National Roadmap for Large-scale Research Infrastructure 2021

2021 National Roadmap for Large-scale Research Infrastructure

Contents

FOREWORD

This publication is the National Roadmap for Large-scale Research Infrastructure 2021. Large-scale Research Infrastructure (LRI) is a driver for innovation in research and for achieving breakthroughs in all research domains. The Roadmap 2021 presents an overview of the large-scale research infrastructure that has the highest priority for Dutch research in the coming decade.

Marcel Levi, president of the NWO Executive Board:
'Greater investment and clear decisions in favour of unique large-scale research infrastructure are important for science as a whole. They are a prerequisite for internationally recognised research in virtually every domain. Providing the right infrastructure unites parties who would not normally sit around a table together. This makes research infrastructure a breeding ground for new developments and the key towards innovation and finding solutions to major societal issues.'

Large-scale research infrastructure is essential to the position of Dutch science: it contributes significantly to innovation and towards solving major societal issues concerning the environment, climate, health and civilisation. There are various types of research facilities, either centralised in a single location or, increasingly, distributed across multiple locations. They can involve highly specialised equipment such as large telescopes, high-field magnets or advanced sensors and monitoring networks needed for biological and earth sciences research. But they can also be "virtual" facilities, such as extensive databases, scientific computer networks, or data and sample collections. For the most part, they are novel infrastructures developed jointly by the scientific field.

Hans van Duijn, chair of the Permanent Committee for Large-scale Research Infrastructure (PC-LRI):
'Large-scale research infrastructure is a driver for innovation in research and for achieving breakthroughs in all research domains. The Committee therefore calls on the new Cabinet to allocate additional funding to the Roadmap 2021, as the current budget is insufficient. In the long run, a research infrastructure is the engine for economic and social development and ultimately for prosperity in the Netherlands.'

The 2021 Roadmap is the next step in a future-proof, long-term strategy for large-scale research infrastructure. In 2015, the Dutch government asked NWO to establish a Permanent Committee for Large-scale Research Infrastructure (PC-LRI). This request emerged from the Vision for Science 2025, which states that strategic choices in the area of large-scale research infrastructure should no longer be left to ad hoc committees. In 2016 the PC-LRI, led by Hans van Duijn presented the Roadmap 2016 with proposals for research facilities in 17 clusters and 16 individual facilities.

The new Roadmap 2021 further expands this strategy, putting it on a stronger footing for the longer term, while asking the research field to step up coordination and collaboration. This will allow investments to be used more efficiently and effectively and enable those working in the field to set priorities for the use of limited resources. In this publication, the Roadmap 2021, nine Groups with substantive thematic or technical interfaces lay down their priorities for the research infrastructures to be established in the coming years.

Ingrid van Engelshoven, Minister of Education, Culture and Science:
'Investing in an innovative research infrastructure contributes to the international position of the Netherlands as a "knowledge country". Science and research cannot manage without appropriate research facilities. In addition, the presence of a unique research infrastructure is a major factor in attracting talent.'

CHAPTER 1
Introduction and background

The National Roadmap for Large-Scale Research Infrastructure is an instrument for making strategic choices for government investments in research infrastructure in universities and national research institutes. Following the presentation of the first list of infrastructures in 2008, the National Roadmap has increasingly developed a multi-annual and future-proof character. The Dutch research field has become more and more actively involved in setting priorities and making choices within the various research domains. This has led to self-organisation and growing collaboration. It optimises the allocation of limited resources among the research domains in the Landscape of large-scale research infrastructure (LRI) and it encourages cross-disciplinary collaboration.

LRIs are catalysts for innovation in research and for achieving breakthroughs in all research domains. There are various types of LRI: centred in a single location or, as happens increasingly often, distributed over several locations. They can consist of highly specialised equipment, such as large telescopes, high-field magnets or advanced sensors and measurement networks necessary for biological and earth sciences research. Alternatively, they may be 'virtual' facilities such as extensive databases, scientific computing networks, or data in sample collections, for instance a collection of soil samples, cohorts of patients and citizens or a university collection of books, survey data and collections of (multilingual) text, speech and multimedia expressions. The definition of an LRI as used by the Permanent Committee Large-Scale Research Infrastructures (PC-LRI) is given in Annex 1.

LRI can also make a considerable contribution to innovation and towards solving major societal issues concerning the environment, climate, health and civilisation. Such facilities also increase the international visibility of the Netherlands. In addition, the presence of a unique research facility is a magnet for talented researchers. It is a place where researchers, engineers, data scientists, and project managers are trained to jointly work on knowledge development, technology development and technology transfer, and innovation that can be utilised in industry. LRI accordingly play a key role in bringing together parties who would not normally sit around the same table.[1]

A large number of LRI in the Dutch Landscape are part of research infrastructures with a European and sometimes global character. These could be large facilities, such as telescopes and particle accelerators that generate data that researchers in the participating countries can use. There are also a growing number of distributed data and sample collections that are interlinked between several countries, often including annotation, enrichment, search tools and links to other datasets accessible to the international community. The participating countries jointly shoulder the high cost for the shared facilities.

The European Strategic Forum for Research Infrastructures (ESFRI) is a European strategic instrument aimed at research coordination and collaboration in the area of research infrastructure. ESFRI publishes a report every few years (the ESFRI Roadmap) that contains an overview of the current state of affairs and progress in realising European LRI ambitions. New international LRI on the ESFRI Roadmap can apply for a start-up grant from the European Commission. The costs for subsequent stages are paid for by the European Member States

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See also NWO Strategy 2019-2022 Connecting Science and Society – https://www.nwo.nl/en/strategy-nwo-2019-2022.
https://www.nwo.nl/nwo-strategie-2019-2022

participating in the LRI. Such collaborations are shaped as an intergovernmental organisation (IGO), an Association internationale sans but lucratif (AISBL) or a European Research Infrastructure Consortium (ERIC).

The cost of designing, implementing and exploiting LRI is considerable. A long-term strategy is necessary to create a future-proof ecosystem of LRI. The National Roadmap 2021 presents a novel strategy to allocate the limited funds as effectively and proportionately as possible for the design and realisation of new LRI, or for substantial updates of existing LRI and exploiting these for a limited start-up period. Maintenance and exploitation of the research infrastructure is, however, mainly the responsibility of the universities and national research institutes. These should also reserve the necessary funds and make an effort to recognise and allot the necessary technical and personnel support.

Permanent Committee for Large-Scale Research Infrastructure (PC-LRI)

The PC-LRI emerged from the 2025 Vision for Science of the Dutch government and was appointed by NWO in 2015 on behalf of the Ministry of Education, Culture and Science (Dutch acronym OCW). The committee spans the necessary breadth of expertise and has 13 members (see Annex 2 for the profiles of the committee members and the Terms of Reference).

Its task is: 'to formulate a national strategy for realising a sustainable, balanced and future-proof ecosystem of LRI'. Based on an inventory and analysis of the Dutch Landscape of LRI, followed by a selection process in consultation with the research field, the PC-LRI has produced the new National Roadmap for Large-Scale Research Infrastructure 2021. Besides an investment agenda, the PC-LRI has also included a strategic framework for the allocation of the Roadmap funding (40 million euros per year) that NWO allocates on behalf of the OCW ministry for funding LRI plans.

The PC-LRI has an IT subcommittee that has itemised the digital infrastructure needs of researchers. This IT subcommittee advises on investments into digital research infrastructure, for which OCW has made available a substantial additional budget (20 million euros per year).

Basic premises of and lessons learned from the Roadmap 2016

In December 2016, the PC-LRI published a first strategic National Roadmap. The strategy introduced by the PC-LRI to 'let the research field play an active role in the Roadmap process' has worked really well. The Roadmap 2016 had 17 clusters of LRI and 16 individual LRI (see Annex 4). These LRI made their own choices with respect to the LRI proposals that could be submitted in the Roadmap funding rounds. By making robust choices, an initial quality assessment was carried out by the researchers, containing the application pressure, resulting in a success rate that was reasonable.

The most important basic premises of the Roadmap 2016 were:
• the field must assume its role in the making and alignment of strategic choices;
• all research fields have a fair chance of obtaining Roadmap funding;
• the process for allocating the available funds is as fair, transparent and independent as possible.

The new National Roadmap 2021

The PC-LRI considers as the most important lessons learned from the Roadmap 2016 that the research field should be given even more responsibility and that self-organisation and collaboration should be further stimulated. The basic premise of the committee continues to be that the limited funding benefits all research domains. The PC-LRI will therefore continue to use the allocation proportion among the three Domains introduced in the Roadmap 2016: Technical & Natural Sciences, Life & Medical Sciences and Social Sciences & Humanities. The committee will strive to allocate the available limited funds in a balanced manner.

Within these three Domains, the committee has defined a total of nine Groups based on substantive thematic or technical commonalities. The Roadmap 2021 no longer contains individual LRI or clusters, but many of the initiatives on the Roadmap 2016 are now part of one of the nine broader Groups within the three research Domains.

Technical & Natural Sciences

- Astronomy & Particle Physics
- Materials
- Technology
- Geosciences

Life & Medical Sciences

- Green Life Sciences
- Health Sciences
- Medical Sciences
- Life Sciences & Enabling Technologies

Social Sciences and Humanities

- Social Sciences and Humanities

The PC-LRI has decided to give the LRI field a key role in realising the new Roadmap 2021 by setting up a framework within which the researchers involved are made responsible for formulating the LRI plans and in this way produce the investment agenda for most needed LRI. To this end, the PC-LRI has requested representatives from the LRI within a Group to discuss the LRI plans within that Group. They could be plans for individual LRI or joint plans for several LRI from the identified Group and Group- or Domain-overarching initiatives.

Each of these Groups was requested to identify, bottom-up, the LRI plans most in need of investments over the next ten years. The nine Groups presented a narrative outlining how the LRI plans contribute to innovations and breakthroughs in academic research and how these relate to current strategic sector or action plans. The Groups were also asked to indicate which of the plans should be given priority for the next five years and, where relevant, to describe how all LRI plans relate to international (ESFRI) initiatives.

All Groups took up this challenge based on the conviction that the Dutch research field should take responsibility for making strategic choices. After all, the Groups are the best judges of specific Dutch strategic needs in the area of LRI.

Ambitions exceed the budget

There is a dire need for new investments in LRI in all research areas. This is apparent from the Roadmap 2016, the Academy Agenda for Large-scale Research Infrastructure (2016), and an analysis of the applications for the LRI Landscape. The total cost for realising the LRI as indicated by the research field is estimated at almost two billion euros for the next ten years. Over the past few years, the PC-LRI has encouraged the research field to advance collaboration and to deploy LRI more widely, in order to limit the costs and increase the benefits. This allows a more effective and efficient use of national investments. In view of the available budget, the PC-LRI further encourages the field to set its own priorities for the use of limited funds.

It is impossible for universities and national research institutes to cover the costs for LRI from their basic funding. A consequence of this is that the funding currently made available to NWO by OCW for the National Roadmap is indispensable. It amounts to 40 million euros per year to fund excellent plans for innovative LRI included in the

National Roadmap. In addition, OCW makes available 20 million euros per year for the updating of the IT infrastructure, including the replacement of the Cartesius supercomputer at SURF and incentive funding for several local and thematic Digital Competence Centres (DCC).

The previous Roadmap 2016–2020 made provisions for a total of 200 million euros in two funding competitions. In addition to this, an extra investment of 30 million euros was made by OCW, and the LRI consortia receiving funding made a matching contribution of 25%. This allowed NWO to totally or partially fund 13 proposals for LRI (see Annex 5). Accordingly, only the highest-ranking plans from the 17 clusters and 16 individual LRI from the Roadmap 2016 were awarded funding. The LRI ambitions thus exceed the available budget considerably.

Dutch research has an outstanding reputation. Research infrastructure provides the basis for significant progress in academic research, which can be expected to lead to societal breakthroughs in due course as well. The NWO Strategy 2019-2022 targets 'Accessible and sustainable research infrastructure' as one of the five main ambitions[2]. Substantial investments in LRI are increasingly necessary to guarantee the leading position of Dutch research in the future.[3,4]

New investments

The Dutch government is currently making room for major investments in R&D. This aim is part of the new Dutch government plans in the context of both the National Growth Fund and the European Recovery & Resilience Fund (RRF). The Growth Fund focuses mainly on projects that contribute in the short term to the structural earning capacity of the Netherlands (economic growth as expressed in gross domestic product).

2

See also NWO Strategy 2019–2022 'Connecting Science and Society' – https://www.nwo.nl/en/strategy-nwo-2019-2022

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See also (in Dutch): Investeringsagenda voor onderzoek en innovatie 2021-2023 [Investment agenda for research and innovation 2021-2023] from the Knowledge Coalition: https://www.nwo.nl/sites/nwo/files/media-files/Investeringsagenda%20voor%20onderzoek%20en%20innovatie%202021-2030_Kenniscoalitie.pdf
https://www.nwo.nl/sites/nwo/files/media-files/Investeringsagenda voor onderzoek en innovatie 2021-2030_Kenniscoalitie.pdf

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See also (in Dutch): Association of Universities in the Netherlands election manifesto 'Investeren in Wetenschap = Investeren in Onze Toekomst' [Investing in Science = Investing in our Future]: https://www.vsnu.nl/

The European Commission has made country-specific recommendations[5] for the RRF expenditure. One important recommendation is the increase of the national investments in R&D to 3% of GDP as agreed upon in the Lisbon strategy, which was repeated in the EU 2020 objective. In the period 2013-2019, the R&D intensity of the Netherlands varied between 2.14 and 2.18 percent[6].

Large-scale research infrastructure form the basis for innovation in academic research and are an important stimulus for multidisciplinary collaboration and for attracting foreign talent. In the long term, all of these issues are the driving force for economic and societal development and, ultimately, the prosperity of the Netherlands. The PC-LRI therefore recommends that the government reserves additional funding for the implementation of the Roadmap 2021, for the realisation and substantial updating of LRI as well as for funding the participation of Dutch Roadmap LRI in international memberships.[7]

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[5]
See also https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1591720698631&uri=CELEX%3A52020DC0519

[6]
See Statistics Netherlands (in Dutch): https://www.cbs.nl/nl-nl/nieuws/2021/09/r-d-uitgaven-passeren-17-5-miljard-euro-in-2019

[7]
Additional funding can already be used in 2022 to increase the budget of the Roadmap funding round that will be realised by NWO once every two years.

CHAPTER 2

Landscape LRI: inventory, observations and analysis

Large-scale research infrastructure in the Netherlands is diverse. For an update of the Landscape LRI 2016, the PC-LRI once again commissioned an inventory via the boards of all universities, national research institutes and national institutes (e.g. the Royal Library, and the Royal Netherlands Meteorological Institute (KNMI)) in the Netherlands. These were asked to submit inventory forms for existing and still to be developed LRI that are important for Dutch science. Only LRI that satisfy the definition of 'large-scale research infrastructure' (see Annex 1) are eligible for inclusion in the Landscape. It was stated specifically to applied research organisations (Dutch acronym TO2), national institute and university medical centres that only those large-scale infrastructures that the research community can use for innovative scientific research can be registered.

In summary, the Landscape lists facilities, sources and services:
- that a research community uses to carry out research in their discipline and to advance innovation;
- with a policy of free access for researchers;
- with a size of at least 10 million euros of total capital investment and the exploitation cost over a period of 5 years, excluding the cost for accommodating the infrastructure;
- that have already been implemented or (are expected to) have a concrete implementation date within a foreseeable period.

NWO received a total of 146 inventory forms in 2020. Once these had been assessed against the definition, 122 LRI were included in the Landscape. In addition, 11 LRI at an early stage of development and without a concrete implementation date were included in an annex to the Landscape LRI 2020: the Ideas List. To keep the Landscape as complete as possible, LRI can continuously submit new registrations for the Landscape. The PC-LRI has two assessment moments every year. A map of the Landscape LRI is provided at https://www.onderzoeksfaciliteiten.nl.

Observations

Together with the NWO office, the PC-LRI analysed the 122 infrastructures on the Landscape LRI 2020 based on the information provided by the LRI themselves. It is important to note that the dataset analysed is not homogenous due to the large diversity in LRI. Several aspects of this diversity are:

Large-scale research infrastructure, research programme or research institute?
The boundary between LRI, large-scale research programme or research institute is sometimes unclear, as already observed in the Academy Agenda for Large-scale Research Facilities (2016), which also provided a guideline for defining a distinct demarcation. The most important reason for this is that many LRI store and process large quantities of data. Besides knowledge about the specific data collected, this also requires specialised current knowledge in the area of IT. This knowledge is typically united in a research programme or research institute.

