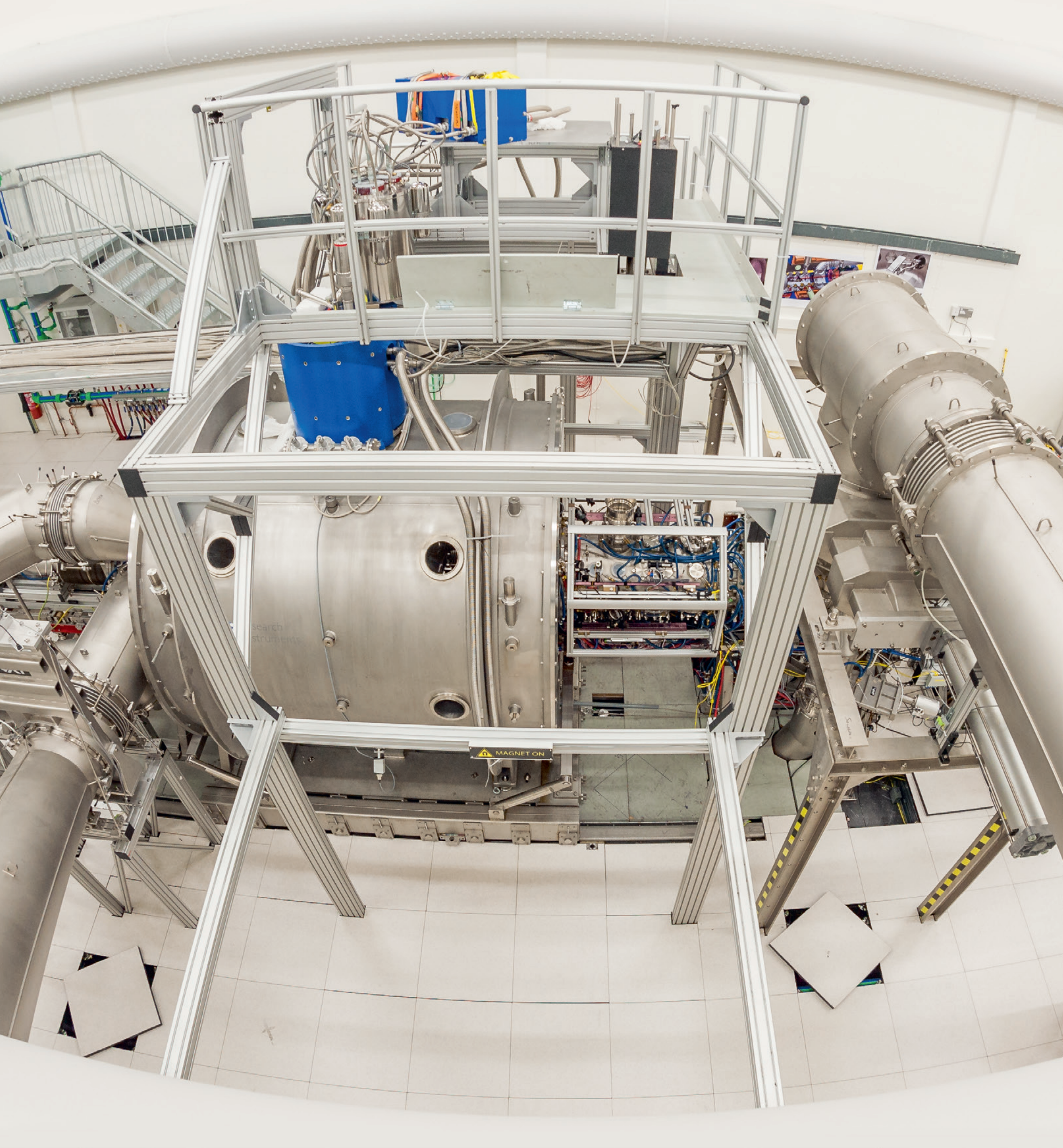
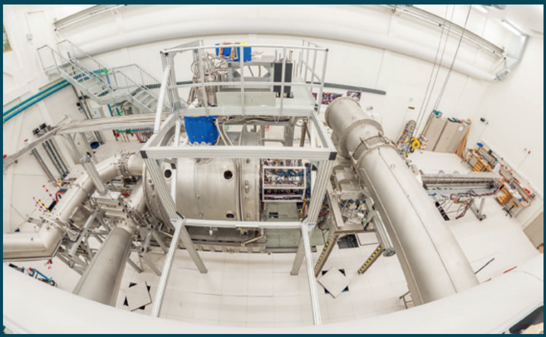
DIFFER STRATEGY 2023 – 2028

MATERIALS, PROCESSES, AND SYSTEMS FOR FUTURE ENERGY





COVER: Magnum-PSI is our largest facility. It is the only setup worldwide to produce the conditions in the divertors of future fusion reactors such as ITER and DEMO. Researchers from all over Europe and the rest of the world come to Magnum-PSI to study plasma-wall interactions during and after long-term exposure.
Picture: Bram Lamers

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DIFFER

NWO

CONTENTS

We are proud to present our Strategic Plan for 2023 – 2028.

DIFFER carries out research that is strategically important for the Netherlands in general and the Dutch scientific community in particular. Our work is internationally leading in multiple areas of research for the energy transition, and we put a great deal of effort into making its relevance visible for society. We create an inspiring environment for researchers and provide access to national and international research facilities.

Energy and climate research are no longer automatically directed by a single or a few knowledge institutes. Dutch universities, for example, have established their own energy research departments.

DIFFER will explore new (inter)disciplinary fields of science and promote science at an international level. Even more than before, we will connect, facilitate, and coordinate the relevant research fields in the Netherlands. We aim to provide added value and complementarity to the Dutch energy research community via long-term programmatic commitment and investments in scientific infrastructure at a scale that enables and necessitates collaboration. We will expand our (large-scale) facilities and establish a materials for energy infrastructure, and we will make these sustainably accessible to national and international researchers in this field.

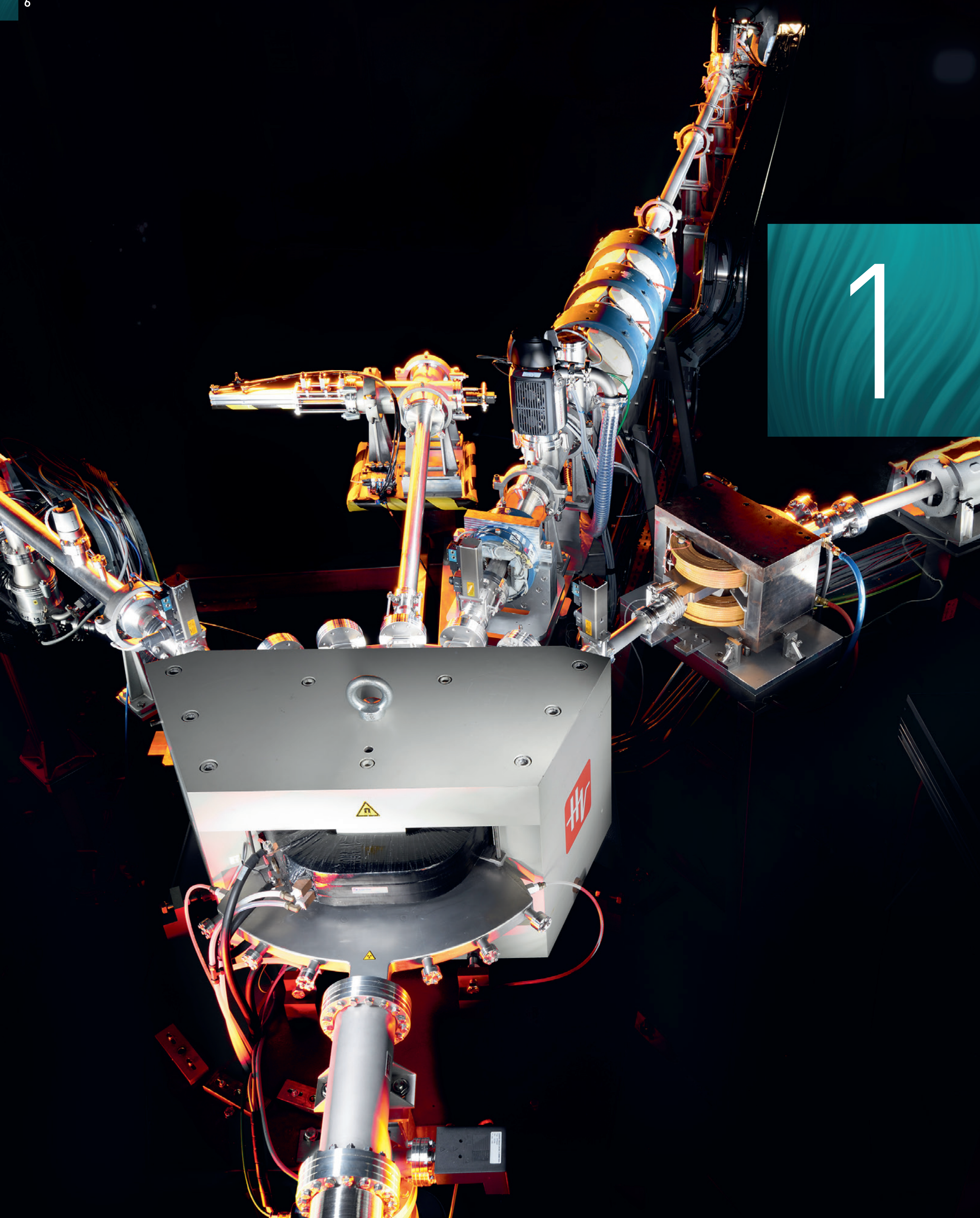
The need for a larger facility for materials research was identified by the Rathenau Instituut in 2020[1]. DIFFER is in the position to establish such a facility targeted at making and characterizing *materials for the energy transition.*

