHasselt. It bundles the research of the partners in fields of sustainable energy and intelligent energy systems. Through this collaboration VITO has access to the extensive lab facilities of Energyville in Genk (Discover the EnergyVille labs| EnergyVille). There is a close link between the Balmatt Deep Geothermal Facility, and the Thermo Technical Lab and oPEN Lab for the transition to positive energy neighbourhoods of Energyville.
The research on deep geothermal is embedded in EERA Geothermal. Together with other partners VITO holds the secretariat of the European Technology and innovation Platform on Deep Geothermal
In the field of deep geothermal, VITO has collaborations with:
- TNO, who operates The Rijswijk Centre for Sustainable Geo-energy (RCSG) – A unique open innovation lab for improving geo-energy technologies;
- Fraunhofer IEG, who operates the TRUDI real laboratory, an underground laboratory for the exploration and large-scale development of the hydrothermal potential in the Ruhr region;
- TU Darmstadt, who is developing the medium-deep geothermal probe and thermal storage system.
- OCAS, a R&D company focussing on metallurgy, coating and application development, by processing and testing of metal-based samples.

Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

Drilling for geothermal heat in the deep subsoil comes with high initial investment costs. Due to today's still limited knowledge of the deep underground there is a significant chance that a drilled well is unusable. The thermal capacity of a geothermal doublet is determined by the amount of water that can be pumped up per unit of time and by the temperature of the water produced. These factors are very difficult to estimate with high accuracy before drilling. Accordingly, geothermal projects carry a high investment risk. In addition, there is relatively little experience in operating and maintaining geothermal installations. Better understanding of the characteristic of the deep limestone reservoir is a primary focus of the research.

Another important focus is the further investigation of the behaviour of the Lower Carboniferous limestone reservoir during geothermal operations. VITO experts are monitoring all parameters to understand the downhole flow and the possible connection between production and injection well.

The brine, that has been collected during the production tests is radiologically contaminated and has to be considered as Naturally Occurring Radioactive Material (NORM). VITO has designed and is implementing an installation to dispose the collected brine in an environmentally acceptable manner, in concert with the Belgian (FANC) and Flemish authorities (VMM).

All above topics are likely to be relevant in other future geothermal installations in Flanders and elsewhere in Europe, which is why it is beneficial that VITO blazes the trail and builds up the necessary knowledge and experience, which can be shared.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

The high investment risk can be reduced by more extensive studies of the underground and/or sufficient insurance coverage. Both governments and RTO's - with risk reduction in their core mission - have a complementary role in this challenge.

The progress of the Balmatt geothermal project shows the importance of an environment that is supportive to development of a deep geothermal project, especially in a green field area like Flanders. To create such an environment, actions must be taken at the local level. However, interregional collaboration could help to develop green-field exploration and project development by.

- Sharing of experience with respect to technical issues between project developers / plant operators;
- Sharing practical approaches to engage with (local) stakeholders.
- Combining research efforts to define solutions and develop technologies / materials for technical issues faced by geothermal project
- Combining efforts to develop new technologies and setting up shared infrastructure / sites to test the technologies under relevant conditions.

Case Study 9 – VTT Technology Infrastructure: VTT Bioruukki Pilot Centre

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Introduction

Name of the Technology Infrastructure (TI): VTT Bioruukki Pilot Centre (Video).

Name(s) or the organisations managing the TI: VTT Technical Research Centre of Finland Ltd

Geographical location of the TI: Espoo, Finland

TI in national/European database of TIs: Pilots4U database; EC Advanced Technologies for Industry (ATI) database; VTT Aalto Bioeconomy infra; Research.fi database (covers all science fields)

Technology field: The whole value chain of bio and circular economy process technologies.

Focus of the TI activities:

- Open access pilot and laboratory facilities for development, scale-up and demonstration of new bio and circular economy process technologies and products. Development and scale-up is supported by versatile capabilities such as process safety studies, techno-economic and environmental assessments, process modelling, advanced analytics.
- Bioruukki facilities are typically utilised the early phase of industrial process technology scale-up by generating information for investment decisions of larger industrial pilot or demonstration units. Typically our projects are at TRL levels 3-6.
- The technology areas cover raw material pre-treatment, biomass processing, thermochemical conversions, chemical and catalytic processes, separation technologies, metals and minerals recovery, cellulose based biomaterials, such as textile fibres and new packaging materials. The main raw material sources for the new technologies are biomass, waste and industrial side streams.