An LRI is driven by scientific objectives and these should determine the character and characteristics of the infrastructure. It is difficult to categorise infrastructures because they are often mixed in nature. This may mean that different aspects of an LRI may be in different phases of development. Three-quarters of all LRI on the Landscape are in several overlapping phases. An example is LRI organised around data that are already in use and continue to be enriched and expanded.

Comparison of Landscape 2020 with Landscape 2016

In line with the Roadmap LRI 2016, some infrastructures clustered. As a result, the absolute number of LRI in the current Landscape is lower than on the Landscape LRI 2016. Examples of this are the Netherlands X-omics Initiative (X-omics), Health-RI, and the Open Data Infrastructure for Social Science and Economic Innovations (ODISSEI). In several cases, some cluster units have also been separately registered.

The allocation over the three Domains Technical & Natural Sciences (45%), Life & Medical Sciences (45%) and Social Sciences & Humanities (10%) has remained more or less the same: there is only a slight increase for the last two Domains compared with the first Domain. In addition, just like in 2016, almost one-fifth of all LRI focus on research questions from a combination of Domains, especially at the interface of Technical & Natural Sciences and Life & Medical Sciences.

Infrastructure types and domains

Large-scale research infrastructure arise from scientific motives from almost all constituents of domains.

Domain Technical & Natural Sciences

The LRI in the domain Technical & Natural Sciences mainly concern hardware at one or more locations. These infrastructures, often large-scale and expensive measurement equipment, produce huge quantities of data. More than two-thirds of the infrastructures in this area are completely international in nature, such as Magnum-PSI, KM3NeT, Extremely Large Telescope (ELT), Laser Interferometer Space Antenna (LISA), ITER and European Spallation Source (ESS). Examples of national initiatives are: Climate and Meteorological Network (C-MetNet), National Characterisation Centre for Sustainable Materials (NC2SM) and Aerodynamics and Propulsion Laboratory (APP-lab). More than half of the LRI in this domain are already operational compared with 80 to 90% in the Domains Life & Medical Sciences and Social Sciences & Humanities. This is because it often takes many years of design and construction before the researchers can actually collect the data. It also regularly concerns (participation in) very expensive international initiatives for which the international agendas have already been set until 2050.

Domain Life & Medical Sciences

There is a huge diversity among the infrastructures in the Life & Medical Sciences Domain. About 15% of the LRI consist of distributed databanks, databases and electronic services. Some of the LRI in this domain are completely international in nature, such as EBRAINS-NL and LifeWatch e-infrastructure for biodiversity and ecosystem research. More than three-quarters are largely national in nature, for example Applied Molecular Imaging at Erasmus MC (AMIE), Metabolic Research Unit Maastricht (MRUM), Netherlands Plant Eco-Phenotyping Centre (NPEC) and UNLOCKing Microbial Diversity for Society (UNLOCK). Various other national medical infrastructures can be considered basic facilities for researchers in the field (such as MRI instruments, instruments for mass spectrometry or DNA sequencing). A large proportion of the LRI in Life & Medical Sciences are already in the exploitation phase, whereas other aspects are still in the implementation phase. This mainly applies to the data-oriented LRI aimed at health research that are simultaneously in the construction, implementation and exploitation phases. More than half of the LRI in this domain are part of a collaboration of complementary infrastructure spread over several locations (in the Netherlands and/or abroad).

Domain Social Sciences & Humanities

The vast majority of the LRI in this domain consist of digital, distributed, complex, at times enriched, databases that can be both structured and unstructured in nature. Some more technological infrastructures for heritage research are new, such as Research Infrastructure for Heritage Science in the Netherlands (E-RIHS NL).

E-infrastructures such as (data) collections are quickly usable, and the vast majority of the LRI are simultaneously in construction, implementation and exploitation phases. In recent years, many (data) collections from individual institutes have been brought together within two broad initiatives: ODISSEI and CLARIAH. Another point to be noted is that cultural heritage institutions manage a substantial part of the data and receive structural government funding for this. More than half of all LRI are necessarily embedded in large-scale international initiatives. This is because no single facility delivers social sciences and humanities data: various countries collect unique data, which are then enriched and need to be linked to each other.

Domain-overarching LRI

One-fifth of LRI are domain-overarching. In addition, many LRI are used by researchers from different disciplines. Examples are data infrastructures and collections of blood or soil samples. Large equipment is also increasingly used for different research purposes, such as LRI developed for materials research that are now used for heritage research.

For the domain-overarching LRI, it can be noted that half of them are in the design phase and are therefore relatively young initiatives or initiatives under development. Three quarters of the infrastructures are connected with other existing infrastructures. The majority of the domain-overarching LRI seem to be driven by fundamental disciplinary questions for which interdisciplinarity and data are necessary.

International aspects

About half of the LRI on the Landscape are international in character and are part of a European partnership (for example, CLARIAH, European Social Survey (ESS), BBMRI-NL, EPOS-NL, eLTER-NL, ELIXIR-NL) or are entirely international, such as Square Kilometre Array (SKA), KM3NeT 2.0, Cherenkov Telescope Array (CTA) and European Spallation Source (ESS). Also, the Netherlands is a partner in the intergovernmental organisations CERN for fundamental research into elementary particles, the European Space Organisation (ESA) and the European Southern Observatory (ESO). Dutch LRI are involved in three-quarters of all projects and landmarks (research infrastructures already implemented) identified by ESFRI (see Annex 6). This strategy that is defined by the European member states plays an important role in formulating national investment strategies regarding large-scale research infrastructures.

Another important infrastructure initiative in the European Landscape is the European Open Science Cloud (EOSC) that is currently under development. The EOSC is a federation of existing national and disciplinary infrastructures that intend to offer researchers and research communities a virtual platform for managing, sharing, analysing, and combining research data across geographical and disciplinary borders. Making this possible requires not just adequate access to research data and the output of research, but also the optimal alignment of standards (interoperability) for the storage of data and tools for the analysis of research data. Via the central registration of generic and thematic service components in the EOSC portal, this federative model will gradually be expanded and provide support to both individual researchers as well as collaborations within and between disciplines.

Relationship Landscape – Roadmap

There is no one-to-one relationship between the Landscape and the new Roadmap 2021. The Landscape contains all LRI that are accessible for researchers in the Netherlands. The Roadmap specifically targets the set of LRI plans whose priority is to realise breakthroughs in academic research.

CHAPTER 3
Strategy National Roadmap 2021

National Strategy LRI

With the Roadmap 2021, the PC-LRI builds on the long-term national strategy that was deployed in 2016 to realise a future-proof, balanced ecosystem of LRI of national importance. An important step forward in this regard is the 'Group process' in which the Dutch research community is actively involved. The Group process ensures widely supported strategic choices with respect to the LRI. It strengthens the national collaboration between LRIs and increases the participation of the research community in the strategic process. This results in the linking of related infrastructures and to agreement, phasing and prioritisation of investments in LRI. This also contributes to realising the two NWO ambitions Infrastructure and Nexus.[8]

The new Roadmap 2021 furthermore continues and refines the strategic framework and conditions formulated in 2016. The framework creates room for strategic management with respect to the allocation of resources and encourages connection with national and international strategic agendas. The Roadmap 2021 also describes the basic conditions that LRI must meet to be eligible for funding from the associated LRI call. These conditions concern governance aspects and access procedures, as well as IT, eScience and digitisation aspects, and joint and future-proof funding.

Group process

Based on the current LRI Landscape, the PC-LRI has divided the LRI desired by the research community into nine Groups. These have substantive thematic or technical commonalities within the three research Domains introduced by the Roadmap 2016:

Domain Technical & Natural Sciences

- **Astronomy and Particle Physics:** Group with LRI plans aimed at scientific innovation in the area of (and interfaces between) astronomy and particle physics.
- **Materials:** Group with LRI plans aimed at scientific innovation in the area of manufacturing and characterising materials.
- **Technology:** Group with LRI plans aimed at scientific innovation in the area of technology in general, and energy in particular.
- **Geosciences:** Group with LRI plans aimed at scientific innovation in the area of geosciences with a focus on infrastructure for research into oceans and atmosphere, deltas and the deep underground.

Domain Life & Medical Sciences

- **Green Life Sciences:** Group with LRI plans aimed at scientific innovation in the area of biosphere, with a focus on infrastructure for research into biodiversity, ecology, habitat, biotechnology and sustainable production.
- **Health Sciences:** Group with LRI plans aimed at scientific innovation in the area of health sciences with a focus on infrastructure for research with population and patient cohorts, and digitalisation.

- **Medical Sciences:** Group with LRI plans aimed at scientific innovation in the area of medical sciences with a focus on infrastructure for medical imaging and real-life tissue models.
- **Life Sciences & Enabling Technologies:** Group with LRI plans aimed at scientific innovation in the area of life sciences and chemistry with a focus on infrastructure for research into individual molecules and their analysis in intact organisms: 'Omics', imaging, techniques and models.

Domain Social Sciences & Humanities

- **Social Sciences & Humanities:** Group with LRI plans aimed at scientific innovation in the area of the social sciences and humanities, including heritage research, with a focus on distributed digitisation, interoperability and on techniques for heritage research.

The PC-LRI has, within the framework set, invited representatives from the LRI in these Groups to consult with each other about the LRI plans that exist or are being developed within this Group. The Group process can also lead to the development of new plans for LRI. The Groups have been asked to determine which LRI are complementary and where collaboration or clustering is possible. Furthermore, there is explicit attention and room for LRI plans that are broader than a Group or a Domain and for which collaboration and alignment between Groups is necessary. Subsequently, each Group has argued, in the form of a narrative, what the range of most important LRI plans is that should be realised in the coming years. Here, the Groups were encouraged to think about phasing and prioritisation of investments in LRI plans within a Group. Despite the choices made, the available funds are too limited to fund all priority infrastructure of the Groups.

Multiannual balance allocation of funding

Balance between the research domains

For the two funding competitions in the coming Roadmap period (2021–2025) a total amount of about 200 million euros is available. The Permanent Committee considers it vitally important to realise a balanced allocation of the available funds across all research areas that have a need for LRI. It wants to do justice to the huge diversity of high-quality LRI plans within the different Groups and Domains. The committee will therefore uphold the guideline introduced in the Roadmap 2016 for the allocation of funding across the three Domains: about 45% of the LRI funding is available for the Technical & Natural Sciences, 45% for the Life & Medical Sciences and 10% for LRI within the Social Sciences and Humanities. This allocation was arrived at on the basis of an analysis of the investment need as well as historical figures from the previous Roadmap competitions. For each funding round, the PC-LRI will advise about the use of this guideline.

Balance between the Groups

The committee aims to balance the allocation of funding across the Groups, as well as the three research Domains. Roadmap funding is insufficient to award funding to all Groups in each funding round. The nature, size and needs of the Groups are not equal, and there are also Group-overarching plans. A proportional allocation of funds does not do justice to this complex situation. The PC-LRI will strive to ensure that, in the longer term, those LRI plans that can make scientific breakthroughs possible across the entire breadth of the Group will be funded. To this end, the committee calls for an increase in the Roadmap funds. The PC-LRI will furthermore come up with concrete proposals to give extra direction to the allocation of funds, if necessary via targeted calls.

Connection with national and international strategic agendas

Top research transcends national borders. The PC-LRI attaches great importance to LRI plans contributing to research questions, challenges and priorities from strategic agendas, sector plans or action plans that have been drawn up by the national and international research communities. Whenever applicable (international) collaboration should prevent duplication and guarantee harmonisation. LRI that request Roadmap funding at the

European level, should connect wherever possible with the relevant infrastructure that is part of the European ESFRI Roadmap.

Basic conditions LRI proposals

The PC-LRI sets the bar high for LRI proposals with respect to the scientific quality, impact and on the organisational, technical and financial aspects: these are complex for LRI and must be carefully thought through and specified. In particular, the latter aspects are vital for successful realisation of the LRI.

Organisation and access

The PC-LRI has determined that clear agreements between (international) partners are necessary for the design and exploitation of LRI, within a clear organisational framework. It is therefore important that the governance and management of the research facility are well defined. Users must furthermore obtain clear information about the accessibility and the associated procedures for this. The committee follows the European Charter for Access to Research Infrastructures in this regard. Extra conditions for research infrastructures on the National Roadmap will be that the infrastructure minimally offers access on the basis of a broad access policy (open access).

IT, eScience and digitalisation aspects

A robust and appropriate IT infrastructure is expensive and plays an important role in almost all LRI. The PC-LRI therefore stimulates harmonisation of the IT, eScience and digilisation needs with national facilities and services, in particular those currently available within, and those provided by, SURF and the eScience Center. In addition, a LRI must make use of the planned investments in the digital research infrastructure, described in the Dutch report *Integrale aanpak voor digitalisering in de wetenschap* [Integral approach for digitisation and science].[9]

The IT infrastructure must be described as a separate part of each proposal. It is important to demonstrate that there is a realistic plan for the deployment of IT resources (hardware, software, and data) and the necessary expertise. Proper arrangements should in addition be made to ensure that externally required capacity (such as from SURF), is available and committed. It is also important to ensure accessibility and sustainability of the data and software produced (FAIR: Findable, Accessible, Interoperable, and Reusable). This should be specified in the data management plan. For the software development (such as for the analysis of parts of data) comparable guidelines apply, including a software management plan.

Joint and future-proof funding

The considerable investments needed for large-scale research infrastructure should not just come from NWO: a matching contribution is requested from the consortium of institutions that want to jointly realise the LRI or participate in it. The NWO funds will be allocated on a competitive basis and are aimed at a capital investment for the construction of the LRI and for the initial phase of the exploitation of the LRI. LRI consortia must therefore have concrete future-proof plans aimed at optimal exploitation of the LRI for a long period after the construction and development phase is completed. This requires plans and a detailed budget for the project duration of ten years and a strategy for the full lifespan of the LRI. An NWO contribution in the exploitation cost of the requested LRI can be requested for a maximum period of five years. This is a one-off contribution restricted to half of the project duration. The remaining costs must be paid for by the consortium. Applicants must provide a guarantee letter for the matching contribution before the start of the project.

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https://www.rijksoverheid.nl/documenten/rapporten/2019/10/01/uitvoeringsplan-investeringen-digitale-onderzoeksinfrastructuur (in Dutch)

Future-proof ecosystem

The PC-LRI attaches great importance to the Roadmap leading to a future-proof ecosystem of LRI in all research domains, overarching the funding of individual LRI plans. The Groups have an important strategic contribution in this regard. Each Group draws up the set of the LRI prioritised for funding to make innovative scientific research and scientific breakthroughs possible. The Roadmap functions as a guideline for planning investments in the development or substantial update of LRI in a multiannual perspective.

IT in the scientific ecosystem

The proposal must specify how it fits within the scientific ecosystem.
- How does the LRI ensure access to data from sources elsewhere (for example, via federated access)?
- How will the reuse of data that the LRI shall produce be ensured?
- Do researchers have access to the latest analysis technology to obtain more value from the data (for example, is AI expertise available within the LRI consortium)?
- What is the strategy to achieve synergy with other researchers with comparable or overlapping objectives, for the purpose of deploying the available funding and expertise as effectively as possible for Dutch science? Examples are collaboration with other Dutch LRI consortia, for example via the thematic Digital Competence Centres (DCCs) currently being set up and also collaboration in international initiatives such as the European Open Science Cloud (EOSC).

The PC-LRI will also support LRI to better integrate these aspects in the implementation phase, so that everyone can learn from each other. Synergy between the LRI is highly desirable: LRI can reuse existing expertise in hardware and software on the one hand and they can make their own expertise in hardware and software more widely available on the other hand.

Digitalisation of science

NWO established an IT subcommittee within the PC-LRI In 2016. The Dutch government commissioned the IT-subcommitee to produce an inventory of the digital infrastructure needs researchers have. Based on the report *Top Wetenschap vereist Top Infrastructuur* [Top science requires top infrastructure], which was further developed into the proposal Integrale aanpak voor digitalisering in de wetenschap [Integral approach for digitalising science] and Uitvoeringsplan investeringen digitale onderzoeksinfrastructuur [Realisation plan investments digital infrastructure], OCW made additional funding available to NWO: a one-off payment of 40 million euros and a structural amount of 20 million euros per year to be allocated to:
- the acquisition and support of (national) computing, data storage and network facilities plus expertise by SURF;
- the setting up of two calls for local and thematic DCCs (Digital Competence Centres).