Two years ago, we started the process to evaluate the science case, required infrastructure, embedding in our organization, required organizational changes, and finances needed for acquiring and operating facilities for energy research.

In the coming five years, we will extend and operate this infrastructure, open it up to more external users from various knowledge institutes, and establish new partnerships and collaborations. With these changes, we are confident about the relevance and success of DIFFER in the foreseeable future.

Marco de Baar, director of DIFFER
Eindhoven, March 2023

1 Jos van den Broek & Jasper Deuten (2020). *Onderzoeksinfrastructuur voor Materialen in Nederland – Knelpunten en oplossingen in beeld naar aanleiding van ADEM-rondetafelbijeenkomst* Den Haag: Rathenau Instituut



1

STRATEGY IN A NUTSHELL

DIFFER's mission is to perform leading fundamental research on materials, processes, and systems for a global sustainable energy infrastructure, in close partnership with (inter) national academia and industry. We host unique user facilities for energy and materials research. We play an active national and international role in bringing together various parties within the energy community. We believe that only through collaboration can we realize groundbreaking energy solutions for the future.

Science for society: future energy

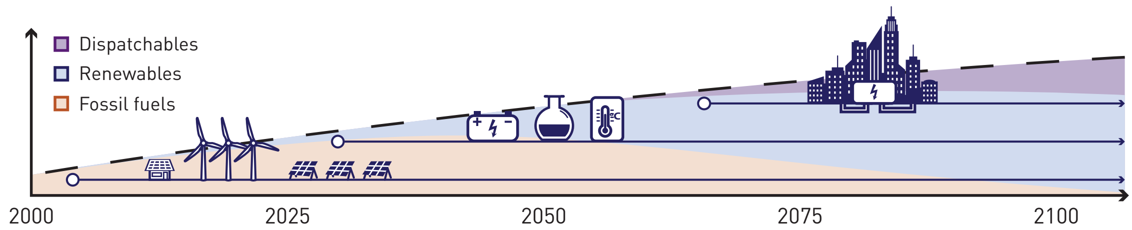
With the Paris Agreement, most countries have declared that they will limit global warming to less than 2 degrees Celsius compared to pre-industrial levels. This calls for zero net CO_2 emissions to be reached during the second half of the 21^{st} century, and thus requires a transition towards a fully sustainable energy supply. By performing fundamental, cross-disciplinary research in the fields of solar fuels and fusion energy, DIFFER can make significant contributions to the crucial phases of the energy transition in developing CO_2-neutral energy systems. This will benefit the entire of society.

Besides the energy transition, a far-fetching electrification of industrial processes is required. All these challenges are exacerbated by the evident problems with nitrogen oxides, carbon dioxide, and the exposed vulnerabilities with gas supplies and high energy prices.

In the future, a significant part of our energy will be produced by solar panels, wind turbines, and other renewables. Given the intermittency and seasonal effects of renewables, solutions for energy conversion and storage are required. Energy from renewables can be stored or converted in technologies, such as fuel cells, electrolyzers, and batteries or in chemicals like ammonia, kerosene, and hydrogen.

Furthermore, we are convinced that there will be an important role for modern, inherently safe nuclear power plants with low waste production, such as molten salt thorium fission reactors, small modular reactors, and nuclear fusion reactors. DIFFER works on a broad spectrum of the solutions mentioned above.

The energy transition is a materials transition, a process transition, and a system transition. Most of DIFFER's research is focused on materials and processes. We develop materials for catalysts and reactors that make chemical reactions run faster and more efficiently or that can withstand extreme operating conditions.



Schematic representation of the three phases of the energy transition: from fossil fuels to renewables and dispatchables.

Systems and process aspects manifest themselves in our work. Examples include investigating chemical and physical processes far from thermodynamic equilibrium or developing control systems to measure, estimate, forecast, and optimally control those processes. Moreover, system engineering models, which account for functionality, disturbances, requirements, and interfaces, will be used to design our high-end instruments (see below), integrate various plasma controllers, including the overarching supervisory controllers.

What has changed during the past strategy period of 2017 – 2022?

In recent years, Dutch universities have increasingly focused on energy research. Maastricht University has started a plasma chemistry group for climate-neutral solutions for the chemical industry. Leiden University is oriented towards batteries and electrochemistry. TU Delft develops electricity-powered refineries and is driving the research on molten salt reactors. University of Groningen and Utrecht University are working on catalysis and hydrogen. University of Twente focuses on energy applications. Eindhoven University of Technology has launched the Eindhoven Institute for Renewable Energy Systems (EIRES) and an increasing number of the university's research groups ranging from systems engineering to artificial intelligence have joined the European fusion research program. AMOLF reorganized and created the department Sustainable Energy Materials. And finally, the Netherlands eScience Center contributes to the European fusion research program and to solar fuels research.

Another change is the emergence of the National Growth Funds. This new line of R&D funding in the Netherlands may significantly impact the scientific landscape with more programmatic research that is closer to application. In addition, large initiatives have started and agendas have been published. Examples are the Dutch Research Agenda (NWA) program Electrochemical Conversion and Materials, the Materials Agenda, and the New Energy Coalition. With the new Minister for Education and Science and the new government agreement (*coalitieakkoord, Omzien naar elkaar, vooruitkijken naar de toekomst*, end 2021), there appears to be more funding for science in general, and even funding for the operation of large scientific facilities.

Furthermore, numerous commercial nuclear fusion endeavors have been successful in attracting private funding (the private investments are now larger than the academic investments for fusion), and they are searching for collaboration with academic fusion labs. Another big change is that ITER is expected to achieve its first plasma within the period of our next strategic program. The successor of ITER, the DEMO reactor, will become more prominent in our fusion research program.

For 2023 – 2028, what will DIFFER be focusing on?

We are pleased to see this changing playing field with new parties and initiatives. It provides us with the opportunity to recalibrate our priorities. In addition to our own research, and our role as a national institute, we want to collaborate with Dutch research groups and new initiatives, and facilitate and accelerate both their research and ours. DIFFER can play a facilitating, stimulating, and strategic role by opening up its large facilities (further) for external users and investing in unique, new facilities for the (inter)national community and industry.

Energy research in the Netherlands is far larger than DIFFER alone. Consequently, DIFFER cannot and should not try to organize the field. However, a major opportunity is emerging for DIFFER to establish relevant partnerships and facilities for stakeholders. Therefore, we are focusing on four actions:

1. **We strengthen our focus on the DIFFER mission.** Our research was, is and will be focused on materials, processes, and systems in the fields of solar fuels and fusion energy. Within this context, we extend our research to other energy applications.