Short history of the TI: VTT Bioruukki Pilot Centre is based on pilot plant development and operations since 1990's in different locations close to Helsinki capital area. Around year 2010 the plans for a large pilot centre concretised due to growth, enhanced safety demands and need to increase effectiveness of pilot operations.

A former printing facility relatively close to VTT's main campus in Espoo was selected as the place for the new pilot centre. The construction and start-up of operation there was done in phases. In 2013-15 the first phase a major renovation was made to renovate the old building and to move, modernise and rebuild relatively large thermochemical conversions pilots (gasification and pyrolysis) and the needed utilities.

VTT Bioruukki's second phase included renovating former storage halls to Biomass processing facilities and moving the existing equipment suitable for processing and fractionation of biomass. As a new capability, laboratory and pilot-scale cellulose textile spinning environments were established. This phase was ready in early 2018.

In 2020 started the Process chemistry platform in a new building. The platform includes a multi-purpose pilot plant for development and scale-up of value added biobased chemicals, new sustainable chemical processes and recycling concepts. The key unit operations are high pressure chemical reactors with versatile separation equipment, supported by the necessary laboratories. The key new capabilities include an automated high throughput catalytic conversion unit. Hydrometallurgy pilot unit was also build to study recovery of metals from low quality ores and industrial waste streams.

In 2021-22 new pilot units are build at VTT Bioruukki, such as renewed hydrometallurgy pilot unit, relocated pilot lines for roll-to-roll surface coating, and a totally new pilot line for regenerated cellulose-based films.

The further expansion of the pilot centre is planned for 2025 with large test units for low-carbon and zero-emission transport with electrification, hydrogen and P2X. However, these units are not included in the TI analysis in this paper.

1. Service-delivery model

1.1. Ownership/management

The pilot facilities of VTT Bioruukki Pilot Centre are owned and managed by VTT, which is a research institute and a non-profit company owned by the Ministry of Economy and Employment of Finland.

All the pilot operations are under VTT's business unit Sustainable products and materials, and the individual pilot platforms are managed by specific research teams of the business unit. VTT Bioruukki Pilot Centre can also rent space and facilities to third parties, such as companies or other RTOs. Currently a start-up company (Infinited Fiber Company Ltd) and a RTO (Luke - Natural Resources Institute Finland) have units in Bioruukki.

1.2. Users

Type of users: The users for bilateral contract work at VTT Bioruukki Pilot centre are typically companies that are looking for new business opportunities in the field of bio and circular economy process technologies. Typical industry sectors are chemical, energy, forest, packaging and mining industries as well as waste management and process industry equipment manufacturers. The main share of contract work revenue comes from large companies, but the share of SMEs and start-up companies is increasing. Other RTOs and Universities can buy contract services of VTT Bioruukki. The share of bilateral contract work is typically 30-50% of the revenue. The share of EU and International customers varies, but it is typically about 1/3 of all bilateral customers. Another large user group is publicly and jointly funded research and innovation projects, both nationally and EU funded. That offers wide possibility for domestic and European RTOs and Universities, as well as participating companies, to use VTT Bioruukki. The share of EU funded projects has increased and is now about 50% of all publicly funded projects. A relatively small part of VTT Bioruukki use for scale-up and demonstration of VTT's own proprietary technologies using VTT own funding.

Openness policy and access conditions: VTT Bioruukki follows the open access principles to both domestic and international research providers and industry, as shown on webpages www.bioeconomyinfra.fi.The facilities and services are available for all users either through joint research projects or against a service fee.

Process to reach new users and/or foster SME access: VTT Bioruukki is a key partner in the Pilots4U network and database, which promotes the awareness of open access pilot facilities in the field of bio and circular economy process technologies. SMEs are a focus of Pilot4U network. Also other domestic and EU databases are actively used. VTT Bioruukki is also clearly visible in VTT's marketing campaigns, thematic webinars and web-pages, where SMEs are regularly one of the target customers groups. New start-up companies are monitored through business database follow-up or created from in-house incubator programmes. One widely used route to reach SMEs is unofficial networks and R&I ecosystem development for selected technology areas.

Projects:
- 50-80 bilateral projects per year.
- Up to 40% share of contracts with SMEs.
- Around 30 projects including use of the TI in competitive public funding programmes.

1.3. Services provided by the managing RTO and skills needed

These technology related services are supported by VTTs wide range of general services, for example: R&I project management support, IPR protection and utilisation, computing and data processing, HSEQ-services, facility services, HR-services, purchasing and accounting.