The IT subcommittee advises NWO and the PC-LRI about the allocation of these additional IT funds and monitors the expenditure planned. The IT subcommittee also wants to encourage the field to work together with SURF to realise a strategy that meets the rapidly increasing digitalisation within science and the associated expertise, support and specific hardware that this requires. Such a strategy can consist of making joint (investment) plans or aligning and sharing hardware, networks and expertise.

CHAPTER 4
Domain Technical & Natural Sciences

Within this Domain, the PC-LRI has defined four Groups with substantive, thematic or technical interfaces.

4.1
Group Astronomy & Particle Physics

4.2
Group Materials

4.3
Group Technology

4.4
Group GeoSciences

4.1
Group Astronomy & Particle Physics

The Universe from the Smallest to the Largest Scales

LRI acronym	Facilities involved	Description	Lead
APP	GRAND/ GCOS/CTA	New or upgraded facilities for detection of EeV cosmic rays and neutrinos and for detection of TeV gamma rays	Nikhef
RADIO	EVN/JIVE, LOFAR2.0, SKA	Boosting NL capabilities in upgrading and exploiting the world's premier radio facilities	ASTRON
DDN	DUNE, DARWIN	Highly sensitive deep underground experiments to explore neutrinos and dark matter	Nikhef
ELT	ELT	Instrumentation for the Extremely Large Telescope of ESO, probing the earliest stars and galaxies and exoplanets	NOVA
GW	LISA	Exploring new frontiers in gravitational waves with ESA's LISA (Laser Interferometer Space Antenna), and the Einstein Telescope: third-generation, ground-based interferometer, probing fundamental physics, astrophysics and cosmology	SRON
	ET		Nikhef
HL-LHC	LHC	Instrumentation upgrades for the high-luminosity version of CERN's Large Hadron Collider	Nikhef

Scientific questions, challenges and priorities

Curiosity and drive for exploration lead humanity to profound questions about the structure and evolution of the Universe as a whole, and the fundamental properties of its constituent particles and objects and their inter-actions. While there already are well-founded standard models for the structure of matter and forces and the evolution of our Universe, some major unsolved problems remain to be addressed: What laws beyond these standard models govern the Universe? How did it start? What are dark matter and dark energy? How do stars, galaxies and black holes evolve with the fabric of space and time? Are we alone as living creatures? Addressing these requires ultra-sensitive research infrastructures and –to plan these and interpret their results– deep thought and theoretical innovation, as well as modelling and data analysis that pushes the frontier of computing.

International

The required research infrastructures are always of a European or global scale, and thus their agendas and decades-long timelines are set in the international arena. Despite being a small nation, the Netherlands plays a significant role in some of these world-leading facilities. This is achieved by significant investments which, while only a small fraction of the total facility cost, are highly targeted to the interest and expertise of the Dutch research community by strong national organisation, sharp prioritisation, and close cooperation in the inter-national planning process via the relevant international organisations, such as the European Southern Observatory (ESO), the European Space Agency (ESA) and the European Organisation for Particle Physics (CERN).

The choices made are reflected in the national strategic planning documents that are produced every seven (Particle Physics and AstroParticle Physics) and ten (Astronomy) years, with their midterm updates. Organisational cornerstones are the national institutes for radio astronomy (ASTRON), space research (SRON), the national partnership for particle physics (Nikhef), and the alliance of university astronomy departments, united in the Netherlands Research School for Astronomy (NOVA). In the recent past, this strategy and the resulting successful bids for roadmap funding have made the Netherlands key partners in Very Large Telescope (VLT) and Extremely Large Telescope (ELT) instrumentation, the detectors for the Large Hadron Collider (LHC), the neutrino detector KM3NeT, the Square Kilometre Array (SKA) and Athena observatories, and provided e-Infrastructure for the intense computing needs for these facilities (FuSE). All these facilities have delivered breakthrough science, with significant Dutch-led results.

Future needs

In the next decade, further investments are needed in instrumentation for ESO's 39-m ELT to investigate the birth of stars and galaxies through cosmic time, to explore planets in other solar systems, and to measure the atmospheric composition of Earth-like planets around other stars. In addition, an upgrade of the leading radio astronomy facilities (via ASTRON) will be needed later on in order to study distant galaxies and examine black holes near their horizons.

For astronomy and particle physics jointly, investments are required in a national gravitational-wave programme: ESA's Laser Interferometer Space Antenna (LISA) will detect coalescence of supermassive black holes at the hearts of galaxies from the earliest cosmic times to the present and provide early warning for spectacular neutron star and solar-mass black hole mergers. The Einstein Telescope (ET) will make it possible to observe those very short-timescale mergers out to the farthest regions of the Universe. Together, ET and LISA will test our understanding of gravity and the geometry of the Universe.

For particle physics, investments are needed in an upgrade of the Large Hadron Collider (LHC) at CERN to High Luminosity (HL-LHC) to inspect the Standard Model of particle physics up to the point where it will break down and new physics shows up. The deep underground experiments DUNE and DARWIN will probe the properties of neutrinos and of dark matter, connecting these most elusive particles with the Universe as a whole.

Another intersection between astronomy and particle physics comes from the fact that extreme astrophysical phenomena produce, besides light and gravitational waves, high-energy particles such as cosmic rays, gamma rays and neutrinos; their study sheds light on extreme particle properties and on the astrophysical sources that emit them. In the second half of the decade, advances in these astroparticle physics (APP) facilities will further establish multi-messenger astronomy, in which electromagnetic signals, gravitational waves and particles are all used together to probe the most extreme and enigmatic objects.

All these facilities need very extensive data processing, large-scale theoretical simulations, and complex inference methods to support their science, and thus require the availability of world-leading, high-performance and data-intensive computing facilities.

The development timescales for these facilities are long: one has to think past the 2040 mark and already start design studies and technical R&D for facilities of the distant future. In this spirit, the thoughts of the particle physics community are turning to the collider facility that will eventually succeed HL-LHC well beyond the 2050s. In astronomy, ESA has already launched its 'Voyage 2050' process to look ahead to the middle of the century, for example with possible designs for revolutionary mid- to far-infrared observatories and X-ray interferometry from space (the 'one-metre Event Horizon Telescope').

At the start of the decade, funding will be needed for ELT instrumentation and for the gravitational-wave programme – initially for participating in LISA, and for R&D to secure a strong role in ET. Next funding will be required for the HL-LHC detector programme and the timing has again been chosen to maximise impact in its design and use. After that, the timings are yet less certain, as the international agenda for DUNE/DARWIN and other top-priority facilities is still under development and likewise thee investment schedule.
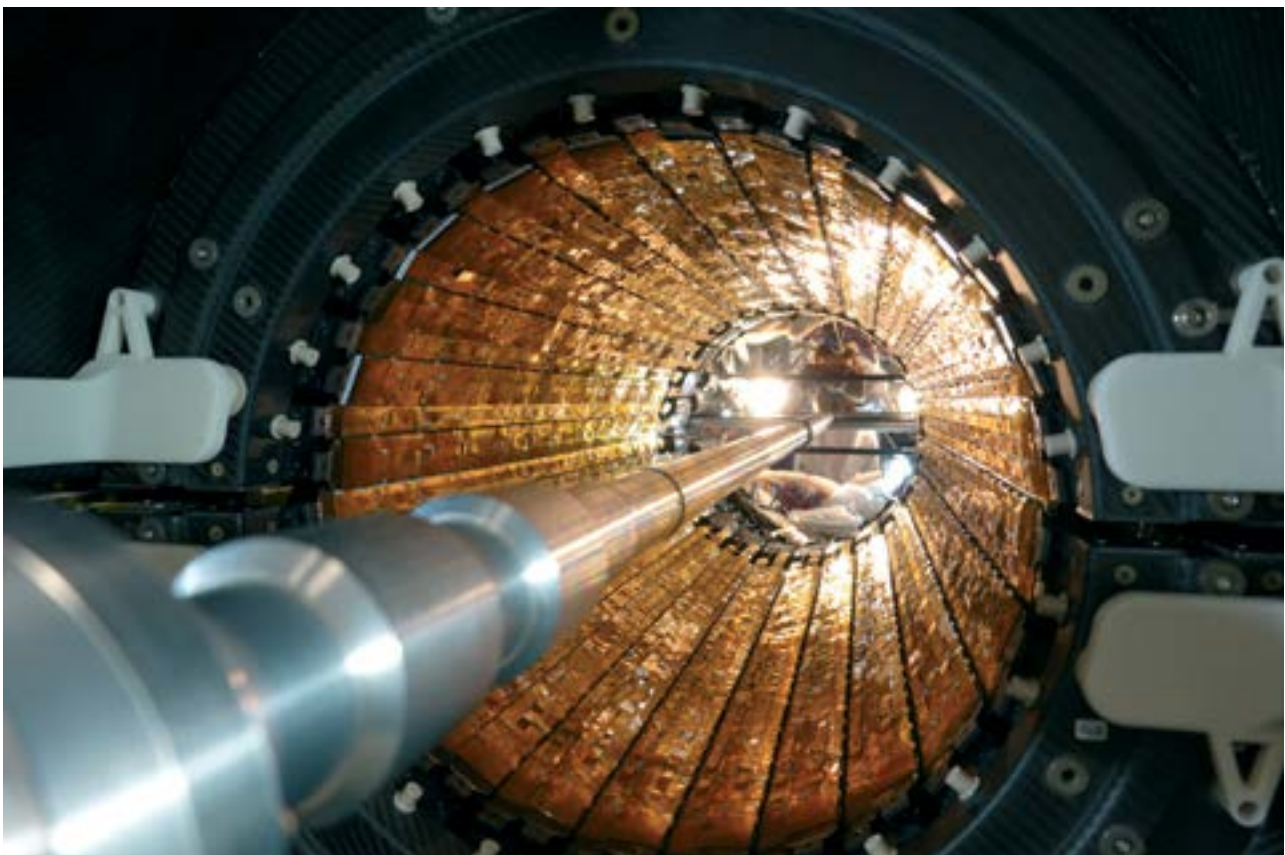
4.2
Group Materials

Dutch Materials Fabrication and Characterisation Platform

LRI acronym	Name of LRI	Description	Lead
Magnum-PSI	Magnum-PSI	Materials under extreme conditions, divertor, nuclear fusion	DIFFER
NanoLabNL	NanoLabNL	Nanotechnology, cleanroom, nanomaterials, quantum technology, biotechnology, photonics	University of Twente
HFML-FELIX	High Field Magnet Laboratory – Free Electron Laser for infrared eXperiments Laboratory	Materials research, condensed matter physics, (bio)molecular physics and chemistry, laboratory astrochemistry, high-magnetic fields, infrared/THz radiation, spectroscopy	Radboud University & NWO-I
ESS	European Spallation Source	Neutrons, materials science, European facility	TU Delft
RID	Reactor Institute Delft	Neutrons, positrons, materials science, education	TU Delft
NC2SM	National Characterisation Centre for Sustainable Materials	X-ray characterisation, laboratory imaging, spectroscopy and scattering, materials	University of Groningen
XNL	X-ray National Lightsource	X-ray analysis, materials science, cultural heritage, medical diagnostics	Eindhoven University of Technology

Scientific questions, challenges and priorities

A fundamental understanding of (functional) molecules and materials is essential to tackle major societal challenges of our time, such as the energy transition, climate change and population ageing. Materials science is concerned with the design, creation, structure, dynamics, properties, use and reuse of new, sustainable materials. It is a multidisciplinary science, bringing together physics, chemistry, biology and engineering. Until recently, functional materials were created mainly by serendipity, but in the coming decades, there will be a transition towards predicting material properties and the controlled synthesising of materials. Large-scale research infrastructures will play a central role in this, laying the foundations for the materials of the future.

Dutch materials science has a leading international position and is well-organised, especially when it comes to drafting roadmaps and research agendas. LRI within the Materials theme have been successful in previous Roadmaps and similar funding rounds (e.g. HFML-FELIX in 2018 and 2020 for upgrades to lasers, magnets and new end-station instrumentation; RID in 2012 to 2022 for the OYSTER upgrade).

In the recent National Agenda Materials (2021), the MaterialsNL platform defined five key themes:

1   materials for energy transition and sustainability;
2   materials for agriculture, water and food;
3   materials for health and care;
4   materials and safety;
5   materials as a key technology for other areas.

Each theme has its own specific scientific challenges. The agenda thus also responds to the Knowledge and Innovation Covenant between government, knowledge institutions and business, which is committed to finding solutions to societal challenges. With an annual turnover in excess of 75 billion euros, materials innovation makes a significant contribution to the Dutch economy.

In the coming years, the focus will be on materials for the energy transition and sustainability. The key question here is: How can we design and create materials that conserve as much energy as possible or consume as little energy as possible to reduce overall energy consumption?

- Examples include materials for energy storage, such as batteries, materials for CO_2 capture and conversion, and materials for energy-efficient data storage;
- It is essential that these new materials are sustainable, replacing materials that are currently scarce or harm the environment.

This requires fundamental knowledge about every component during both production and operation.
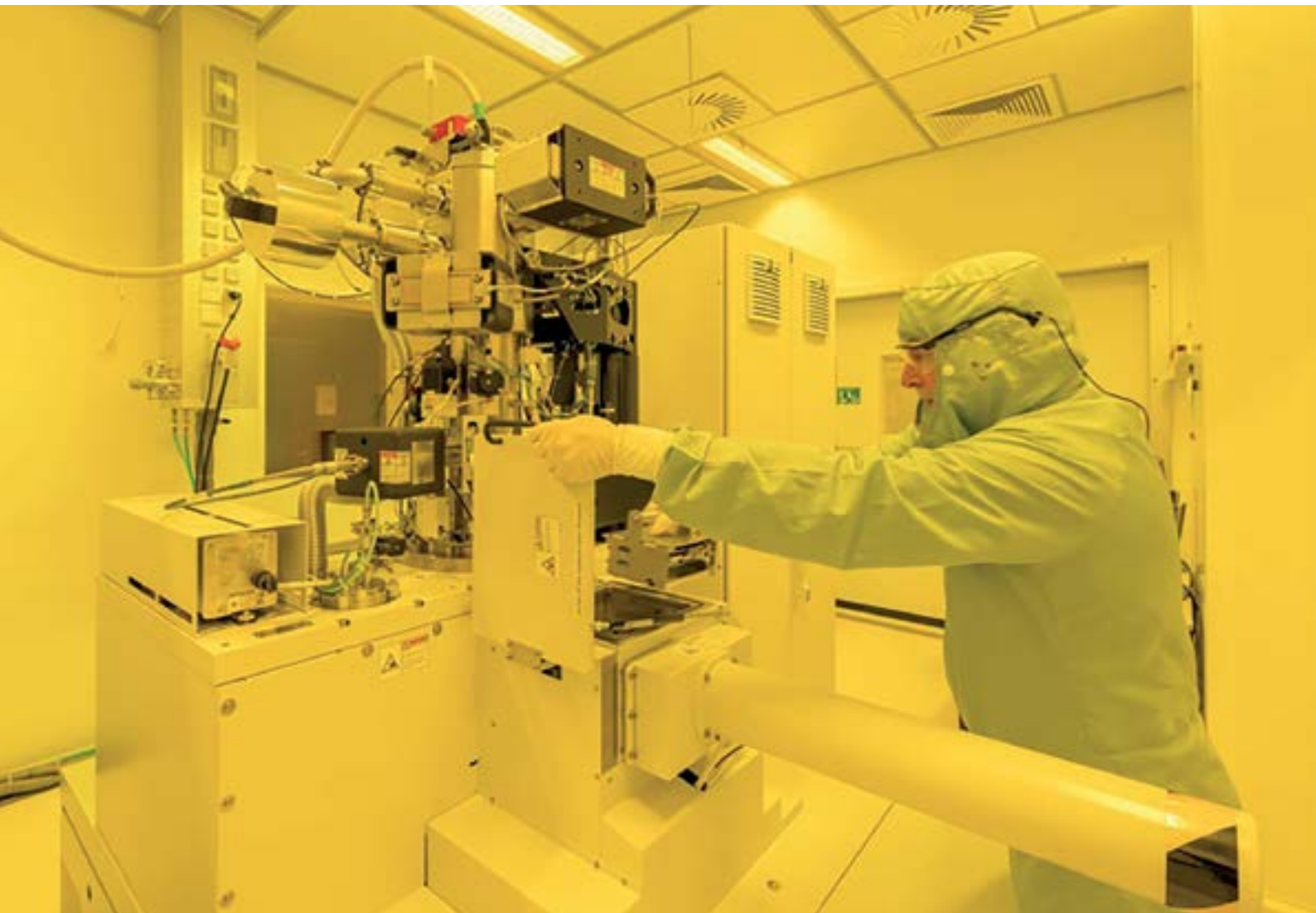
To remain internationally competitive and keep a leading position, the Dutch materials science community must have access to the full spectrum of state-of-the-art fabrication and characterisation techniques. Everything must be immediately and easily available. Only then can the Netherlands make a significant contribution to the scientific challenges in the field of materials within all themes listed above.