2. **We open our facilities to more users.** Our flagship facilities are Magnum-PSI and Upgraded Pilot-PSI for fusion research, the Ion Beam Facility for materials research for nuclear fusion and fission, and solar fuels. These facilities are highly relevant to academic and private partners in solar fuels and fusion research.

3. **We invest in new facilities**. Those investments focus on research into materials for energy. They are centered around fabricating and characterizing high-performing materials for energy applications. The results will be fed back to advanced materials modelling, which will provide better selections of candidate materials. We are currently realizing the Liquid Metal Shield Lab to investigate liquid metal walls in fusion reactors. We have decided to realize a Pulsed Laser Deposition Facility with multiple in-situ diagnostics, a system for in-situ and operando ion beam measurements, and a Compact X-ray Facility.

4. **We enhance our relations with academia, applied research, industry, and society.** We valorize our science in co-development with industry and through technology transfer. We foster the interaction with academia, applied research institutes, society, and private nuclear fusion endeavors, where these are in line with our own scientific interests and strategy.

Why more facilities?
Our facilities are unique and we have proven to be excellent hosts for (inter)national users. Furthermore, universities and industrial partners find it difficult to operate and upgrade their larger scale facilities. Also, our research and our facilities are not separate entities. They strengthen each other, and together, they strengthen our position in the Netherlands, Europe, and the world.

What will be invested in the next 6 years?
We expect to invest about 20 million euros in our existing and new facilities. This budget also includes personnel, consumables, and maintenance costs during the exploitation phase. The capital required will partly come from our reserves, but we also intend to attract external funding from various sources such as the Dutch Research Council (NWO), the EU, National Growth Fund, Interreg, and roadmaps.

What about the employees?
Our staff is our greatest asset. Our unique in-house scientific and technical expertise is invaluable for operational activities, experimental setups, and scientific output. It is our staff and their expertise that contributes to our strategic goals.

2

ABOUT DIFFER

DIFFER's mission is: *To perform leading fundamental research on materials, processes, and systems for a global sustainable energy infrastructure, in close partnership with (inter)national academia and industry.* In short, DIFFER performs science for future energy. Our research focuses on two scientific themes: Solar Fuels and Fusion Energy. These are also the names of our two research departments. They are supported by the Facilities & Instrumentation department and Support Facilities department.

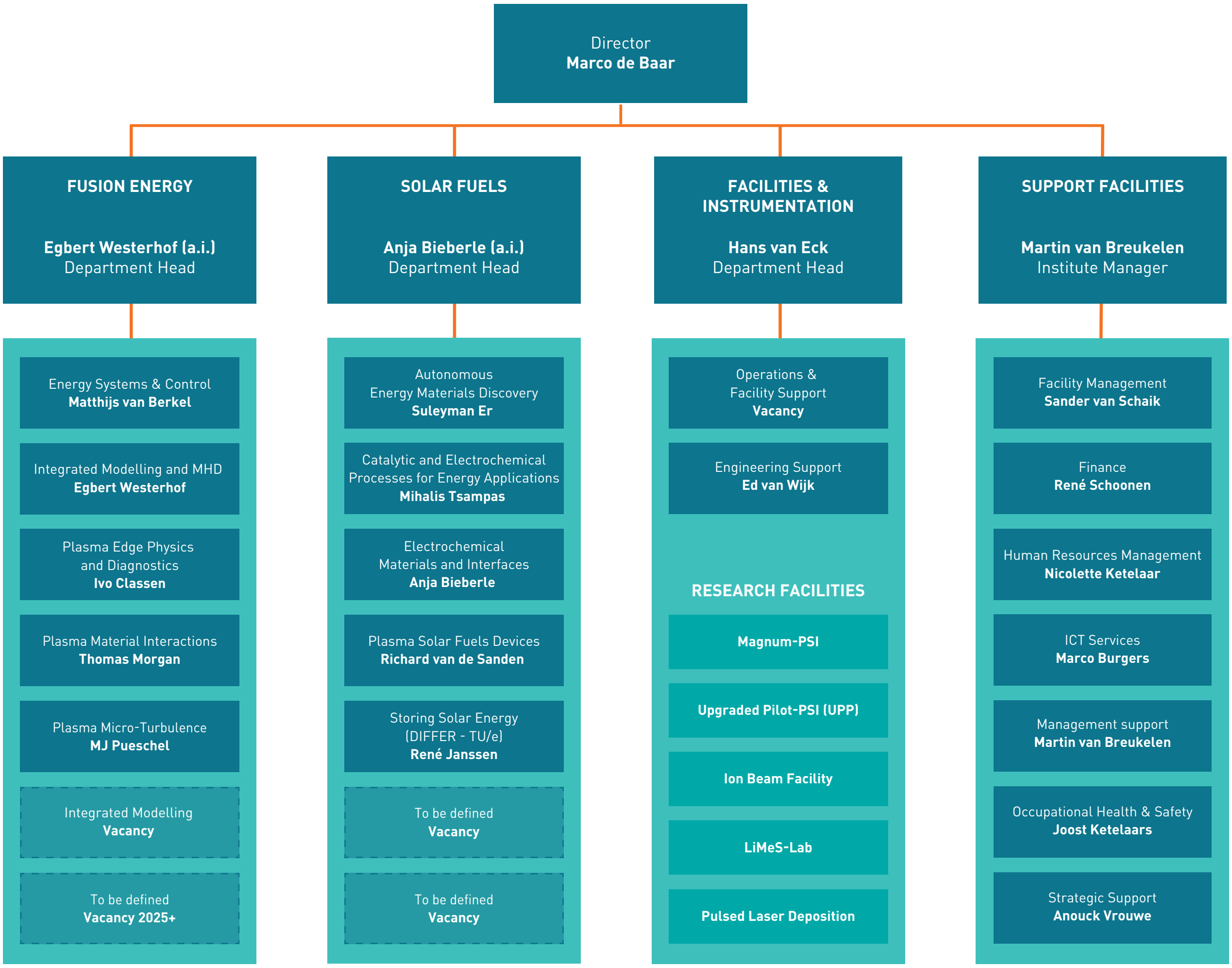
DIFFER is headed by a director who reports to the Executive Board of NWO. That board is advised by the Scientific Advisory Committee on the long-term scientific strategy of DIFFER, and by the Institute Advisory Board on political and socioeconomic relevant topics.

Although the director is ultimately responsible for the DIFFER policy, all strategic decisions are discussed within the management team. The management team of DIFFER has five members: the director, the department head Fusion Energy, the department head Solar Fuels, the department head Facilities & Instrumentation, and the institute manager (see also the organizational chart).

2.1 | Solar Fuels

The Solar Fuels department focuses on three main fields: materials science, electrochemistry, and plasma chemistry. The groups investigate the materials, interfaces and underlying processes through experiments, modelling, and simulations. We investigate all length scales: from atomistic, molecular, interface, over membrane and component up to device level.

The department owns and uses materials processing and characterization facilities and in-situ and operando functional characterization. In addition, modelling codes and databases are part of the department's modelling facilities. In collaboration with the DIFFER workshop, dedicated measurement compartments, reformers, and small-scale systems are built in-house. The department collaborates with research groups around the globe and is actively involved in national and European programs, agenda-setting, and networks. The department strongly supports the valorization of its research results.



Organizational chart of DIFFER.

2.2 | Fusion Energy

The Fusion Energy department does research to unlock the enormous potential of hydrogen fusion as a clean, compact and almost inexhaustible energy source. Fusion energy can stabilize the grid and provide baseline or dispatchable power. Publicly funded fusion energy research focuses on magnetic confinement fusion, the successful completion of the worldwide ITER project, and developing a commercially viable fusion reactor design (DEMO). ITER is expected to demonstrate a sustained fusion reaction around 2035.