Technology-related services: VTT Bioruukki Pilot Centre is a focal part of VTT's service offering for innovation especially when developing new solutions for biobased, low carbon and circular economy technologies. The core of the VTT Bioruukki service offering is experimental piloting at the four pilot platforms: 1) thermochemical conversions, 2) process chemistry, 3) hydrometallurgy and 4) biomass processing and biomaterials. Piloting provides experimental process data for next step process design and product samples for material testing and pre-marketing. The service offering can be further complemented with VTTs other pilot plants e.g. Polymer processing and converting pilot (Tampere, Finland) or Fibre based materials pilots (Jyväskylä, Finland). The core piloting services can be supported by wide range of related technology services, such as laboratory and bench scale experiments, process safety assessments, advanced analytics, versatile pre-engineering techno-economic and environmental assessments, and process and material modelling.

Non-technological services: The technology related services can be complemented with VTT's services and expertise e.g. business model development, value chain analysis, ecosystem developments, industrial eco-design, criticality assessment on economic and supply risks and substitution, integration of economic, environmental and performance data.

2. Funding model

2.1. Initial investments for the creation of the TI

The VTT Bioruukki Pilot centre was developed and constructed in three main steps in time period 2013-2021. The total investments to the pilot halls, facility technics, process utilities and new process equipment are about 35 M€, meaning that each main step costed about 11-13 M€. The funding for the investments came from three main domestic sources roughly at the same 1/3 share: a special funding by the Ministry of Economy and Employment, VTT own funding, and investment rent funding of the real estate owner (paid by VTT in rents).

Creation of this TI included in national/regional strategic roadmaps/plans: The original creation of VTT Bioruukki Pilot centre was an initiative of VTT supported finically by the Ministry of Economy and Employment, which was in line with the National Bioeconomy Strategy.

Size of initial investment: 35 MEUR.

Sources of funding:
- Special grants from national government budgets: 13 M€
- Owner of the estate (paid in rents): 10 M€
- VTT's own capital investments: 12 M€

2.2. Upgrade/upscale investments (long-term sustainability)

The VTT Bioruukki Pilot Centre requires continuous annual investments to upgrade of offering and new equipment. The annual level of the upgrade investments is about 1-2 M€. That is mostly funded by VTT own investment funds, but notable support (about 20%) has been received through the investment support mechanism of Finnish roadmap of national research infrastructures (FIRI).

Upgrade of this TI included in national/regional strategic roadmaps/plans: When started operations in 2014-15 VTT Bioruukki Pilot Centre came a "higher TRL part" of Aalto-VTT BIOECONOMY RI which is at the Finnish roadmap of national research infrastructures (FIRI). The BIOECONOMY research infrastructure (RI) is an openly accessible research, education and innovation research environment hosted by Aalto University and VTT, covering the research value chain from lab to pilot scale and combines research and innovation facilities for material and chemical technologies as well as for biotechnical processes.

Size of (past & foreseen) investments for upgrades/upscales: 1-2 M€ per year.

Sources of funding for upgrades/upscales (estimates):
- 50-70% Own funding
- 10-30% National roadmap funding (FIRI)
- 0-20% Other public funding (e.g. ERDF)
- 0-10% Private co-funding

2.3. Operational costs (usage/maintenance/depreciation)

Average operational costs: 3-4 M€/year (estimates)

Types of operational costs for running the TI: The key operational costs for running VTT Bioruukki pilot centre are rents, depreciations, utilities (electricity, water, district heating, propane gas…), maintenance and facility services.

Operational costs coverage foreseen: The operation costs are financed either from the VTT budget or the funding is obtained as part of the external project funding. The operational costs of VTT are largely covered by the research facility cost, which is charged from the RI-related research projects based on unit costs by working hour.

Share of these operational costs covered in competitive publicly funded projects: 40-60%

3. Role in the RD&I ecosystem/innovation hub

Role of the TI in the RD&I ecosystem: VTT participate actively in the European bioeconomy RI cooperation to create globally competitive open access networks of research infrastructures across Europe. The target is to form a co-creation platform for complementary excellence profiles in the research value chains and innovation ecosystems. Our collaboration at Nordic level, is targeted to establish a strong Nordic core for forest based European RI collaboration. The Nordic RTOs RISE, VTT, SINTEF and GTS signed in 2019, a MoU to collaborate around testbeds and technology infrastructures. VTT and RISE have also an agreement on bilateral collaboration in the areas of forest-based biorefineries, circular bio-economy and digital solutions for bioeconomy (signed 2019).