## LRI plans of national importance

The Group of large-scale research infrastructures presented in this narrative aims to establish and maintain a combination of excellent facilities, both for the fabrication of complex material systems with precision down to the atomic scale and for the characterisation of materials at the relevant length and time scales. This can be done via highly advanced analysis techniques using neutron flux, plasma, electron beams, high-magnetic fields and intense infrared and X-ray radiation, accompanied by data analysis and computational approaches such as machine learning and artificial intelligence.

This is to take shape within the Dutch Materials Fabrication and Characterisation Platform. The platform will ensure full nationwide availability of the entire range of the above-mentioned complementary techniques for materials synthesis and characterisation (i.e. neutrons, photons, electrons, high-magnetic fields and plasma). In addition, the platform will steer the ongoing development of all relevant LRI in a coordinated manner. To this end, both existing and newly proposed national and international LRI will join forces within this platform to coordinate the development of beyond-state-of-the-art instrumentation and to stimulate research to ensure that the potential of the instrumentation is fully utilised.

A high priority for the intended platform is a competitive infrastructure for X-ray analysis/characterisation. This is not only because the Netherlands lacks a national synchrotron or beamlines at international synchrotrons, but also because recent developments are enabling local application of increasing numbers of laboratory techniques for X-ray scattering and spectroscopy. To this end, the Group plans to set up a distributed Dutch X-ray Characterisation Platform (DXCP), to be realised in three phases.

The first phase involves setting up the three NC2SM core sites with relevant pilots at other LRI (see LRI plan: NC2SM). In the second phase, developments will be rolled out by installing and operating X-ray facilities at all participating LRI (see LRI plan: DXCP). This will make available a range of X-ray spectroscopy techniques (high, medium and low energy X-rays), scattering techniques (small-angle, wide-angle and grazing incidence) and imaging techniques (XRF, XANES), which should facilitate groundbreaking results. This second phase may also incorporate a new advanced X-ray source (XNL). In time, the latter will further reduce the dependence on synchrotron facilities outside the Netherlands and potentially allow for entirely new X-ray analysis techniques. Via this source and developments at HFML-FELIX, the Group also plans to further develop the time resolution of X-ray techniques. Finally, in the third phase, the techniques will be incorporated into cross-Group and cross-Domain applications within the LRI on the Roadmap.

In parallel with setting up the DXCP X-ray platform, further development of all individual LRI (NanoLabNL, RID, HFML-FELIX, etc.) must be initiated promptly to ensure that the platform remains competitive in the long-term, i.e. in relation to (nano)fabrication of materials as well as neutrons, positrons, free-electron lasers and high-magnetic fields. Moreover, integrating the DXCP and related instrumentation into these LRI is ultimately critical in order to remain competitive and state of the art at a global level. Importantly, in the field of neutron technology, coordination with developments and investments in ESS is also required in addition to the RID.
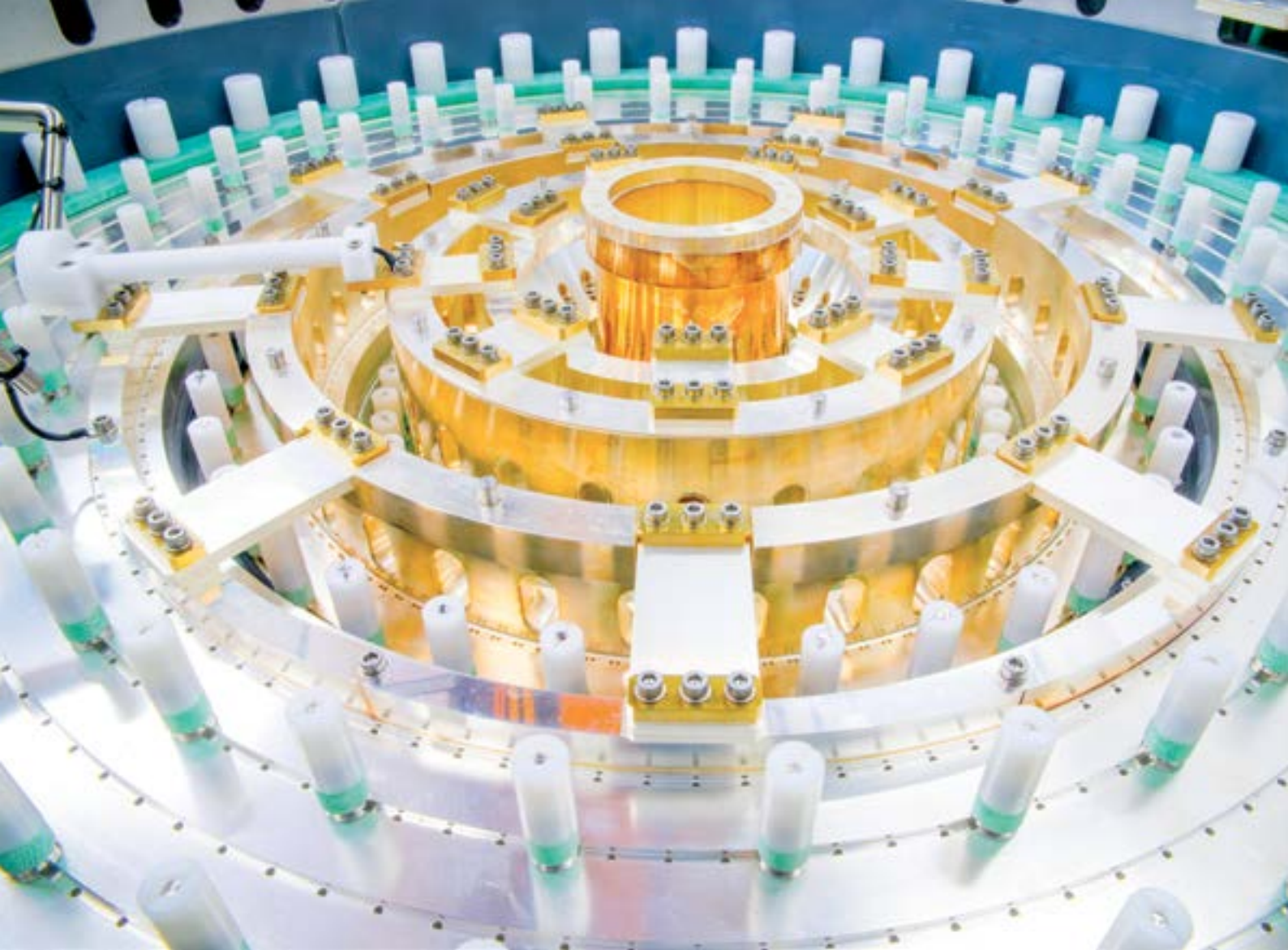
LRI coherence

Each LRI in this Group has drawn up its own long-term plans, coordinated these with the others and integrated them into an overarching Dutch Materials Fabrication and Characterisation Platform. This platform primarily facilitates cooperation among LRI by identifying the most pressing needs for the development of specific next-generation technologies, such as exceptionally powerful magnets, photon and neutron sources, and materials synthesis with in situ analysis capabilities. Cross-Group collaborations with individual LRI such as NEMI or micro-NMR-NL will benefit from these developments, as will a theme such as Arts Conservation, and the LRI Groups "Technology" and "Life science and enabling technologies".

International

The LRI within the Materials Group are internationally pre-eminent and bring together expertise and infrastructures in the field of design, development and structuring of materials, as well as characterisation, manipulation and control using high-performance techniques. This enables scientists in the Netherlands to maintain their competitive international position and increase the impact and effects of materials research on a previously unforeseen scale. This is also clear from the role and recognition of HFML-FELIX in international networks such as Laserlab-Europe, EMFL, LEAPS and ARIE.

4.3
Group Technology

Infrastructure for fundamental research into the generation, conversion and transportation of sustainable energy

LRI acronym	Name of LRI	Lead
EnergyLabNL	EnergyLabNL	DIFFER
Solliance	Solliance	TNO
ELab	Electrification Laboratory	TU Delft

Scientific questions, challenges and priorities

Fundamental scientific breakthroughs in key technological and engineering fields such as materials science, artificial intelligence, electrical engineering, chemical engineering, optics, construction, mechanics, fluid dynamics and systems design open avenues to new engineering challenges and to new solutions for healthcare, energy, logistics, digitisation, electronics and many other sectors.

For the National Roadmap 2021, the Group Technology focuses on fundamental scientific challenges concerning sustainable energy. One of the biggest and most urgent challenges facing humanity is the transformation to a sustainable and circular society. A green energy supply based on sun, wind and fully sustainable streams of materials is a crucial element in this transition. In its national Climate Agreement, the Netherlands aims to produce 70% of its energy from wind and solar power by 2030.

Although huge progress has been made in recent decades, there are as yet no pathways towards these energy solutions, let alone on the required terawatt (= tonnes per hour) scale. Fundamental, disruptive, deep-tech breakthroughs are of great importance here. These challenges divide roughly into three areas:
- **Energy generation:** technology for generating energy from sun, wind, water and other natural sources as cleanly and efficiently as possible.
- **Energy conversion:** technology within energy systems with varying demand for the conversion of green electricity into fuels, batteries and other energy carriers and vice versa.
- **Energy transport:** technology for the efficient and effective transportation of energy to the end user.

It is vital that these challenges are seen not separately from each other but as parts of a single integrated system in which generation, conversion, storage and transport are coordinated with optimum efficiency.

LRI plans of national importance

In the Roadmap for 2021–2025, the Technology Group opts for two LRI plans addressing the challenges of energy generation and energy conversion: SolarLab NL and LRI Energy Conversion.

SolarLab NL focuses on the challenge of developing efficient electricity generation from sunlight (photovoltaics, PV). Advanced designs of solar cells can greatly increase or even double current efficiencies. For this, each component of the energy conversion process as well as their combination must be perfected: light absorption, extraction of electrical charge carriers using semiconductor materials, interfaces and contact layers. The aim is to create a central shared facility and satellite facilities for spectroscopy, microscopy, fabrication and testing of new PV materials, and to apply new PV designs in PV systems.

The LRI Energy Conversion focuses on the challenge of developing fossil-free chemical building blocks by designing efficient conversion technologies from electricity to fossil-free chemicals and fuels or energy carriers. Radically increasing the efficiency of conversion processes requires the development of new catalysts and new conversion concepts. This will require the integration of conversion processes from atomic to system level and at the terawatt scale. This technological challenge poses new questions for fundamental energy conversion research. The aim is to develop a national research infrastructure with satellite facilities that provides an environment for the design, fabrication and testing of groundbreaking concepts and solutions at a system scale.

Complementarity of LRI plans

Bearing in mind the energy transition and the scientific challenges it poses, this cohesive approach offers an excellent opportunity to strengthen both the research and its impact. The LRI plans for energy generation and conversion strongly complement other LRI and research facilities for materials and flow research at nano, micro and meso level, guaranteeing complementarity at the Roadmap level, but also between institutions.

International position

The Netherlands is an international leader in key areas of energy research and is very strong across the board, with many institutions and researchers contributing from different perspectives. The step to be taken now is the joining of forces, with the LRI acting as key focal points. This joining of forces will enable Dutch researchers to expand their competitive position, attract talent and increase the basis for impact, which will help to drive the energy transition.

4.4
Group GeoSciences

Geosciences research infrastructures-NL – The landscape of large-scale research infrastructure for geosciences in the Netherlands

LRI acronym	LRI parts	Description	Lead
		Theme: **Ocean and Atmosphere**	
ATMOS-NL	NSAO	North Sea Observatory for Atmospheric and Environmental Research	Royal Netherlands Meteorological Institute (KNMI)
	C-MetNet	Climate and Meteorological Network	KNMI
	Ruisdael	Ruisdael Observatory for Atmospheric Research	TU Delft
OOU-NL	NMF	National Marine research Facilities / RV Pelagia	Royal Netherlands Institute for Sea Research (NIOZ)
		Theme: **Deltas**	
DANUBIUS-NL	DANUBIUS-NL	Netherlands Centre for Advanced Studies on River-Sea Systems	Utrecht University
	Delta Facilities	Infrastructure for Research on Hydraulics and Soil & Groundwater and Interactive Data Research & Open Source Software Laboratory	Deltares
	DWRC	Delft Water Research Cluster	TU Delft
		Theme: **The deep subsurface**	
eNLarge	EPOS-NL	EPOS-NL: European Plate Observing System – Netherlands	Utrecht University

Scientific questions, challenges and priorities

Humanity's living environment is under pressure: greenhouse gas emissions are warming the planet, while global population growth is placing ever greater demands on land use and natural resources. The effects have already become apparent. Against a background of global urbanisation in delta regions, we see an Earth with melting ice caps, rising sea levels, acidifying oceans, more extremes of weather, prolonged droughts, pollution, a biodiversity crisis and deteriorating air quality. The earth sciences focus on the integrated physical, chemical and biological processes in the whole earth system in order to understand the changes, predict future trends and develop solutions. Urgent questions are:

1   How is the atmosphere changing due to emissions of trace gases and particulates, and changes in land use? What does this mean for weather and climate? What is the role of ocean-atmosphere interactions?
2   How are the oceans changing due to climate change and human activity, as we are already seeing with rising sea levels and declining biodiversity? Can we use the oceans to combat climate change and for the sustainable extraction of raw materials, energy and food?
3   How are the delta regions changing due to climate change, rising sea levels and human intervention? How do sediments and the substances in them distribute across a delta? Can we control this process to make vulnerable delta regions more resilient to climate change?

4   How can we safely obtain natural resources and energy? How can we use the deep subsurface for the safe and sustainable storage of greenhouse gases and renewable energy?

The interaction between human activity and natural processes always plays a key role in these questions. As stated in the recent sector portrait for Earth and Environmental Sciences, a deep understanding of these processes will be needed to provide humanity with a safe living environment and make sustainable use of the ecosystem services that the earth provides for both us and future generations.

LRI plans of national importance

Ocean and Atmosphere

Whereas Ruisdael Observatory focuses on measuring and modelling the atmosphere over land and urban areas, NSAO aims to do the same over the North Sea, a dominant factor in the climate of Western Europe. C-MetNet is an extension of the national network of meteorological monitoring stations, including the associated data centre for storage and dissemination. Studying related ocean processes as they happen and in places that are difficult to reach calls for innovative and often autonomous methods. This need is met by the multidisciplinary monitoring conducted by the NIOZ-NMF, the facility for ocean research and ocean-atmosphere interactions. These facilities for studying the atmosphere and oceans will yield a better understanding of future weather and climate conditions and help to maintain the Netherlands' leading role in international science.

Deltas

DANUBIUS-NL, Delta Facilities and DWRC collect data on water movement, sediment, carbon and nutrient flows and bio-geomorphology in the Rhine-Meuse delta. This is done using a new observation network for long-term monitoring and event surveys, the only one of its kind in the world. The network spans the entire river-estuary-coast sequence, combined with experimental facilities that feed numerical models.

For the first time, this allows us to understand the system effect and change processes at delta scale. This knowledge is essential for innovative solutions to ensure the continuing survival of delta regions.

The deep subsurface

EPOS-NL studies deep subsurface responses to the extraction of natural resources and geothermal energy, subsurface storage of materials such as CO_2, and subsurface behaviour in the run-up to natural earthquakes and volcanic eruptions. It does this through direct monitoring, lab experiments and structural analyses of subsurface rocks at the nanometre to kilometre scale. The data provide an insight into the short- and long-term processes that underpin the safe exploitation, use and reuse of the deep subsurface.

LRI coherence

The thematic coherence leads to integration of the LRI, following on closely from the sector portrait for Earth and Environmental Sciences. Moreover, C-MetNet offers opportunities for expansion, allowing the inclusion of data flows from other institutions as well. Synergies are possible with Green Life Sciences, such as NEMMET. EPOS-NL laboratories are linked to enabling technologies for Life and Materials Sciences. The Dutch geochemistry labs are essential to all geosciences. It is therefore important to bring them together for the future national infrastructure.

International

The Dutch Earth Sciences have a strong international position, as shown by comparative studies of scientific impact and a leading role in various international networks. For example, Ruisdael Observatory, EPOS-NL, NIOZ-NMF and DANUBIUS-NL are part of the ESFRI infrastructures ACTRIS, ICOS, EPOS, EuroFleets+ and DANUBIUS.