Through the EUROfusion consortium, DIFFER researchers have access to and perform experiments on a range of large-scale fusion research facilities operated by our European partners[2]. Furthermore, collabo-

2 Examples are the European flagship tokamak JET (UKAEA in Culham, the largest tokamak and the only tokamak at the moment capable of operating with the deuterium-tritium fusion fuel mix), ASDEX Upgrade (in MPI IPP Garching), and TCV (at EPF Lausanne).

rations exist with fusion research facilities worldwide. As affiliated entities to DIFFER, Dutch researchers from Eindhoven University of Technology and University of Twente participate in the European fusion research program.

2.3 | Facilities & Instrumentation

The Facilities & Instrumentation department focuses on designing, realizing, operating, and upgrading the facilities for materials for the energy transition. This technical-oriented group allows strong embedding of the facilities and the accompanying high-level technical expertise in the organization. The group is already running the existing (user) facilities, such as Magnum-PSI, the Upgraded Pilot-PSI, and the Ion Beam Facility. The department will be responsible for a programmatic approach for the new infrastructure investments.

2.4 | Support Facilities

The Support Facilities department was restructured in 2021 and consists of seven support groups: Facility Management, Finance, Human Resource Management, ICT Services, Management Support, Occupational Health & Safety, and Strategic Support. Support Facilities aims to ensure a smooth operation of the DIFFER organization so that the scientific groups can focus on their research activities.

2.5 | Commitment to personnel

DIFFER aims to offer an open and inspiring working environment, with an atmosphere of trust and mutual acceptance, in which employees feel appreciated and rewarded at every level of the organization. In this positive and stimulating atmosphere, science can flourish.

Our four commitments to the personnel:

- We enable scientific excellence in a multidisciplinary and trustworthy environment.
- We stimulate collaboration, both internally and externally.
- We maintain a viable, healthy organization with a diverse, highly educated, well-trained staff.
- We educate and train our M.Sc., Ph.D., and junior scientists to the highest standards.

Our staff are our greatest asset. Our unique in-house scientific and technical expertise is invaluable for the operational activities, experimental setups and scientific output. Without our staff and their expertise, we cannot achieve our strategic goals.

We carried out a network analysis to assess the internal collaborations within DIFFER. These are predominantly within the departments. Opportunities for cross-departmental collaboration have been identified along the DIFFER mission. Those opportunities are an extension of the autonomous materials discovery activities towards nuclear reactors, an extension of the control activities to the Solar Fuels department, and an increased effort on the system aspect of the DIFFER facilities.

As an international research institute, DIFFER strives to have a diverse international staff, with a healthy gender balance. DIFFER will carry out honest and transparent recruiting and selection procedures for its positions and, in cases of equal qualifications, will favor an increase in the diversity of its workforce. Staff members will undertake diversity awareness training, and selection committees for new employees will have at least one member trained in diversity awareness issues. We have a confidentiality council, and two counselors to whom employees can go for confidential counseling.

The Eindhoven region is booming and we experience a significant industrial pull of staff. High-level scientists have crossed over to high-tech private companies. In this market, it is difficult to attract new staff across the board, whether these be technicians, scientists or administrative specialists. In this environment, it is easy for our Ph.D. students to start a career in the high-tech industry. We consider this a direct valorization of the Ph.D. education and very valuable extensions of our network.

Nuclear fusion is transitioning from a program focused on highly sophisticated fusion reactor physics to an engineering program. Fostering engineering talent is essential to ensure the further development of nuclear fusion as an energy source. DIFFER is well-positioned in this field by the group Energy Systems & Control, combined with the various funding schemes focused on this.

A very interesting new development in nuclear fusion is that private companies, backed by ample financial resources, are pioneering new reactor concepts. DIFFER aims to collaborate with some of these companies to ensure that the best of our knowledge is valorized and because it will help us to further develop our science and engineering program. Intensifying our collaboration with these private companies will bring new opportunities, but it may also impose a risk that we lose knowledge or even experienced staff to them.

3

STRATEGIC CHOICE 1

WE STRENGTHEN OUR FOCUS ON THE DIFFER MISSION

Our research has been, is and will continue to be focused on materials, processes, and systems in the fields of solar fuels and fusion energy. We are extending our research to other energy applications, such as modern fission and the advanced control of fusion reactors. This chapter briefly describes our research and provides our motivation for this strategic choice.

DIFFER focusses on materials, processes and, to some extent, on systems. These three areas of our research program have strong mutual interconnections and need to be studied in conjunction. The systems that we consider are either complex instruments or plasma-chemical, electrochemical/catalytic or thermo-nuclear plasma systems.

The Fusion Energy department focusses on plasma-wall interaction, divertor plasma transport, control, stability and turbulence, and transport in nuclear fusion plasmas. The Solar Fuels department focuses on converting renewable energy into chemical products by means of stimuli, such as light or plasma.

We continue our research on materials, processes, and systems in the fields of solar fuels and fusion energy and keep contributing to acceleration of the energy transition with our fundamental research. We will improve the departmental collaboration and strengthen the research lines to increase our impact and visibility. We will extend our research to other energy applications, such as modern fission, where possible and relevant.

An opportunity for cross-departmental collaboration will be to extend the use of artificial intelligence methods developed by the Solar Fuels department to identify suitable materials for the Fusion Energy department. A second example is present in the Fusion Energy department, which now uses its energy systems and control for fusion research on system identification and control within electrochemical systems and in plasma-chemical systems of the Solar Fuels department. DIFFER obviously wants to stimulate and exploit those initiatives.

3.1 | Solar Fuels: materials, electrochemistry, and plasma by experiments and modelling

The Solar Fuels department investigates materials, plasma chemistry, and electrochemistry experimentally and by modelling from fundamental studies up to small-scale systems. We do this research for a wide range of applications, such as water electrolysis, electro-fixation of nitrogen and carbon dioxide, aiming to accelerate progress towards the electrification of chemical industry. We want to deepen in the coming years our focus on this entire value chain and on the following unique combinations of disciplines:

1. The combination of plasma chemistry with electrochemistry and materials science allows us to stimulate electrochemical reactions in a new manner. It enables new reaction pathways, reactor designs, as well as alternative system concepts in the field of solar fuels. The circular production of (synthetic) aviation fuels is a topic on which DIFFER has already demonstrated success.

2. The combination of electrochemistry and control theory allows us to simulate electrochemical data that closely matches experimental data. On the microkinetic level, this allows us to identify reaction mechanisms and the limiting processes at the electrode-electrolyte interface of electrochemical energy applications. A logical and promising path forward is the extension to cell and system level.

3. Multi-scale modelling and machine learning (individually or in combination) enables us to develop databases, to predict materials and experimental data, and to validate models. This is needed urgently to accelerate the energy transition, which requires a significant increase in performance and efficiency of energy applications.

New groups around our infrastructure investment will be started in the coming years.

3.2 | Fusion Energy: materials, instrumentation, modelling and model-based control

Fusion energy holds the promise to supplement intermittent renewable energy sources like solar and wind, by using hydrogen as a virtually inexhaustible energy source.

Major progress in fusion research and related technologies has been made over the past few years. This is resulting in a growing number of start-ups that promise to accelerate the commercialization of fusion energy, attracting substantial capital from private investors rivalling for public fusion funding. Various new concepts have been proposed, varying from magnetic confinement[4] to approaches that are akin to inertial confinement. These initiatives have obtained very significant capital investment and will search for collaboration with publicly funded laboratories to keep the momentum going.

We have had intense interactions with three of these new initiatives and are likely to collaborate with all of them. In fact, the collaboration with the UK initiative STEP has already started[5]. From our perspective,

3 In the EU funded KEROGREEN project (no: 763909) DIFFER, together with European partners integrated the individual, separate processes and installed these into a shipping container.

4 In particular, Commonwealth Fusion Systems (CFS, a spin-out from MIT) should be mentioned, which focuses on the potential of high-temperature superconductors to generate higher magnetic fields allowing for more compact and potentially cheaper fusion reactors.

5 The UK has launched a publicly funded initiative, the Spherical Tokamak for Energy Production (STEP), which also aims to accelerate the commercialization of fusion energy.

collaboration is welcome but has to be aligned with the long-term goals and quality standards of DIFFER in general and the Fusion Energy department in particular.