Role of the TI in knowledge creation/technology transfer
- 10 first patent filings in 2020
- 50 peer-reviewed publications/year
- 2 spin-offs created since the creation of the TI

Success story on the spotlight:
VTT-based start-up Infinited Fibre Company Ltd has used extensively VTT Bioruukki Pilot Centre's textile fibre spinning and process chemistry pilots for scale-up and demonstration of their Infinna™ textile fibre technology. The core of the technology is sustainable and industrially feasible production process for high-quality recycled textile fibres from low-grade textile waste. The piloting done at VTT Bioruukki Pilot Centre has convinced customers and funders, since the company has announced to build a 30 000 t/a flagship factory in Finland using post-consumer textile waste as feedstock. Production is scheduled to begin in 2024.

Connection with other TIs at regional/national/European level:
VTT has technology infrastructure collaboration agreements with Aalto University (Finland) and The Research Institute of Sweden - RISE. VTT's role in collaboration is at higher TRL level activities. VTT is a key partner in the IBISBA consortium (ESFRI 2018) for industrial biotechnology and synthetic biology. This links us to several EU level establishments (e.g. ELIXIR, FAIRDOM, ISBE, Open Science Cloud). VTT had key roles in H2020 ERIFORE European Research Infrastructure for Circular Forest Bioeconomy (2016-18), a design study for ESFRI planning targeting to an application for the ESFRI Roadmap. VTT is a partner in BRISK2 RI network for biofuels, and VTT was a key member in the bioeconomy pilot plant networks SmartPilots (Interreg Europe, 2016-20) and Pilots4U (BBI, 2017-19); Pilots4U has continued as an European database and network of bioeconomy pilot plants.

Conclusion: Challenges faced & Recommendations to policy makers

Main challenges faced for the creation and running of this TI:

The success of VTT Bioruukki is based on a customer or user approach, where the users have to hire the expertise of VTT's staff and its equipment, and the users have been able to formulate their leasing contracts according to their needs. VTT Bioruukki is facing some challenges as the users consider their services to be quite expensive, even though public funding is available in some cases. Future opportunities can be e.g. to develop PPP's for funding and ownership for investments to new equipment, and making facilities and equipment even more accessible to SMEs' through better financial support for buying pilot services.

The continuous development of offering and new equipment is essential to keep the pilot facility competitive. The predicted investments level (1-2 M€/a) may be difficult to maintain, especially in low economic periods. New funding sources for investment support is needed, both public and private, domestic and EU. Partial private funding from the industry is aimed for such large investments as joint innovation ecosystems and pilot plants. Skilled and experienced staff is essential for the success. VTT Bioruukki is relatively well positioned in that respect thanks to VTT's good employee reputation and the location in the capital region. However, new recruitments are continuously needed due to growth, replacement needs and retirements.

The further extension of digitalisation, data processing and user/customer interphases require money and skilled professionals. That is increasingly required by the users and funding bodies.

Typically, large-scale technology infrastructures have very high initial cost and then require further investment and maintenance costs. Therefore, supporting innovation policies on the regional, national as well as the European level, is of utmost importance to safeguard the long-term existence of these innovation accelerators.

Recommendations for policy makers which might be included into the upcoming EU Strategy on TIs:

- Invest wisely and focus on maintaining and further developing existing facilities to keep their state-of-the art equipment up-to-date. Europe already has significant open access pilot facilities. The gap analysis executed within the framework of the Pilots4U project did not reveal a shortage in facilities as such, in terms of capability to meet industry needs, but rather a strong need to further strengthen and invest in existing open access infrastructures to keep them state-of the art and increase flexibility. This is applicable to most areas of Europe, with the exception of Eastern Europe, where a small number of open access pilot exists and new centres may be required in the future.
- Create mechanisms to encourage usage of already existing shared pilot facilities, even if these are located outside their own region. To maximise the investments in and the potential of the existing facilities a better mobility of funding across Europe would be needed, especially on a cross-regional basis, by extending the remit of existing regional funding mechanisms. Companies must be able to gain access to the equipment and expertise they need across Europe. Pilot facilities, wherever they are located, should be accessible to all European companies/SMEs using own regional funding.
- Increase coordination and collaboration between pilot facilities, improve users' awareness of the available facilities and avoid overlapping investments in Europe. The potential of existing open access infrastructure in Europe could be optimised, and risks of unnecessary duplication minimised, by the creation of collaborative networks that own complementary infrastructures within a specific value chain, that could be used to facilitate co-working. Pilots4U Network is an important first step in this direction.
- Encourage companies to work together with pilot facilities from an early stage. Research projects oriented to solve scale-up knowledge gaps should be funded to build the knowledge base among experts, increase the pool of expertise and stimulate the development of bio-based technologies.