Priorities for the next five years

To maximise scientific added value, the eight infrastructures will be merged into ATMOS-NL, OOU-NL, DANUBIUS-NL and eNLarge respectively, as described in the specific LRI plans. The Dutch Earth Sciences community envisages the following timeframe for investment in these infrastructures:
- 2021–2022: investment applications for DANUBIUS-NL and eNLarge for Deltas and The Deep Subsurface
- 2023–2024: investment applications for ATMOS-NL and OOU-NL for Ocean and Atmosphere

For efficiency and synergy, the data infrastructure framework will be developed within eNLarge for use by all infrastructures.

Domain Life & Medical Sciences

Within this Domain, the PC-LRI has defined four Groups with substantive, thematic or technical interfaces.

5.1
Group Green Life Sciences

Green-RI-NL

LRI acronym	LRI parts	Description	Lead
		Theme: **Biodiversity, ecology and living environment**	
ARISE	NIEBA-ARISE	Netherlands Infrastructure for Ecosystem and Biodiversity Analysis: Authoritative and Rapid Identification System for Essential biodiversity information (including KNAW-WI, LifeWatch)	Naturalis
LTER-LIFE	Naturalis	Naturalis Biodiversity Center	Naturalis
	eLTER-NL	Long-Term Ecosystem, Critical Zone & Socio-Ecological Research Infrastructure – Netherlands	Netherlands Institute of Ecology (NIOO-KNAW)
	LifeWatch	LifeWatch e-infrastructure for biodiversity and ecosystem research	University of Amsterdam
	NEMNET	National Environmental Monitoring Network	National Institute for Public Health and the Environment (RIVM)
XL-EFES	XL-EFES	Large-scale Experimental Facilities for Ecosystem Simulations	NIOO-KNAW
		Theme: **Biotechnology and sustainable production**	
UNLOCK	UNLOCK	UNLOCK – UNLOCKing Microbial Diversity for Society	Wageningen University & Research
NPEC	NPEC	Netherlands Plant Eco-Phenotyping Centre	Wageningen University & Research
BIOTECH-NL	IBISBA-NL	Industrial Biotechnology and Synthetic Biology Accelerator – Dutch Node	Wageningen University & Research
	SMART-FABRIC	Food and Biobased Research & Innovation Centre	Wageningen University & Research
	WI-KNAW	Westerdijk Fungal Biodiversity Institute	Westerdijk Institute (WI-KNAW)

Scientific questions, challenges and priorities

Humanity is entirely dependent on the resources of our planet. Although life on earth surrounds us, our fundamental understanding of how life works is patchy and insufficient to ensure a healthy living environment for current and future generations. This fundamental scientific understanding forms the basis for innovative solutions for safe and healthy food in circular production systems, for longer, healthier lives, and for using robust food crops. All of this is aimed at restoring biodiversity and improving our living environment. These solutions are essential in order to solve a global issue: how can humanity meet its needs for raw materials without damaging the healthy living environment? Major scientific questions in this respect are:
- What are the fundamental design rules of complex biological systems?
- How can we predict the behaviour and functioning of these systems?
- How can we use this knowledge to restore, improve, design and redesign natural and synthetic systems?

The Green Life Sciences provide the insight, overview and scientists to answer these questions, at all organisational levels of life: from DNA, viruses and single-celled prokaryotes and eukaryotes, via multi-celled organisms and local communities, to complex regional and global ecosystems, with all their complicated interactions and changing environmental conditions. Universities and institutions work together with business, because a fundamental understanding of how life functions is essential for the long-term survival of the Green Life Science business community, while businesses in turn challenge and stimulate fundamental research to make new discoveries. To answer the big questions in the Green Life Sciences, we are looking to understand emergent properties, and system approaches are very successful in this respect. State-of-the-art, highly developed and highly integrated LRI are essential.

The first step has been taken with the recent funding of three LRI: UNLOCK, NPEC and ARISE. However, these do not address all relevant organisation levels, which is a key requirement to provide the extensive and diverse research field with essential research infrastructure. Therefore the emphasis in the coming period will be on setting up overarching and connecting LRI to benefit the organisation levels not yet addressed and for the efficient interpretation and use of the Big Data provided by the Green Life Sciences.

Green Life Sciences LRI

The LRI in this Group are strongly embedded internationally and are already part of six European infrastructures in the ESFRI Roadmap. At the international level, open science is a basic principle, as it is for all LRI in the Green Life Sciences Group. This implies that data storage and processing are FAIR-compliant and that a research environment is created in which scientists and stakeholders can collaborate as effectively as possible. This will allow us to model and predict complex biological systems with greater accuracy and to develop innovative digital research tools such as Digital Twins. The latter will be instrumental in unlocking scientific knowledge through advanced human-machine interaction.

Within the Green Life Sciences, two complementary domains are differentiated: one focused on Biodiversity, ecology and living environment, and the other on Biotechnology and sustainable production. Both domains are of international pre-eminence and clearly relevant to the pressing societal challenges we face.

Biodiversity, ecology and living environment

The LRI within the domain of Biodiversity, ecology and living environment focus on research into complex ecological systems, from DNA level to interactions between organisms, and on the functioning of ecosystems and landscapes. The LRI mobilise, integrate and analyse the wealth of data on the Netherlands' biodiversity and living environment, ensuring that both our fundamental and more applied research remain world-leading. The LRI are also essential to solutions for resilient nature, a healthy and climate-resistant living environment and a circular agriculture and economy.

The complementary set of Green Life Sciences LRI will significantly boost our knowledge and understanding of the vast complexity of life on Earth in its various ecosystems. Naturalis and WI-KNAW generate knowledge about biodiversity through their collections and laboratories. ARISE (part of the ESFRIs MIRRI and DiSSCo) combines DNA methods, image recognition, artificial intelligence and data science. This allows identification of species and their interactions for the first time, while NEMNET monitors statuses and trends in relation to environmental conditions such as air, soil and water quality. LTER-NL provides the infrastructure for long-term systems research in a selection of representative landscapes and is part of ESFRI eLTER with research land-scapes across Europe. This allows data sets of soil, vegetation, micro- and macro-biomes to be integrated and linked to changing environmental characteristics and socioeconomic data. Within LifeWatch, these data are used for a complete analysis of biodiversity and living environment, as part of ESFRI LifeWatch ERIC, the European network of innovative and integrative research in this field. Finally, XL-EFES can be used to set up large-scale experimental outdoor facilities (mesocosms) for the study under controlled conditions of complex issues in the field of biodiversity, ecology, environment and climate. Synergies are possible with the Geosciences Group, for example with the "Deltas" theme.

Biotechnology and sustainable production

The LRI in the field of agriculture and food, industrial biotechnology, pharma and environmental technology fall within the domain of Biotechnology and sustainable production. These LRI are essential in order to address major new challenges for biotechnology and agri-food production, namely the development of closed cycles and sustainable production. Control of conditions and accurate monitoring are crucial here. This field is often characterised by a circular chain approach, taking account of every aspect from fundamental groundbreaking research through to the development of industrial processes.

Detailed knowledge of biological systems, including molecular interactions within and between cells and organisms, enables the application of synthetic biology. This opens up a world of previously unknown possibilities for developing partly or entirely new chemistries and biological systems. IBISBA-NL, part of ESFRI-IBISBA, focuses on automated construction, evolution and phenotyping of biotechnological production strains, through to the design of new biological and hybrid systems. Unravelling and exploiting the complex interactions of microorganisms in microbial communities is the focus of UNLOCK, while WI-KNAW, affiliated to ESFRI-MIRRI, focuses mainly on the biodiversity and biotechnological application of fungi and bacteria. Developing and identifying robust, climate-change-resistant food crops is important for the national seed breeding and horticultural production industry. To this end, NPEC, part of ESFRI-EMPHASIS, facilitates the automated, high-resolution, efficient phenotyping of plant growth and development both above and below ground. SMART-FABRIC focuses on the development and application of technologies to create new zero-emission value chains in the food and biobased domain. In this case, synergies are possible with the Groups "Materials" and "Life Science & Enabling Technologies".

Priorities for the next five years

Over the next five years, the emphasis will be on setting up LRI to complement existing facilities so that all organisation levels are served. Green Life Sciences focuses on:

1   An integrated set of measuring instruments that can simultaneously monitor biodiversity, ecology and living environment in a selection of representative landscapes, and that can make available and maintain long-term data sets. For the first funding round, we are focusing on an integrated proposal led by eLTER and LifeWatch (LTER-LIFE), with linkages to NEMNET, ARISE and XL-EFES. For the second round, we aim to follow on from this and focus on realising representative large-scale experimental facilities in which we can study the effects of biodiversity and climate change under controlled conditions on site, on campus and online, involving XL-EFES, ARISE, NEMNET, eLTER and LifeWatch.

2   An integrated infrastructure for the system-oriented use of synthetic biology to develop custom-made biocatalysts (BIOTECH-NL), led by IBISBA-NL, with linkages to SMART-FABRIC, UNLOCK and WI-KNAW. In the second round, the focus will be on setting up LRI for the benefit of the organisation levels not yet addressed, and for the efficient interpretation and use of the Big Data that the Green Life Sciences will provide.

5.2
Group Life Sciences & Enabling Technologies

LRI acronym	LRI parts	Description	Lead
		Theme: **Omics**	
Omics	BDC	Biomarker Development Center	University of Groningen
	GCF	Genomics Core Facility	Erasmus University Medical Center
	NMPC	Netherlands Metabolic Phenome Centre	Leiden University
	NPC	Netherlands Proteomics Centre	Utrecht University
	Proteomics Center	Erasmus MC Proteomics Center	Erasmus University Medical Center
	X-omics	Netherlands X-omics Initiative	Radboud University Medical Center
		Theme: **Imaging**	
Imaging	AMIE	Applied Molecular Imaging at Erasmus MC	Erasmus University Medical Center
	M4i	M4i, The Maastricht MultiModal Molecular Imaging institute	Maastricht University
	NEMI	Netherlands Electron Microscopy Infrastructure	University Medical Center Utrecht
	NL-BI	NL-BioImaging AM: a national infrastructure for multiscale light microscopy in life sciences	University of Amsterdam
	uNMR-NL	Ultra-high-field NMR facility for the Netherlands	Utrecht University
		Theme: **Tools & Models**	
Tools & Models	BSL3	BioSafetyLab3	Erasmus University Medical Center
	CPC	Chemical Probe Consortium	Leiden University
	Glycoenable-NL	The Netherlands Center for Functional Glycoscience	Utrecht University
	MCCA2.0	Models to Combat Cancer and Ageing consortium	Netherlands Cancer Institute
	MRUM	Metabolic Research Unit Maastricht	Maastricht University

Scientific questions, challenges and priorities

The Group Life Sciences & Enabling Technologies (LS&ET) consists of LRI that are uniquely positioned to investigate the molecular foundations of life. This requires integration of life science technologies, including omics, (bio)molecular imaging, metabolic phenotyping and molecular structure elucidation. Basic technologies for this mission include structural biology, imaging, next-generation sequencing, mass spectrometry and gene-editing methods, which together span the full range from molecular level to complete organisms.

The LS&ET Group consists of consortia including scientific experts, some of whom have already received recognition and partial funding under the Roadmap. The Netherlands Electron Microscopy Initiative (LRI NEMI) has delivered highly advanced cryo-EM techniques to determine the structure of the SARS-CoV-2 virus, leading to rational vaccine and drug development. The Netherlands X-omics Initiative (LRI X-omics) is now the central point of expertise for (multi-)omics technologies and biomarkers in the Netherlands, associated with Health-RI. The Dutch magnetic resonance community (LRI uNMR) has acquired a new ultra-high-field (1.2 GHz) magnet system and established a national network to visualise molecular functions and dynamic processes in unprecedented detail. The LRI BSL3 has proved indispensable in the broader context of infectious disease research, notably for experimental research into high-risk pathogens and pathogen-host interaction.

Our ambition and dream is to combine and accelerate this research, enabling groundbreaking research into the molecular foundations of health and disease. By combining imaging and omics and using an innovative, versatile chemical toolbox, we aim to investigate the functions of molecules and proteins in living cells and organisms in order as to create a highly detailed picture of life. We will make innovative life sciences techniques available for scientific breakthroughs, thus creating new strategies for diagnosis, treatment and prevention.

The envisaged infrastructure plays a critical role for the national and international omics, microscopy and NMR research communities; thousands of life sciences researchers in the Netherlands are currently using it to conduct pioneering research. LRI from LS&ET are internationally recognised as outstanding and, in many cases, are world leaders in technology-driven innovation and application in the fundamental life sciences. Their experts are leading partners in various European and global networks, such as European research infrastructures (EATRIS-ERIC, BBMRI-ERIC, Euro-Bioimaging) and flagship projects (including European 1 Million Genomes, iNEXT-Discovery and PANACEA). The members of the LS&ET Group also participate in various activities to establish data management, cloud computing environments and new data processing tools for enabling technologies across Europe.
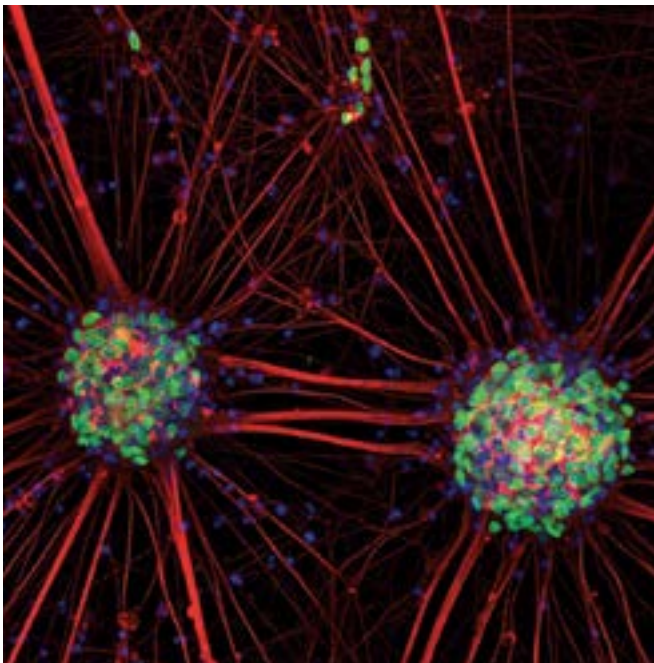
LRI themes and coherence

The omics technologies have a unique capability to understand the molecular building blocks of life, explaining the underlying mechanisms of disease, health and new treatments. To achieve this, we aim to continue developing the techniques of sequencing, mass spectrometry and bioinformatics, and to link these high-quality omics analyses with functional imaging, phenotyping and other research data.

Complementary imaging techniques allow us to visualise molecules and proteins in their biological environment with the highest possible resolution and to understand their function in cellular and subcellular processes. To achieve this, we plan to make use of the toolbox and models developed within this Group. By coupling omics analyses with imaging, and especially by doing so in a functional way over time, we can better understand and manipulate life processes at the cell and tissue level.

For optimal cross-fertilisation within and between omics and imaging, unique tools will be developed to study biological processes from molecule to living cell and ultimately to pharmacology in living organisms. Various infrastructures will be designed to study highly infectious pathogens, diseases such as cancer, and metabolic and ageing-related conditions, leading to biomedical applications. All of these activities are closely linked to the omics and imaging LRI within LS&ET, including data management and AI data analysis, and offer various linkages with other LRI Groups on the Roadmap.

We envisage ambitious moonshot challenges that will radically alter the Life Sciences field, such as:

- Understanding the relationship between the structure and function of biologically relevant molecules, pathogens and cells so as to accelerate the development of innovative medicines;
- Better understanding the genetic and functional basis of health and disease, and prompt identification and acknowledgement of person-related disease risks to allow improved population-wide and person-centred prevention;
- Developing innovative (bio)materials in health care, (bio)technology and agri-food for a more sustainable society.