In this exciting and vibrant research field, the DIFFER Fusion Energy department is focused along three research lines that are crucial for realizing a fusion reactor: a solution for the plasma exhaust of the reactor, advanced control schemes to operate the reactor optimally, and fast and accurate multi-physics (integrated) modelling to optimize scenarios. DIFFER is leading plasma control work and the development of a 'flight simulator'. The Fusion Energy department has been very successful in ITER and EUROfusion projects and grants.

Firstly, our facilities Magnum-PSI and Upgraded Pilot-PSI mimic the plasma-surface interactions under the plasma exposure conditions of ITER, which enables testing of new reactor wall materials. Our new setup, the Liquid Metal Shield Lab (see also 4.3), will allow us to produce, expose, and analyze molten metal technology for nuclear fusion reactor walls. Another new setup, named DICE, will allow us to study synergetic corrosion-neutron-induced material damage[6]. This is relevant for nuclear fusion as well as fission applications in generation-4 molten salt reactors.

Secondly, we are developing advanced control schemes for the operation of fusion reactors. This includes the development of high-end sensors and actuators. The department has established an outstanding international reputation in system identification of turbulent transport properties and the control of the reactor exhaust. Our research into complex, integrated control of burning plasmas is already looking ahead to applications in electricity-producing reactors with fewer sensors and actuators. Model-based approaches allow for off-line controller synthesis, observation, and faster than real-time prediction. Modelling and experimentation have started the integrated control of the density and exhaust. This will be extended in the coming years, where advanced hybrid controllers for the control of the plasma density with pellets will be developed. We are involved in the definition of a Joint EXperiment (JEX) on density control and aim to be involved in the International Tokamak Physics Activity (ITPA) IOS Integrated Operation Scenarios, and ITPA Diagnostics Topical Groups. Besides that, we will work on developing a 'flight simulator' and the interfacing with multiple complex controllers.

Thirdly, three research groups are devoted to modelling various aspects of a fusion reactor. The modelling activities can be separated into:

- modelling of the confined plasma region with closed magnetic field lines;
- modelling of the open field line region, where the plasma heat and particle flux is exhausted onto a material target in the divertor;
- and developing a fast and accurate *flight simulator* for optimization and control-oriented applications.

The use of machine learning and artificial intelligence for the development of tractable models is done in close collaboration with private companies.

6 Financed by the Province of North Brabant and HORIZON-EURATOM-2021-NRT-01. In collaboration with NRG, Reactor Institute Delft, and private companies Thorizon and Orano (France).

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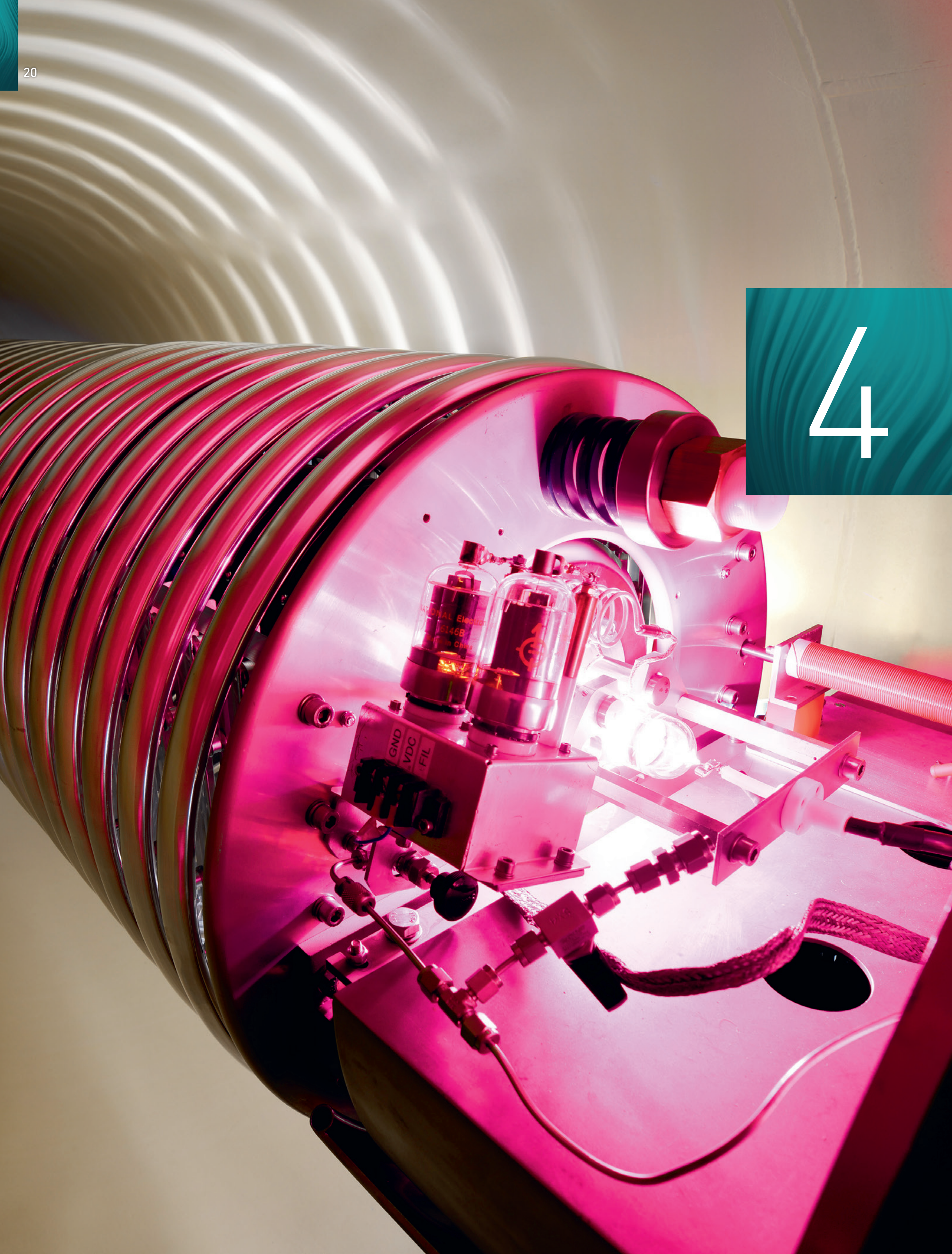

STRATEGIC CHOICE 2

WE OPEN OUR FACILITIES TO MORE USERS

Our flagships are Magnum-PSI and Upgraded Pilot-PSI for fusion research, the Ion Beam Facility for nuclear fusion and solar fuels research, and the Liquid Metal Shield Lab to investigate liquid metal walls in fusion reactors.

4.1 | Magnum-PSI and Upgraded Pilot-PSI

Our largest facility, Magnum-PSI, is the only setup worldwide to produce the expected steady-state and dynamic conditions in the ITER and DEMO divertors. The superconducting magnet allows for long-exposure, high-fluence experiments.

Upgraded Pilot-PSI (UPP) is a second, smaller, linear plasma device, with copper coils yielding slightly lower magnetic fields and plasma fluxes. It has the unique capability of in-situ and operando ion beam exposure. UPP, which has just started operation, will allow us to study the synergistic effects of plasma exposure and neutron irradiation, and to perform operando ion beam analysis to study dynamic changes in materials under plasma exposure.

We continue providing easy access to our unique PSI facilities where researchers from all over the world perform their experiments. In spite of the many years of experimentation, we expect that the facility remains relevant for the European fusion program, and will be selected as a mid-size facility for the following European framework program. Also, we anticipate attracting new collaborators from private nuclear fusion start-ups. We will also make the facilities attractive to new researchers and collaborators, notably from commercial fusion enterprises. We will extend the diagnostic park to fully characterize the role of molecules, neutrals, and excited species. Furthermore, we expect that studying this challenge at the heart of the fusion exhaust problem will further increase the visibility of the Magnum and PSI facilities.

4.2 | Ion Beam Facility

DIFFER operates a unique Ion Beam Facility. The facility can be used for two types of setups. The first is ion beam analysis, a non-destructive, quantitative, quick, and cheap method of elemental depth profiling, primarily in solid materials. The second type is ion irradiation, for the induction of defects in materials.