Clusters and capacities within the LS&ET Group
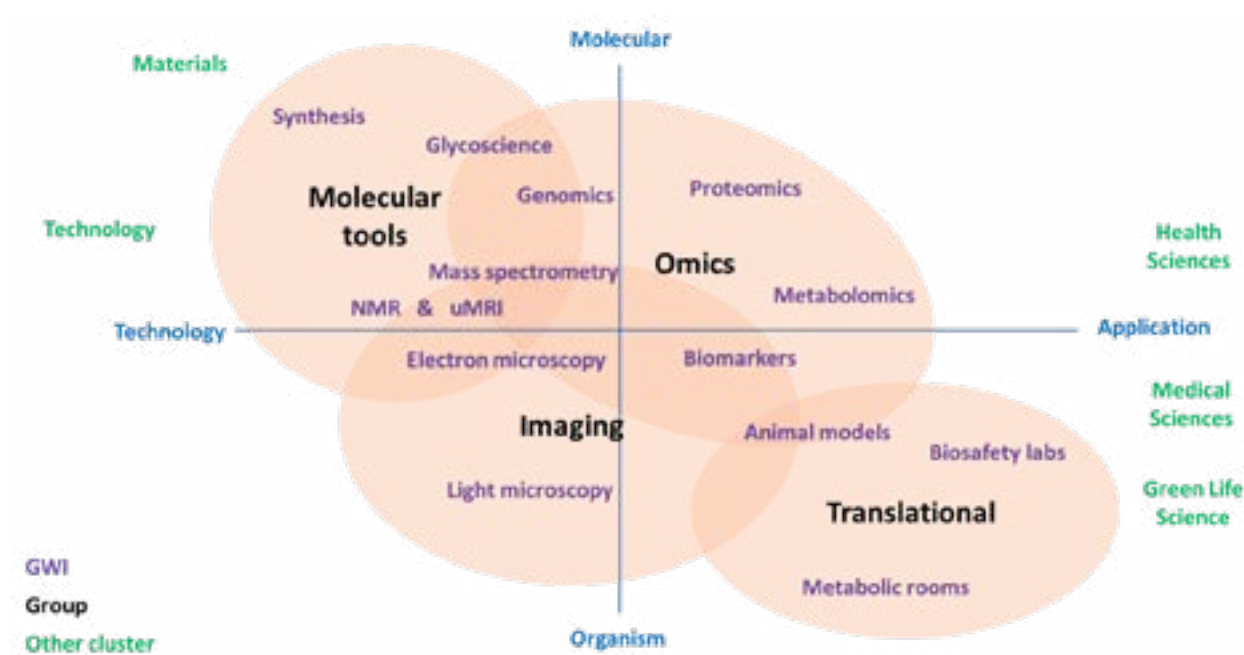
Priorities for the next five years

The mission of the LS&T Group is to be active on two dimensions:

1 **Linking research into individual molecules with their analysis in intact organisms** (from molecule to organism).
  This ranges from omics technologies (genomics, proteomics, lipidomics, metabolomics, bioinformatics and translational biomarker platforms) that can synergise in an integrated, comprehensive multi-omics approach to imaging technologies (spectroscopy, NMR, electron microscopy and advanced optical imaging micro-scopy) enabling functional imaging of cells and organisms; this in combination with platforms for high-content screening technologies for genetic analysis screening and new drug research.

2 **Translating the next generation of life science technologies into applications and scientific breakthroughs in all fields** (from technology to application).
  This ranges from (supra)molecular synthesis, detection and structural analysis technologies (advanced chemistry, EM, MS, NMR, X-ray crystallography) to in situ and in vivo technologies allowing research into chemical, biological and biomedical processes in natural or near-natural environments. This may require specific infrastructures, such as whole-body room calorimetry, mouse disease models, metabolic respiration rooms and biosafety laboratories.

The priority here will be combined imaging and omics, made possible by innovative chemical tools. This will allow us to study the functional consequences of genetic, pharmacological and synthetic changes in their natural environment. These developments will be linked to developments in other LRI Groups on the Roadmap.

5.3
Group Medical Sciences

Medical Sciences for Personalised Medicine

LRI acronym	LRI parts	Description	Lead
	Theme: **Advanced personalized Therapies & human Model Systems**		
	NECSTGEN	Netherlands centre for the clinical advancement of stem cell and gene therapies	Leiden University Medical Center
	hDMT INFRA	hDMT Organ-on-Chip Infrastructure	hDMT (Institute for Human Organ and Disease Model Technologies)
AT&MS	Utrecht CTF	Utrecht Cell Therapy Facility: National expert center ATMP development and Cellular Therapy	University Medical Center Utrecht
	RMU	Regenerative Medicine Utrecht	University Medical Center Utrecht
	NPORT	Netherlands Platform for Organoid Technology	University Medical Center Utrecht
	Theme: **Precision Imaging & Image-Guided Intervention**		
	Scannexus	Scannexus – Brains Unlimited B.V.	Maastricht University
	DYNAMIC	Dutch National 14 Tesla Initiative in MRI and Cognition	Radboud University
	RTC Imaging	Radboud Imaging Center	Radboud University Medical Center
PIGI	SC	Spinoza Centre for Neuroimaging	SC
	CIS	Center for Image Sciences	University Medical Center Utrecht
	AUMC Imaging Center	Amsterdam UMC Imaging Center comprising Tracer Center Amsterdam	Amsterdam University Medical Center
	HollandPTC R&D	HollandPTC infrastructure for fundamental research up to clinical implementation in proton therapy R&D	TU Delft

Scientific questions, challenges and priorities

Medical science research revolves around cells: how do these building blocks of the body relate to each other? How do they communicate in the development of organs and tissues? How does this lead both to health and to disease?

Stem cell technology and imaging techniques are essential for understanding molecular, cellular and functional processes. Together, they can point to the cause of individual differences in diseases and treatment responses. This combination of technologies, in which the Netherlands is a front runner, will lead to scientific breakthroughs in the Medical Sciences in the next ten years.

LRI themes and coherence

The medical sciences in the Netherlands face two challenges. The first is to create realistic tissue models of sick and healthy people. This can be done through a combination of stem cell technology, genetic technology, organoid technology and organ-on-a-chip technology, generating new insights into disease mechanisms and individual differences as a basis for personalised therapies (LRI plan: Advanced personalized Therapies & human Model Systems, AT&MS).

The second challenge is to develop innovative imaging techniques that map biological processes in humans and in human model systems at the functional, molecular and cellular level. These techniques can then be a basis for controlled treatment for improved functioning (LRI plan: Precision Imaging & Image-Guided Intervention, PIGI).

In combination with a smart micro-environment including immune cells, stem cells can address the need for standardised model systems, mimicking the function, heterogeneity and dynamics of cells and organ tissues in the body. These "individual-specific" stem cell models, such as organoids and organ-on-a-chip models, may be better predictors of disease and health in humans than animal models, and may even be a game changer in healthcare. Stem cell models can unravel the molecular and cellular mechanisms responsible for disease and developmental disorders. They can identify molecules as targets or components for advanced drugs. This will lead to the best therapy for individual patients and to new medicines for previously untreatable diseases.

Thanks to existing LRI and planned expansions, we expect these two challenges to yield answers to the following questions:

1. How can we develop human model systems that faithfully mimic healthy and diseased organ tissue?
2. Which dysregulated molecular, cellular and functional processes lead to a given congenital abnormality or disease, and how can they be repaired?
3. How can dysregulated processes at the molecular and cellular level be visualised in model systems and in the human body?
4. Which individual-specific traits determine individual differences in disease onset and severity, and the effectiveness of treatment?
5. How can these insights be translated into new therapies?
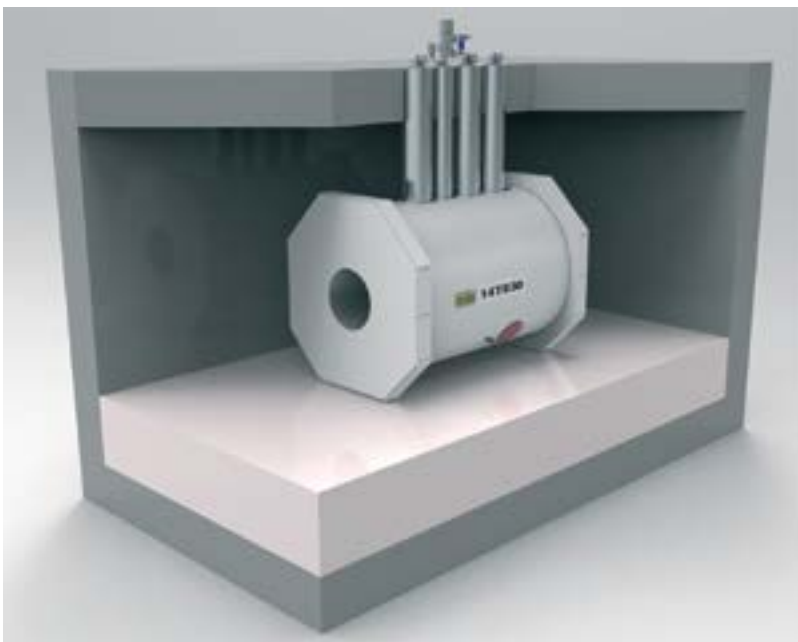
Priorities for the next five years

At the patient level, Dutch medical science is not only developing contrast media/tracers for targeted cellular treatment but also investing in imaging facilities including artificial intelligence.

Examples include total body PET-CT, high-field MRI, real-time MRI and optical modalities, possibly associated with treatment equipment such as targeted MRI-guided radiotherapy, MRI-guided intervention, personalised nuclear therapies, ablative treatment or topical medication.

These developments lead to better detection of anatomical abnormalities, mapping of physiology and organ function, an understanding of metabolism and medication kinetics, reduced burdens on patients and staff, shorter treatment times and real-time availability of crucial imaging information. The next four years should see investments in the world's most powerful *in vivo* imaging system (14T MRI), needed for the accurate study of functional and metabolic activity of cell/organ systems in health and disease and in response

to medication, and also in establishing a national stem cell infrastructure with the right micro-environment to set up individual-specific model systems; these investments will thus bridge the gap between PIGI and AT&MS.

International

Medical research is of vital urgency: the cost of medicine use, for example, is a trillion euros worldwide. Only a minority of patients benefit from treatment with medicines; the majority experience no benefits but often experience side effects. An internationally leading infrastructure is necessary if we are to get a grip on these per-patient differences and to maintain the Netherlands' lead in the field of human disease models, stem cell technology and imaging techniques compared to with cooperation partners worldwide (such as EUROBIOIMAGING, ELIXIR, EATRIS and BBMRI-ERIC). This can only be achieved by combining the strengths of the proposed LRI for these areas: in this way, fundamental scientific research will underlie the development of better treatments with the ultimate aim of providing the right therapy for each individual.

HUMAN STEM CELLS:
Where do they come from? What can you do with them?

Derived from human embryos

pluripotent Stem cells

Induced pluripotent stem cells

'Reprogramming'

Can form all cells in the body

From bone marrow, gut, lung, liver, pancreas (as organoids) retina, cornea, skin, hair....

Adult stem cells

Form cell types of the tissues from which they are derived

From skin, blood, urine etc.

Mummery, van Meer
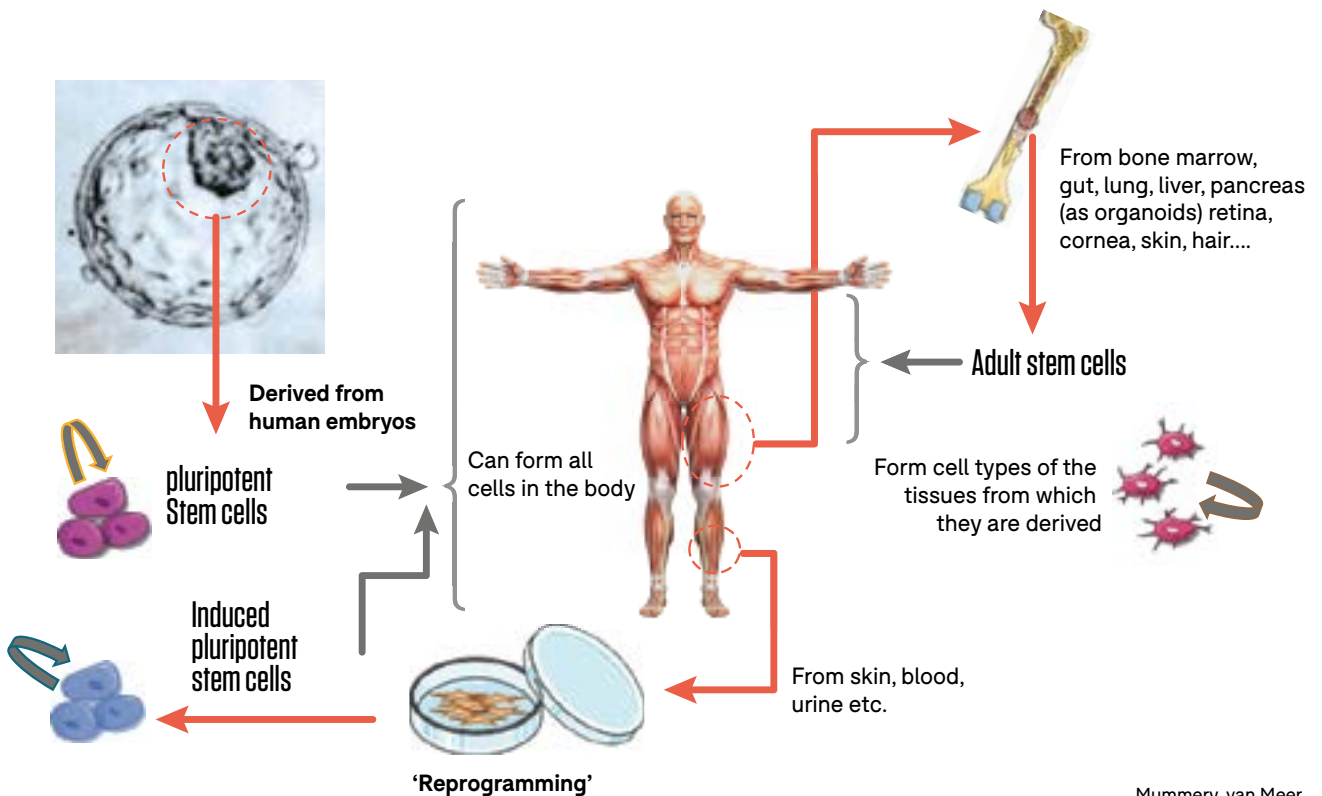
5.4
Group Health Sciences

Federated Dutch Cohort Infrastructure

LRI acronym	Name	Lead
EPIC-NL	EPIC-NL	University Medical Center Utrecht
NTR	Netherlands Twin Register	VU Amsterdam
anDREa	accessible network Digital Research Environment alliance	Erasmus University Medical Center, University Medical Center Utrecht, Radboud University Medical Center
DIAS	Data and AI Systems Lab	TU Delft
NIFER	National Infrastructure for Exposome Research	Utrecht University
Health-RI	Health Research Infrastructure	Netherlands Federation of University Medical Centres
HELIUS	Healthy life in an urban setting	Academic Medical Center Amsterdam
ERGO	Erasmus Rotterdam Health Research (Rotterdam Study)	Erasmus University Medical Center
PHT	Personal Health Train	Maastricht University
NCC	National Cohort Consortium (NCC)	Maastricht University Medical Center+
EATRIS.nl	European Infrastructure for Translational Medicine – NL national node	Netherlands Cancer Institute
BBMRI.nl	Biobanking and Biomolecular Research Infrastructure	University Medical Center Utrecht
CCRDBC	Clinical Cohorts Research Data & Biobanking Center (CCRDBC)	University Medical Center Utrecht
MFE	Movement for everybody: more, better and smarter	VU Amsterdam
ELIXIR-NL	ELIXIR-Netherlands	VU Amsterdam
EBRAINS-NL	EBRAINS NETHERLANDS	University of Amsterdam

*(Row group label in left margin: **Health-RI**)*

Scientific questions, challenges and priorities

The Netherlands has a rich tradition when it comes to setting up high-quality population and patient cohorts. These cohorts provide unique, in-depth, real-world data across the entire health spectrum and are a fantastic resource for breakthroughs in the health sciences. This field of science provides the data and methodology to understand the population's health and resilience and identify factors involved in health and disease. It facilitates early detection of disease and identification of predictive and prognostic factors. This knowledge forms the basis for promoting a healthy lifestyle and individually tailored treatments, focusing on a fit and healthy life for all. It also provides a platform for establishing adaptive clinical studies and rapid introduction of innovative research, e.g. in the case of acute health risks (see box).

Investments are necessary to ensure that the Netherlands retains its leading position in this field and to facilitate the implementation and acceleration of pioneering new research. Specifically, our aim is to set up a Federated Dutch Cohort Infrastructure that will create and maintain high-quality health databases, data analysis methods and modelling tools. This infrastructure will combine the resources of various initiatives and institutions, covering a wide spectrum of data ranging from genetics, omics, imaging, physiology and clinical data to environmental data and real-time health data collected by citizens and patients themselves, including through the use of wearables. The infrastructure will thus facilitate research into the complex relationships between health status and disease on the one hand, and genetic factors and a wide range of lifestyle factors (e.g. diet, exercise) and environmental factors on the other. The coronavirus pandemic has shown that such an infrastructure is necessary and what it can deliver, in both scientific and socioeconomic terms. The Federated Dutch Cohort Infrastructure will be designed to take full advantage of the power of artificial intelligence (AI) and multifactorial modelling and simulation. These techniques play a key role in the life sciences because they can model complex relationships between large volumes of high-dimensional health data.

Setting up the Federated Dutch Cohort Infrastructure requires two types of investment:
- **Infrastructure support for existing cohorts and new data collections.** The strength of the Dutch cohort landscape lies in its diversity. Connecting these cohorts and enriching them with additional data sources will lead to a rich, diverse set of data with different demographic backgrounds, in-depth phenotype information on specific pathologies, and variation in follow-up time. Thanks to this diversity, a Federated Dutch Cohort Infrastructure will be able to answer questions spanning the entire health spectrum. Investments are needed to guarantee the longevity of these collections and thus the quality and richness of the data that can be accessed via the Federated Dutch Cohort Infrastructure. Continuous collection and enrichment of cohort data with relevant data collections is essential in order to keep the cohort infrastructure up-to-date and relevant. National coordination is needed to set priorities for this enrichment. To this end, a national cohort/register infrastructure will be set up with support from Health-RI. Transparent communication about how data are used, by whom and for which purposes will ensure the trust of the parties sharing data (e.g. citizens, patients).
- **FAIRification & data integration.** Dutch population-based and clinical cohort research is very diverse. Consequently, there is considerable scientific interest in combining data from independent cohorts. This is a challenge, due to the heterogeneity of the collected data and the ontologies and the data cataloguing. Achieving a Federated Dutch Cohort Infrastructure will require data management that makes the data FAIR, in other words Findable, Accessible, Interoperable and Reusable. In this way, data can be combined for integrated analysis and linking to other data sources. This requires agreements on matters such as ethical, legal and social implications (ELRI), governance in data sharing, infrastructure investments in data steward-ship and data management at the source. On top of this layer of federated Dutch cohorts, we will build an IT infrastructure enabling federated access, federated learning (AI), modelling and simulation. This will enable us to answer important new health questions. This part of the Federated Dutch Cohort Infrastructure will be organised in cooperation and alignment with Health-RI, which has already established coordination in this field at the national level. By means of a Growth Fund investment, the foundations will be laid for a health data infrastructure specifically geared to the revenue potential of the Netherlands. The infrastructure investments required within the framework of LRI will have a different emphasis and will focus on the functionality needed to support innovative research within the life sciences.

LRI coherence

The Federated Dutch Cohort Infrastructure will consult and work with national organisations such as the Ministry of Health, Welfare and Sport, SURF and the eScience Center, and with European research infrastruc-tures in the life sciences such as BBMRI, ELIXIR, Euro-BioImaging, EATRIS, EBRAINS and the European Health Data Space. The organisation will also be aligned with data initiatives in, amongst others, the social sciences and humanities, such as ODISSEI and CLARIAH, and with hospital data collections such as DICA, NKR/IKNL and PALGA.

By operating as a Federated Dutch Cohort Infrastructure, we will enable Dutch researchers in the health and life sciences not only to address new questions, but also to implement new models and simulations. This is possible

COVID-19

The sudden onset of the coronavirus pandemic posed the global scientific community with a challenging task: to investigate all risk factors for susceptibility to the infection, the severity of its progression and the long-term consequences of COVID-19. The high-quality population and patient cohorts in the Netherlands allowed coronavirus research to be set up immediately. The wealth of data (including genetic, omics, clinical and exposome data) collected over decades within individual cohorts permitted early identification of risk factors for susceptibility to SARS-CoV-2 infection, severity of progression, treatment options and the long-term health effects of COVID-19. Had a Federated Dutch Cohort Infrastructure been available, the power of the combined data would have enabled us to answer many additional questions, avoiding duplication of effort, with the potential to detect risk factors for severe progression of COVID-19 at a very early stage and to offer individually tailored treatment options as early as possible. This would have yielded better results, with less far-reaching consequences for society compared to the current situation.

by working on a scale comparable to that of other large national initiatives. Where others have chosen a single national resource (FinnGen, the German national cohort NAKO, the UK Biobank), the Federated Dutch Cohort Infrastructure will opt for flexibility: by allowing heterogeneity in the contributing cohorts, it will be able to answer specific questions in specific populations.
However, it will aim to achieve the highest possible level of interoperability and standardisation of data collections.

LRI plans and priorities

In the coming years, the LRI Health Group envisages LRI plans that will jointly achieve the vision of a rich, Federated Dutch Cohort Infrastructure allowing innovative research. These plans will contain various components, as shown in the attached figure: Investments will be made to (i) broaden data collections by linking with existing collections and data initiatives, (ii) deepen data collections with new data acquisition, and (iii) establish and maintain prospective (longitudinal) data collections. Other investments will be made in (iv) harmonisation and interoperability, linking and making available the rich longitudinal data collections, and (v) an infrastructure that facilitates advanced data analyses, including AI applications and modelling based on the rich dataset. These five LRI components are described in more detail in the LRI plans in the appendix.

CHAPTER 6
Domain Social Science & Humanities

Within this Domain, the PC-LRI has defined one Group with substantive, thematic or technical interfaces.

6.1
Group Social Science & Humanities

6.1
Group Social Science & Humanities

The SSH Macroscope – a shared infrastructure for the social sciences and humanities for studying change, crises and division

LRI Acronym	Description	Lead
	Theme: **Material heritage**	
E-RIHS NL	Research Infrastructure for Heritage Science in The Netherlands	Cultural Heritage Agency of the Netherlands
NICAS	Netherlands Institute for Conservation+Art+Science+	University of Amsterdam
	Theme: **Language, speech and image**	
CLARIAH	Common Lab Research Infrastructure for the Arts and Humanities	Huygens Institute for the History of the Netherlands (Huygens ING)
IISG	International Institute of Social History Collections	International Institute of Social History (IISG)
Delpher	Delpher, digitised texts from Dutch newspapers	KB National Library of the Netherlands
DIR	Digital infrastructure government archives	National Archives of the Netherlands
EHRI	European Holocaust Research Infrastructure	Institute for War, Holocaust and Genocide Studies (NIOD)
	Theme: **Surveys, cohorts, registry data**	
ODISSEI	Open Data Infrastructure for Social Science and Economic Innovations	Erasmus University Rotterdam
MIDAS	Microdata Services	Statistics Netherlands
LISS	LISS panel: Long-term Internet Studies for the Social Sciences	CentERdata / Tilburg University
ESSNeth	European Social Survey in the Netherlands	Netherlands Interdisciplinary Demographic Institute (NIDI)
GGP	Generations and Gender Programme	NIDI
NKO	National Voter Survey	SKON
EVS	European Values Study	Tilburg University
	Theme: **Data and archive services**	
DANS	Data Archiving and Networking Services	DANS-KNAW

Scientific questions, challenges and priorities

Societies face constant challenges in the form of transformations, crises and divisions, which each have a degree of uncertainty. Human behaviours and their consequences are extremely complex yet have far-reaching consequences for the way in which culture is generated and shared and how society is structured and organised. Understanding the mechanisms underpinning these processes requires an integrated research infrastructure that allows for the simultaneous study of their development over time, interlinkages and contemporary manifestations.

Urgent questions are:

1 How is cultural identity, of both individuals and groups, shaped and changed? What is the role of various forms of material and immaterial cultural heritage in this process? How are dominant cultural identities enshrined in shared symbols and historical memory and how are these actively challenged and adjusted to reflect changing historical and social circumstances?

2 How do different inequalities intersect and amplify each other to create parallel worlds within one society? Which integrated and interdisciplinary interventions can help mitigate and reduce these ripple and echo effects to produce a more inclusive and resilient society?

3 How can the impact of the digital revolution be properly assessed, given the scale and complexity of the massive quantities of variegated data that have to be handled? How can the many problematic aspects of this revolution be successfully negotiated, such as scale (information overload), trustworthiness (fake news), the growing digital divide, and the rapid remediation between real and material versus digital?

4 How can better linkages and syntheses of perspectives and data at the level of individuals, groups and societies be achieved? How do individuals make sense of long-term and large-scale social and cultural transformations and how does this translate into choices, behaviour, creativity and collaboration? How do the choices people make in their lives aggregate into larger structures and institutions?
The social sciences and humanities contextualise developments in the past to make sense of contemporary societal and cultural structures and challenges and to signal future trends.

LRI plans of national importance

The existing infrastructures and plans for the social sciences and humanities domain fall within the overarching concept of the Macroscope; a machine to study the infinitely complex. The Macroscope can zoom out to the level of populations and cultural systems and can zoom in, down to the level of individual constituents. Analyses can go in-depth, for charting long-term change and trends; broad, for tracing societal developments from different types of data ranging from the built environment and physical artefacts through to the digital bread-crumbs left behind today; live, for tracking the state of events in real time; and predictive, using models to extrapolate observed trends, detect early warning signals, and develop interventions that help researchers and policy makers shape the society of tomorrow.

The following plans provide operative parts for this Macroscope and are instrumental in answering the urgent questions posed in Section A:

1   The Aperture of the macroscope will facilitate interoperability and allow researchers to switch between andintegrate data and information flowing from its various operative parts, as well as zooming in and out. Integrating diverse data on human behaviour, creativity and communication will generate innovative nodes of knowledge, providing a more diverse historical and material context to study, both quantitatively and qualitatively, the generalisability of social and cultural mechanisms in human behaviour.
2   The Spatial Lens integrates geographical information, which plays a key role in multidisciplinary studies on a wide range of socially and culturally relevant topics. By adding a spatial lens, questions that focus on degrees of mobility and on local and regional variations in data can be tackled and results better visualised. The integration of open source and highly secure geographical datasets in the Macroscope can greatly enhance the efficiency and depth of social sciences and humanities (SSH) research.
3   The Historical Lens will radically simplify researchers' access to information and enable macro investigations into past patterns, structures and trends and their representations in contemporary society by integrating the huge quantities of dispersed data held in separate archives and collections. Transforming dispersed information into an interlinked open data cloud will make it ready for computationally enhanced research.
4   The Language Lens is a suite of new software tools for automatic text processing and information extraction, as well as for speech processing. This suite will assist in providing deep access to yet unexplored and rich varieties of language and speech data on any topic and in any domain, fuelling new SSH studies that were previously impossible to perform at human scale.
5   The Media Lens is an overarching, interoperable framework to support and integrate existing media and communications infrastructures. This would allow the combined analysis of literary texts and reception studies on online reviews with rich demographic and survey data. The media lens would bridge media analysis with survey and administrative data infrastructures in secure research environments.

LRI coherence

ODISSEI and CLARIAH, two complementary infrastructures already funded through the PC-LRI, are collaborating on common infrastructural components. CLARIAH and EHRI have established common ground. Research with a focus on the effects of human behaviour within the social sciences has clear implications for the Health Sciences Group. NICAS and E-RIHS, with a focus on material analysis of cultural heritage, connect strongly to the Material Sciences area. Within the current SSH Group the proposed infrastructure offers ample opportunities to enrich the research potential of all those parties, providing vital societal and cultural context for object-related research while data on objects and materials adds a new dimension to research within the SSH domain.

International and medium term

Components for the SSH Macroscope are being constructed currently in the Netherlands by CLARIAH and ODISSEI, which contribute to and are member of larger European infrastructures: ESFRI initiatives and ERICs CLARIN, DARIAH, EHRI, E-RIHS, CESSDA, SHARE and ESS.

CHAPTER 7

Funding instruments for the development of LRI

Large-scale research infrastructures are funded in various ways in the Netherlands. A funding boost is often needed for the development of new research infrastructure or large updates of existing infrastructure because the universities and national research institutes cannot cover such costs from their own basic funding.

NWO has two funding instruments specifically aiming at research infrastructure. Other NWO funding instruments offer the possibility to include a module for research infrastructure as well. Various European funding possibilities also exist.

7.1
Large-Scale Research Infrastructure – National Roadmap consortia

7.2
Research infrastructure – National consortia

7.3
Other funding instruments from NWO with an infrastructure module

7.4
European funding

7.1
Large-Scale Research Infrastructure – National Roadmap consortia

Via the funding instrument '**Large-Scale Research Infrastructure – National Roadmap consortia'**, the Groups associated to the Roadmap 2021 can apply for funding to realise their prioritised LRI plans. During the course of the Roadmap 2021, two Calls for proposals will be published with an expected budget of 80–100 million euros each. As explained in Chapter 3, the guideline introduced in 2016 for the allocation of funding will remain: across the entire Roadmap period, about 45% of the available funding for LRI will be used within the technical and natural sciences, 45% for LRI within the life and medical sciences, and 10% for LRI within the social sciences and humanities. For each funding round, the PC-LRI will advise about the use of this guideline.

The funding instrument intends to facilitate groundbreaking scientific research in all scientific disciplines by realising access to high-quality LRI for the Dutch research community. The funding is intended for the development, acquisition or construction of new LRI and for the upgrade of existing LRI so that they can be used to achieve new scientific breakthroughs. Furthermore, proposals should have a strategic and national importance. This means that the applying consortia consist of a broad group of relevant researchers from all over the Netherlands, there is a proper governance structure and a broad and transparent access policy formulated.

To safeguard their priorities and long-term commitment, proposals will be submitted by the project leader on behalf of the highest administrative body of the research organisations concerned or the intended main applicant of a national consortium. Consortia can only submit proposals on behalf of the Groups that are mentioned in the Roadmap; the call is not open to consortia that are not associated to the Groups on the Roadmap. In the call, it will be stated how many proposals may be submitted by consortia associated to the Roadmap Groups. The size of the LRI grant that can be applied for is at least 10 million euros. In addition to this NWO grant, the consortium partners provide a mandatory matching contribution of at least 25% of the total project size. In line with previous funding competitions, capital investments and a limited part of the exploitation costs can be applied for. Research that is carried out by using the infrastructure will not be funded. Costs for the sustainable long-term exploitation of the LRI must be guaranteed by the applying consortium. Therefore this funding instrument only provides a starting grant for creating the LRIs but does not support long-term sustainability.

More information: https://www.nwo.nl/en/researchprogrammes/national-roadmap-large-scale-research-facilities

7.2
Research infrastructure: national consortia

Besides Roadmap funding, NWO has another funding instrument open to all disciplines specifically aimed at research infrastructures, named **Research infrastructure: national consortia** (formerly NWO Investment Grant Large). With this instrument, NWO also wants to strengthen the research infrastructure ecosystem for the Dutch research community at universities and national institutes. The budget that can be applied for is more limited than that in the associated Roadmap funding instrument. The size of the research infrastructure (RI) grant that can be applied for is at least one million euros for investments within the social sciences and humanities and at least 1.5 million euros for all other sciences. For this NWO grant, the consortium partners also have to commit a matching contribution (25%). The costs for the sustainable exploitation of the RI are also the responsibility of the requesting consortium partners.

Thus this funding instrument also only provides a starting grant for creating the LRIs but does not support long-term sustainability.

Just as in case of the Roadmap, the funding is not intended for the costs of research and long-term exploitation of the RI. Consequently, PhDs cannot be funded from LRI and RI funding. But personnel (such as technicians and postdocs) can be funded for the development and/or implementation of national RI. This means that a broad group of relevant researchers from throughout the Netherlands will be involved at an early stage (during the writing of the proposal), that they receive a relevant role in the governance, and that a broad and transparent access policy must be implemented.

More information: https://www.nwo.nl/en/researchprogrammes/nwo-investment-grant-large

7.3
Other funding instruments from NWO with an infrastructure module

- The NWO funding instrument *Gravitation* is primarily aimed at research. Besides the funding of researchers, this instrument also offers room for the necessary infrastructure (maximum 25% of the total budget applied for). N.B. The average size of Gravitation proposals is between 17 and 20 million euros.

More information: https://www.nwo.nl/en/researchprogrammes/gravitation

- Knowledge and Innovation Covenant Long-Term Programmes (KIC-LTP) is aimed at funding sustainable collaboration. NWO offers strong public-private consortia the possibility to apply for funding for a 10-year research programme. KIC-LTP funding proposals have a size of between 9 and 25 million euros, for which NWO funds 30% of the costs, and from this amount, a maximum of 1.5 million euros may be allocated to research infrastructure. In addition, private parties and knowledge institutions must contribute 70% of the funding (private parties at least 30% in cash, knowledge institutions at least 10% in kind or in cash, and the remainder of the budget can be in cash or in-kind contributions by knowledge institutions, private parties or public parties).