After further upgrades in 2023 – 2024, the facility will allow for ion beam measurements and ion irradiation during plasma-wall interaction experiments. Another exciting new development at the Ion Beam Facility is the realization of DICE, a loop through which liquid metals or molten salts can be pumped[7]. With this unique setup, we study the synergetic damage due to neutrons and corrosion in liquid metals or molten salts. Applications exist in the domains of both nuclear fusion (liquid metal divertors, tungsten divertors with FLiBe coolant or a PbLi blanket) and modern generation-4 fission plants.

Our Ion Beam Facility is aimed at attracting more external users and will continue to enable experiments for both nuclear fusion and solar fuels research.

4.3 | Liquid Metal Shield Lab

Recently, DIFFER, together with Eindhoven University of Technology, obtained funding in the NWO Investment Grant Large program to realize the Liquid Metal Shield Lab. This is a new facility for 3D printing of refractory metals, wetting these structures with lithium or tin, and exposing these mixed components to plasma. We will realize this lab to investigate liquid metal walls in fusion reactors. We will open this facility and invite researchers from other institutes to come and measure with us.

7 Financed by the Province of North Brabant and HORIZON-EURATOM-2021-NRT-01. In collaboration with NRG, Reactor Institute Delft, and private companies Thorizon and Orano (France).

5

STRATEGIC CHOICE 3

WE INVEST IN NEW FACILITIES

Most investments focus on research into materials for energy. They are centered along three paths to develop high-performing materials for energy applications: design/modelling, fabrication, and characterization. Examples are a Pulsed Laser Deposition Facility with multiple in-situ diagnostics, realization of in-situ and operando ion beam measurements, and a Compact X-ray Facility.

The study of plasma-chemical and electrochemical processes requires methods to select and fabricate materials and to study them in situ and/or operando. This is commonly done with small-scale setups that can be bought off-the-shelf or designed and built by individual research groups. However, larger scale facilities are needed, as well. An individual research group may lack the financial and (technical) personnel resources to maintain these facilities over their entire lifetime, upgrade them to remain a world-leading setup, and operate them as user facilities. DIFFER, however, as a national institute, has technicians and continuity of personnel to not only build but also exploit, maintain and upgrade the infrastructure and operate it as a (inter)national user facility.

Therefore we will install a suite of unique large-scale research instrumentation that will allow our own scientists, as well as scientists from other knowledge institutes or industry, to carry out unique, seminal, and world-leading research in the field of energy research.

5.1 | Pulsed Laser Deposition Facility

High-quality, well-defined, small- and large-area thin films of complex metal oxides are needed by a large user community for energy conversion and storage applications (to be verified in in-situ and operando experiments). Together with University of Twente and Eindhoven University of Technology and many partners from other knowledge centers, we have submitted a plan for designing and building a tailor-made Pulsed Laser Deposition Facility, including multiple in-situ diagnostics. The complex metal oxides we investigate in such a facility can function as a catalyst in electrochemical reactors, as membranes or hydrogen barriers.

We seek to systematically study how to scale up pulsed laser depositions to larger deposition areas. At the same time, we can fabricate the required *small and large* area thin films for and with the users.

Due to the feasibility of large-area thin-film deposition in combination with materials screening and in-situ diagnostics, this facility is also well-suited for collaboration with industry[8].

The collaboration with the University of Twente is instrumental in this program. The researchers there want to study upscaling but this requires a machine with both a small and a large area deposition chamber. Twente will focus on thin-film growth while DIFFER will focus on the energy application. The instrument will be the only PLD with small and large deposition area in the Netherlands. It will explicitly allow the investigation of the scale-up process, bridging the gap between small-scale test samples and industrial applications. Vacuum suitcases will be used to transport samples to other facilities in the Netherlands. A collaboration with Reactor Institute Delft at TU Delft on exploiting their positron beam and slow neutron diagnostics is foreseen and of mutual benefit.

5.2 | In-situ and operando ion beam measurements

Quantitative materials analysis during the operation of a component or a device is a bottleneck in the field of energy conversion and storage. We will extend our Ion Beam Facility with two dedicated end stations to realize in-situ and operando ion beam measurements.

Firstly, we plan to build an electrochemical measurement compartment and connect that to our current ion beam line for proof-of-concept experiments. Once this successfully operates, we will build an additional beamline to enable operando ion beam experiments for external partners. Secondly, we will realize DICE (see also 4.2) to study synergetic neutron damage and corrosion defects.

5.3 | Compact X-ray Facility

X-ray facilities to measure materials properties are in the range of a lab-scale tool or an end station to synchrotron facilities. A revolution in this field is a facility with a tunable X-ray source with a brilliance that approaches synchrotron radiation. Eindhoven University of Technology is currently building a prototype of such an X-ray source. It is a new technology based on inverse Compton scattering. DIFFER currently participates in a consortium with Eindhoven University of Technology and TU Delft, the universities of Antwerp and Ghent, as well as Dutch private industries to produce low-energy photons[9]. In 2023 and 2024, the plan is to increase the photon energy and work on system engineering aspects. Once functional, this design will constitute a major breakthrough in X-ray generation.

DIFFER is a candidate to build an X-ray facility with such a new, tunable X-ray source and multiple end stations. It will be a unique add-on to the material characterization instrumentation in the Dutch materials landscape, in which DIFFER plays a national role. However, if this high-risk, high-gain initiative cannot be realized, we will consider alternatives such as a conventional X-ray source with superior detection.

8 In the submitted WINC proposal PLD4Energy, many partners from Dutch universities and knowledge institutes are involved.

9 At the start of 2022, DIFFER and Eindhoven University of Technology signed a Memorandum of Understanding to realize a facility based on technology developed in the Interreg consortium Smart*Light.

5.4 | Auxiliary instrumentation

Besides the facilities mentioned above, DIFFER will also invest in smaller, complementary instrumentation. Some examples are:

- **High-end active spectroscopy** setup to study neutral atoms and molecules and their interaction with the plasma in the divertor of a fusion reactor.
- **Automated lab** for developing novel catalysts. Setting up a *self-driving lab* in which an artificial-intelligence-assisted pipeline selects promising candidate materials, with a future extension towards automated material synthesis.
- **Chemical cell for transmission electron microscopy** and scanning probe microscopy for localized, to nanometer-scale operando determination of material and surface properties under realistic conditions.

5.5 | Outlook

The strategic choice to invest in new infrastructure and open up for external users fits our strategy and national role. The infrastructure will be in support of, not be in competition with, our in-house research program. Our facilities strengthen our research, and our research strengthens our facilities. Realizing infrastructure at this scale differentiates DIFFER from other knowledge institutes, universities, and NWO-I sister institute AMOLF, but will also foster collaboration with them on materials for the energy transition.

For the exploitation of the facilities, we will use the model of Magnum-PSI. At Magnum-PSI, time is reserved for internal and external users. External users enter via a consortium or directly via DIFFER. A committee evaluates and selects the proposals based on relevance and excellence. We are aware that scientific knowledge is required to manage the selection process of submitted proposals and ample time will be reserved to carry out this task. In the coming years, we will expand this model to other facilities that we want to open up.

The technical support for building and operating the new infrastructure has been analyzed, and we have identified the need for a team of approximately 20 research technicians. The realization of the instrumentation is phased so that the DIFFER technical staff involved in the realization, operation, and maintenance of our facilities are not unduly overburdened. The Facilities & Instrumentation department, founded in January 2023, optimizes efficiency and fosters career and skills development of the technical team.

6

STRATEGIC CHOICE 4

WE ENHANCE OUR RELATIONS WITH ACADEMIA, APPLIED RESEARCH, INDUSTRY, AND SOCIETY

We valorize our science through technology transfer and co-development with industry. We have a long-standing industrial collaboration in the field of solar fuels. We foster the interaction with private nuclear fusion endeavors, where these are in line with our own scientific interests and strategy.

DIFFER is well embedded in the Dutch and European research communities. DIFFER is mentioned in the latest National Roadmap of Large-Scale Research Infrastructure in the Group Materials of the Domain Natural and Engineering Sciences. By setting up new facilities, expanding the user community, teaching and training early-stage researchers, and providing internships, we will further strengthen these ties.

6.1 | Solar Fuels: extend national and international roles

Staff of the Solar Fuels department are connected with national initiatives, such as the platform Electrochemical Conversion & Materials, the Dutch Council for Chemistry, and the Center for Computational Energy Research. The Solar Fuels department is currently extending its national role from an organizational role[10] to supporting the field by designing, building, operating, and maintaining large-scale facilities for the materials community. We plan to build three large facilities (see Chapter 5) in close collaboration with Dutch academia, organizations for applied research (TO2s), and industry. The new facilities will be built as user facilities. Our strategy is to connect with (inter)national researchers and (inter)national community platforms[11].

DIFFER's solar fuels research is well-aligned with European research agendas and activities. Our science program fits well with European Joint Programmes[12]. Our staff actively contribute to these programs and also have management roles. Furthermore, we contribute to and coordinate successful research with-

10 Organization of solar fuels workshops, being a link between universities, universities of applied sciences, and companies, representing the energy community in commissions.

11 In the recently submitted WINC proposal PLD4Energy, many partners from Dutch universities and knowledge institutes are involved and represent the national community platforms. For other large-scale facilities, we will also approach the researchers through these platforms.

12 Examples are AMPEA, SC, and DfE.

in European science programs[13] and we are part of European networks to influence agenda-setting in Europe[14]. We collaborate with leading industrial parties in the field (for example, Toyota) in numerous national, European, and bilateral projects and develop experimental techniques together. We want to extend all these activities further.

6.2 | Fusion Energy: established international role in academia

Since its founding as the FOM-Institute for Plasma Physics Rijnhuizen, DIFFER has been the main center for fundamental fusion research in the Netherlands. DIFFER had been and is the access point for Dutch fusion researchers to large-scale European facilities and programs.

Our fusion research is well integrated into the larger European fusion research program. We are the Dutch beneficiary within the EUROfusion consortium that executes the research on the European Roadmap towards Fusion Energy and that is co-financed by the European Commission under the Horizon 2020 and Horizon Europe Framework Programmes.

Eindhoven University of Technology and the University of Twente are DIFFER-affiliated entities. Where the participating Eindhoven research groups strongly align with the DIFFER research themes, the Twente groups complement the Dutch fusion landscape with their focus on high-temperature superconducting magnets. Close collaborations with Eindhoven University of Technology exist, especially with their groups of Science and Technology of Nuclear Fusion, Mechanics of Materials, and the Control Systems and Technology. Another example of collaboration is the Liquid Metal Shield Lab, which is being developed jointly by DIFFER and Eindhoven University of Technology.

DIFFER is also a focal point for integrating Dutch industry and additional knowledge institutes into fusion research. For example, DIFFER, together with the scientific software consulting start-up Ignition Computing and the Netherlands eScience Center (NLeSC), has been awarded ITER contracts for developing integrated modelling infrastructure, a development with long-term sustainment potential. With TNO, Chromodynamics, and AST, we are involved in a program to establish the Visible Spectroscopy Reference System at ITER. We will remain involved in designing and realizing instruments for heating and diagnosing large fusion experiments.

6.3 | Education: teach young people and encourage staff to affiliate

Our research is driven by Ph.D. students, postdocs and internship students from universities and universities of applied sciences (Dutch and from abroad). We are committed to excellent education and supervision of these junior researchers. Most of our Ph.D. students graduate from Dutch universities. We aspire to affiliate each DIFFER senior scientific researcher with a university. Although DIFFER staff are not required to teach, some staff members are already involved in voluntary teaching at universities, which is supported and encouraged by DIFFER management.

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13 For example, COST Actions 18234, KEROGREEN and M-Eranet, and various Horizon Europe projects.

14 Such as EERA, SYNERGY, and European Clean Hydrogen Alliance.

6.4 | Valorization: co-develop and spin off

DIFFER's main focus is on performing world-leading fundamental energy research. Part of our research may contribute to developments that are of interest for industrial applications or have been performed in collaboration with industrial partners. As explicitly mentioned in its mission statement, DIFFER aims to actively participate in and contribute to co-development, spin-off, and valorization activities for future energy applications.

Current collaboration with industrial partners is significant, and the portfolio built up by the Solar Fuels department is impressive. The potential to expand these activities is considerable and should be nurtured and explored in the future. DIFFER will hire an industrial liaison officer who will also be a member of the Dutch Industrial Liaison Officer network.

Besides valorizing our scientific research, there is a drive to push the boundaries of our research instrumentation. The new instruments we will establish are complex and unique and will be designed in collaboration with small and medium-sized enterprises (SMEs) in the high-tech industry. DIFFER's investment plan foresees collaboration with industrial partners and co-development of projects to find solutions for the technical challenges that arise when designing and building complex systems. Co-developed solutions may be used by companies and are likely to benefit Dutch SMEs.

Highly relevant are new fusion energy start-ups, some of which have expressed the intent to collaborate with the DIFFER Fusion Energy department on integrated modelling, materials, plasma control, and instrumentation. This may present us with possibilities to accelerate our program. However, we will need to carefully assess, on a case-by-case basis, how such collaborations match our strategy and scientific ambitions and whether the needs of these private companies are compatible with the typical Ph.D. and postdoctoral research we carry out.

6.5 | Open Science: more open access, more datasets

DIFFER is committed to the NWO open science policy, which states that 100% of the scientific publications financed by NWO must be publicly available and accessible. 119 of our 123 publications in 2021 were published open access: 56 via gold/hybrid, 63 via green. As the gold access route is preferred, we aim to further improve the ratio gold/green.

Collected data used in journal publications is already publicly available. Datasets used in Ph.D. theses will be stored in data repositories as well. DIFFER will publish more datasets following the FAIR data policy principles from the European Commission.

6.6 | Communication: enable employees as ambassadors

DIFFER's outreach and communication plan aims to provide a coordinated and consistent message to our academic and industrial partners, facility users, and other stakeholders. We strive to keep them informed about the developments of DIFFER.

We therefore convey our message to the following target groups:

- The Dutch science community
- Stakeholders (NWO, NWO-I)
- Policymakers and decision-makers
- The fusion energy and solar fuels community
- Industry
- STEM students
- General public
- DIFFER staff

Our main communication tool is the DIFFER website, where all our news is published and all relevant information can be found. DIFFER actively increases its visibility for a wider audience by being present on several social media platforms, publishing a newsletter, and publishing articles in professional journals. Since our employees are in the best position to convey DIFFER's message, the communications group supports them in their role as ambassadors of the institute.

7

FINANCE

DIFFER has a sound financial situation. Part of our financial reserves will be used to invest in research instrumentation and facilities so that we can fulfil our strategic ambition.

At DIFFER, we have established a working group on large scientific infrastructure with representatives from both scientific departments, Solar Fuels and Fusion Energy. Staff members were invited to come forward with suggestions for infrastructure relevant for the in-house scientific programs, the larger Dutch, or even European, community of researchers, and researchers from private companies. In addition, we probed the interest of industrial partners to co-develop such instruments.

The table below shows the scientific instrumentation, including a budget estimation, that DIFFER wishes to install to strengthen its national and international position. The almost 20 million euros in investment costs are significant and will be covered by successful grant applications and our reserves. For example, the Liquid Metal Shield Lab has already received 2.3 million euros of external funding for the building phase. The Pulsed Laser Deposition Facility is in the final evaluation stage for a grant of 5.0 million euros.

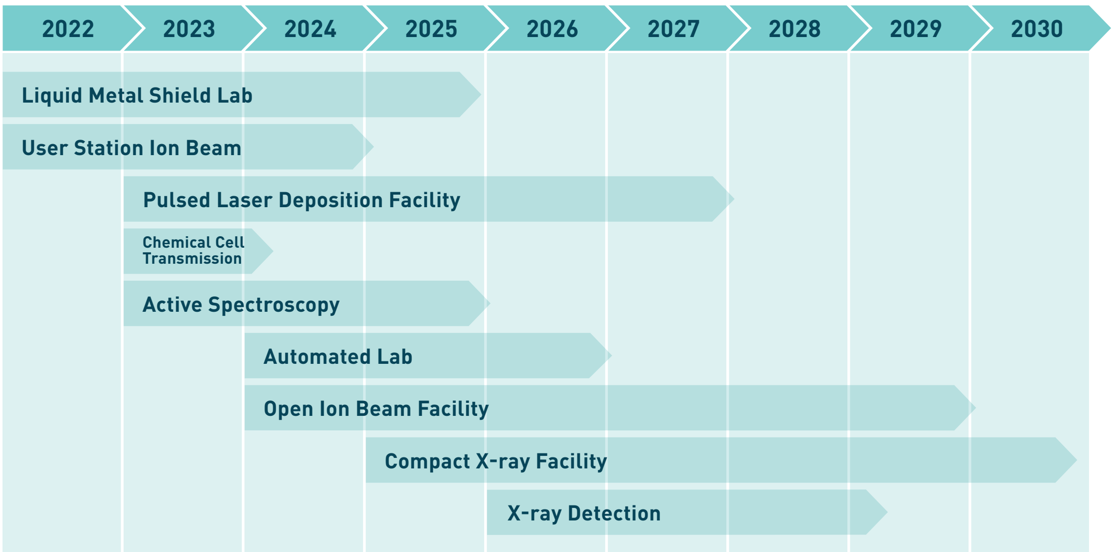
The first investments are *confirmed*. These will be executed and funding is available. For the instrumentation and facilities with the status *reservation made*, the decision will be made at a later stage. We will

DESCRIPTION	START BUILDING	START EXPLOITATION	INVESTMENT BUDGET	STATUS
Liquid Metal Shield Lab	2022	2025	M€ 2.3	Confirmed
User Station Ion Beam	2022	2024	M€ 0.3	Confirmed
Pulsed Laser Deposition Facility	2023	2027	M€ 5.0	Confirmed
Chemical Cell Transmission				
Electron Microscopy	2023	2023	M€ 0.18	Confirmed
Active Spectroscopy	2023	2025	M€ 0.5	Reservation made
Automated Lab	2024	2025	M€ 1.0	Reservation made
Open Ion Beam Facility	2024	2029	M€ 2.5	Reservation made
Compact X-ray Facility	2025	2030	M€ 8.0	Reservation made
X-ray Detection	unknown	unknown	unknown	Reservation made
TOTAL			**M€ 19.78**	

Investment budget and planning of instrumentation and facilities.

determine whether our financial situation is still sound, sufficient (support) staff is available, and the equipment still fits with our science and strategy program.

We acknowledge that building new facilities and operating a user facility may put undue pressure on our current technical and support staff. We are aware that our operational budget needs to grow over the years so that DIFFER can function well as a research institute with large-scale infrastructure. Together with our stakeholders, we will investigate which route needs to be taken to structurally realize our ambitions. The figure shows our plan to realize this in phases.



The construction and operation of the facilities will be phased to allow for the optimal deployment of technicians and support staff.

ANNEX: SWOT

In preparation for this Strategic Plan, DIFFER performed a SWOT analysis. We identified internal and external factors that can aid or hinder in achieving our goals.

STRENGTHS	WEAKNESSES
• Research questions are driven by urgent societal needs (energy transition). • Unique infrastructure, housed on well-equipped campus. • Multidisciplinary approach (e.g. physics, chemistry, materials science and engineering, and control engineering). • Significant financial reserve. • Solar Fuels has a strong program with private parties. • Fusion Energy is well embedded in the European community.	• Current number of scientific staff is low and support departments are small for future ambitions. • Lack of diversity among personnel. • Some gaps in expertise exist (e.g. nuclear material modelling, divertor modelling). • Synergy between Solar Fuels and Fusion Energy departments can be improved. • Insufficiently connected to regional, national and international policy makers.
OPPORTUNITIES	**THREATS**
• Renewed interest in nuclear energy, and increasing energy prices. • More fusion initiatives in private sector (e.g. fusion start-ups). • Funders have more attention for financing large-scale research infrastructure, large projects, and different research technology levels. • NWO is more aware of the importance of well-operated and maintained user facilities, and dedicated personnel. • Many knowledge institutes seek collaborations with DIFFER. • With the general need for an energy transition, short to mid-term energy solutions, such as Solar Fuels, are urgently needed.	• Inflation, stressed labor market with uncompetitive salaries. • Unforeseen changes in NWO funding schemes. • Possible shifts in national funding (more to universities, less to research institutes). • Large fusion initiatives like ITER can be delayed. Fusion start-ups do not deliver as promised. • Universities or institutes may change their mission and interfere with ours.

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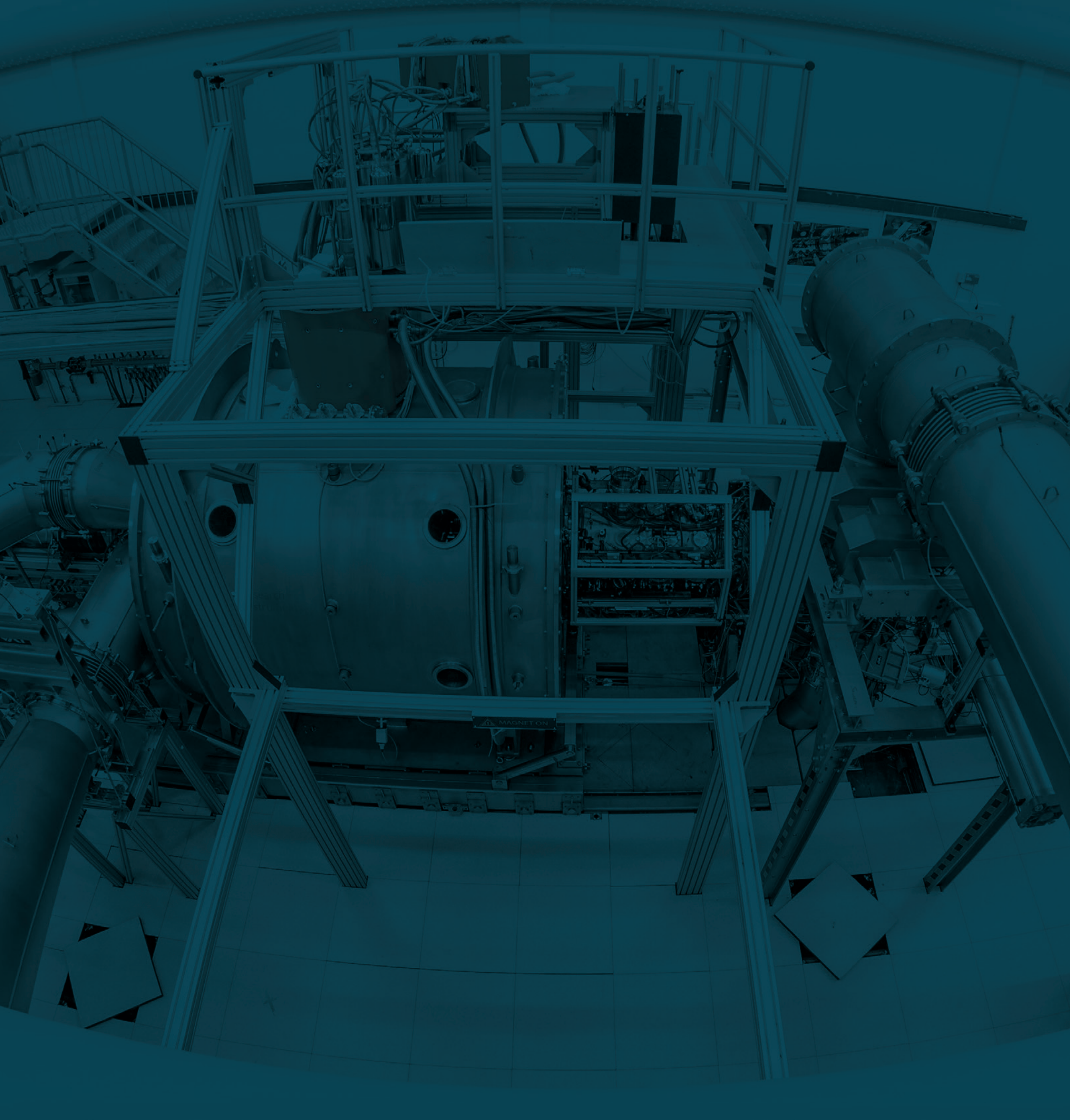
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