More information: https://www.nwo.nl/en/researchprogrammes/knowledge-and-innovation-covenant/long-term-programmes-kic-2020-2023

- In addition, calls from specific NWO domains and calls from other NWO funding lines (aimed at specific themes and/or disciplines) provide room for RI as part of a proposal. In that case, such a call contains the Module Investments (€ 150,000 – € 500,000) as part of the proposal budget. Examples of calls from specific domains are the Open Competition ENW- M-invest (NWO Science), Perspectief (NWO-AES) and Open Competition (NWO-SSH). There are also calls in the funding lines within the Dutch Research Agenda (NWA) and the Knowledge and Innovation Covenant (KIC) that contain this budget module.

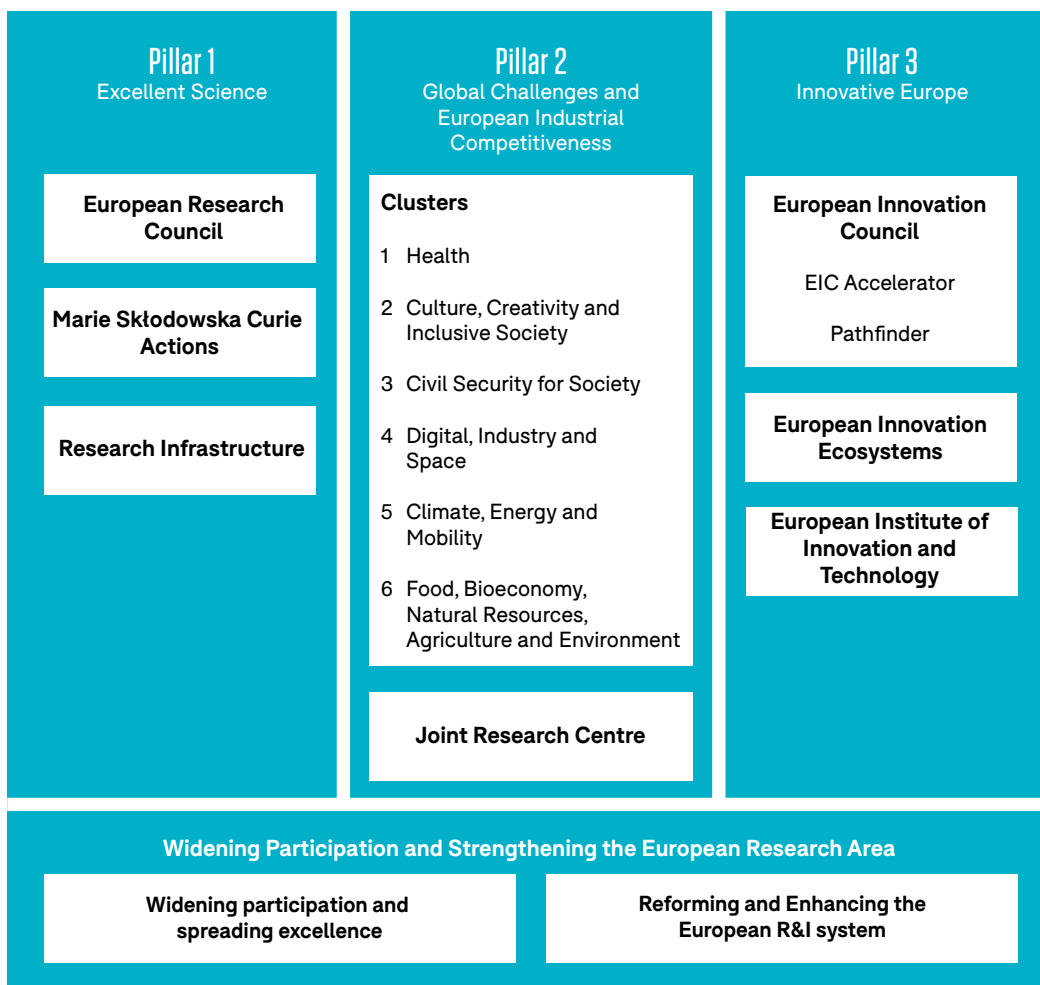See the NWO website and the integral call planning for more information.

7.4
European funding

A considerable proportion of the LRI are, in one way or another, part of an international RI initiative. For these international infrastructure consortia, the European Commission provides several funding possibilities for infrastructure projects. The first pillar of the Horizon Europe Programme is called "Excellent Science". The aim of this pillar is to maintain science in Europe at a top level or raise it to this level. In addition, the actions from this pillar contribute to making Europe an attractive location for the world's best researchers. Europe wants to attract research talent, and develop and provide access to the best research infrastructures.

The pillar Excellent Science has three parts:
• European Research Council (ERC) for excellent, groundbreaking research;
• Marie Skłodowska Curie Actions for facilitating the training and international mobility of researchers;
• Research infrastructures for strengthening the quality and accessibility of research infrastructures.

More information about the Horizon Europe funding possibilities can be found on the Netherlands Enterprise Agency website https://english.rvo.nl/subsidies-programmes/horizon-europe-research-and-innovation/horizon-europe-research-infrastructures.

Pillar 1 Excellent Science	Pillar 2 Global Challenges and European Industrial Competitiveness	Pillar 3 Innovative Europe
European Research Council	**Clusters** 1 Health 2 Culture, Creativity and Inclusive Society 3 Civil Security for Society 4 Digital, Industry and Space 5 Climate, Energy and Mobility 6 Food, Bioeconomy, Natural Resources, Agriculture and Environment	**European Innovation Council** EIC Accelerator Pathfinder
Marie Skłodowska Curie Actions		**European Innovation Ecosystems**
Research Infrastructure		**European Institute of Innovation and Technology**
	Joint Research Centre	

Widening Participation and Strengthening the European Research Area

Widening participation and spreading excellence	**Reforming and Enhancing the European R&I system**

CHAPTER 8

Appendix

APPENDIX 1
Definition of Large-Scale Research Infrastructure

Large-scale research infrastructure are facilities, resources, and services used by a research community to conduct research and promote innovation in its field. Where relevant, the infrastructure can also be used for other purposes than research, for example education or public services.

Among other things, it concerns important scientific equipment or collections of instruments; knowledge-based resources such as collections of natural specimens, archives and collections of scientific data; e-infrastructure such as (interlinked) data files, and computer systems and communication networks; and any other unique infrastructure that is critically important for achieving excellence in research and innovation. This could refer to infrastructures situated in a single location, or virtual or distributed infrastructures in the Netherlands or abroad.

A research infrastructure's policy must guarantee free accessibility for research, for researchers from outside the hosting organisation and ranging from fundamental to applied science.

The following points apply for distributed research infrastructure:
- They must provide one central access point for researchers and external organisations, even if the infra-structure is spread across multiple locations;
- They must have one management board responsible for the entire infrastructure;
- They must have a legal structure.

The size of the infrastructure, in terms of total capital investment[10] and operating costs for 5 years, amounts to at least 10 million euros. These costs do not include accommodation costs for the facility. The operating costs pertain exclusively to the costs needed to make the facility accessible. In other words, they do not include the costs for the research programme.

10

Capital investments are costs for development, purchase/construction of the infrastructure, either costs for necessary adjustments of an existing infrastructure necessary for achieving scientific breakthroughs.

APPENDIX 2
Composition of the Permanent Committee for Large-Scale Research Infrastructure

Chair

Hans van Duijn (1950) is Rector Magnificus Emeritus of the Eindhoven University of Technology (TU/e). He held this position from April 2005 to April 2015. Furthermore, he is a professor at TU/e and Utrecht University (UU). He is a member of the Supervisory Board of Erasmus University Rotterdam, chair of the board J.M. Citizens Centre for fluid dynamics and scientific director of the UU TU/e Darcy Center.
He studied Applied Physics at the former Technical University of Eindhoven and in 1979 obtained his doctorate in mathematics from Leiden University. He worked at TU Delft (TUD) as assistant and associate professor, and later became a part-time professor, combined with a position at CWI in Amsterdam. In 2000, he was appointed Professor of Applied Analysis at TU/e. In 1996, he received the Master Award from TUD and, in 1998, the German government's Max Planck Award.

Committee Members

Humanities/Social Sciences

Ans van Kemenade (1954) has been Professor of English Linguistics at Radboud University since 1999. She studied English Language and Literature, and obtained her doctorate in 1987 from Utrecht University. Her research is on grammatical variation and historical changes in the West-Germanic languages, in particular English and Dutch. Van Kemenade was co-creator of a number of data collections and infrastructures in this field. She was research director and vice-dean of research in the Faculty of Arts at Radboud University and a member of the Board of Humanities at NWO from 2008–2014, where she was responsible for the infrastructure portfolio.

Kees Aarts (1959) is Professor of Political Institutions and Behaviour and Dean of the Faculty of Behavioural and Social Sciences at the University of Groningen. He is interested in the functioning of democracy, elections and electoral behaviour and in data and research methods of the social sciences. He was closely involved in long-term and internationally coordinated projects such as the Dutch Parliamentary Electoral Studies and the European Social Survey. Aarts is a member of the Royal Netherlands Academy of Arts and Sciences (KNAW).

Medical/Life Sciences

Roland Kanaar (1961) is Professor of Molecular Genetics and Head of the Department of Molecular Genetics at the Erasmus University Medical Center. His research addresses the molecular mechanisms and biological and physiological relevance of the DNA damage response. His work integrates interdisciplinary approaches from molecules to cancer patients. His research group exploits fundamental insights into how the DNA damage response operates and how it can be manipulated to design and explore novel cancer treatments. In 2002, he was elected as a member of the European Molecular Biology Organization (EMBO) and, in 2013, he was elected to the Royal Netherlands Academy of Arts and Sciences (KNAW). In 2020, his research team won the 'Ammodo Science Award for groundbreaking research' in the field of Natural Sciences.

Peter Luijten (1954) is Professor of functional medical imaging at the University Medical Centre Utrecht and chair of the Division Imaging & Oncology. He studied physical and theoretical chemistry in Amsterdam. After his PhD (1984, Amsterdam and San Diego) he became a research scientist at Philips where he was involved in the development of MRI systems. From 2000 to 2005, he worked in the US establishing public-private partnerships with a large number of leading academic medical centres. In 2007, he was appointed Chief Scientific Officer of the Centre for Translational Molecular Medicine, a position he held jointly with his academic appointment at Utrecht University. He served on the board of trustees of the International Society of Magnetic Resonance in Medicine and received European Magnetic Resonance Award in 2002.

Annemarie van Wezel (1968) is a Professor of Environmental Ecology at the University of Amsterdam and scientific director of the Institute for Biodiversity and Ecosystem Dynamics (IBED). Van Wezel conducts research into the environmental quality and risk assessment of synthetic substances and solutions to prevent these risks. She has a special interest in translating science into policy and society. Van Wezel is also a member of the Health Council of the Netherlands and the Board for the Authorisation of Plant Protection Products and Biocides (CTGB).

Exact Sciences

Frank Linde (1958) is Professor of Experimental High-Energy Physics –elementary particle physics– at the University of Amsterdam. He has worked on experiments at large particle accelerators such as LEP (Z and W bosons) and LHC (discovery of the Higgs boson) at CERN (Geneva). From 2004 to 2014, he was director of the National Institute for Subatomic Physics (Nikhef). In 2015–2016 he was APPEC (Astroparticle Physics European Consortium) chair. Since 2017 he leads gravitational waves research at Nikhef. Linde has extensive hands-on and managerial experience with large scientific research infra-structures.

Ewine van Dishoeck (1955) is Professor of Astronomy at Leiden University. Her special-isation is molecular astrophysics, especially the chemical processes that occur in clouds where new stars and planets are born. She was closely involved in the establishment of several large telescopes, in space and on earth. Van Dishoeck was chair of the Committee for Large-Scale Research Infrastructures of the Royal Netherlands Academy of Arts and Sciences (KNAW). Furthermore, she is a member of the KNAW, and a foreign member of the US, German, Norwegian and Russian academies of sciences. Van Dishoeck received the NWO Spinoza Prize and the Academy Professor Prize, as well as the 2018 Kavli Prize for Astrophysics.

Engineering & Applied Sciences

Gerard Beenker (1954) was scientific director of NXP Semiconductors until 2014. After that, he was affiliated until April 2018 at Eindhoven University of Technology (TU/e) as an advisor on strategic partnerships in the area of the development of high-tech systems. Beenker has been active in various committees and boards: he was a major driver for the Components and Circuits roadmap in the Top Sector High Tech Systems and Materials (HTSM), member of the technology and innovation committee of the Confederation of Netherlands Industry and Employers (VNO-NCW), member of the board of Technology Foundation STW, chair of KWR's scientific advisory board, member of the Presidium of Artemisia and board member of the Business Cluster Semiconductors. He retired in April 2018.

Special thanks to John Schmitz for his additional contributions

John Schmitz (1954) studied Chemistry at Radboud University, where he received his PhD in 1984. He has over thirty years' experience in the semiconductor industry at such companies as Philips, Genus Inc, SEMATECH and NXP. Schmitz holds a total of six patents, has more than fifty publications and contributions in peer-reviewed journals and at international conferences to his name, and has published books on semiconductor technology, as well as a popular scientific work on thermodynamics. From 2017 until 2020, he was Dean of the faculty of Electrical Engineering, Mathematics and Computer Science of TU Delft (TUD). Schmitz has held advisory roles on such bodies as the Confederation of Netherlands Industry and Employers' Technology and Innovation Committee (VNO-NCW), the Governing Board of MESA+, the National Science Foundation, the Scientific Advisory Board of Imec and the Supervisory Board of the Chip Integration Technology Centre. He is currently a member on the advisory boards of Philips MEMS and Micro-devices Systems and of Applied Nano-Layers and a member of the Investment Committee of Photon Delta. He is also the chair of the Board of The Green Village of TUD and quartermaster of the 24/7 Autonomous Energy Site of TUD.

Suzanne Hulscher (1966) became professor Physics of Water Systems and head of the group Water Engineering & Management, cluster Civil Engineering, University of Twente in 2002. She received her PhD from the Faculty Physics and Astronomy at Utrecht University (UU) in 1996; her PhD subject was modelling of bed patterns in coastal seas. The research was conducted at WL|Delft Hydraulics (now DELTARES) and the IMAU (UU). She won the Minerva award from FOM-NWO in 2002, and from Technology Foundation STW she received the Simon Stevin Meester prize in 2016. From 2007–2010, Hulscher joined the board of the Dutch Innovation Platform, chaired by Dutch Prime Minister Jan Peter Balkenende. From 2009–2012 she was a member of the OCW commission regarding the natural gas revenues. Hulscher chaired the STW Perspectief programme RiverCare (2013–2019). In 2017, she became a member of the Royal Netherlands Academy of Arts and Sciences (KNAW) and since 2019, she has been a member of the Netherlands Scientific Council for Government Policy (WRR).

Data science

Franciska de Jong (1955) is a professor of e-Research for Humanities at Utrecht University and the executive director of CLARIN ERIC. She is also professor of language technology at the University of Twente and director of the Erasmus Studio of the Erasmus University in Rotterdam. Her main research interest is in the field of information retrieval, text mining, the disclosure of cultural heritage collections (in particular spoken audio archives and interview collections) and e-research at large. She was a member of the governing boards of NWO (2008-2016) and the National Library of the Netherlands. Currently she serves on the board of the Netherlands eScience Center and the Executive Board of ERIC Forum.

Peter Apers (1952) is emertitus professor at the University of Twente, where he was Dean of the Faculty of Electrical Engineering, Mathematics and Computer Science (Chair Data Science) from 2014 to 2018. Peter Apers is co-director of COMMIT (a public-private IT FES-project) and has been a member of the Advisory Board of the Einstein Institute Digital Future since 2010. In 2012, he won the IT Personality Award awarded by Nederland IT for his special merits in the IT sector. Peter Apers was chair of Technology Foundation STW from 2005 to 2014.

NWO LRI team

The PC-LRI is supported by the NWO LSO team consisting of: Alice Dijkstra (coordinator), Jelte Wouda, Katrien Uytterhoeven, Maarten de Zwart, Rob Hermans, Mark van Assem, Ana de Castro, Naomi Chrispijn, Martine Margés and Kirsten Verkaik.

Terms of Reference (ToR) for the Permanent Committee for Large-Scale Research Infrastructure

(as determined in 2015)

The 2025 Vision for Science describes the task of the committee as follows.

'This committee will be concerned with facilities used by universities, knowledge institutes, applied research organisations (TO2) and national institutes such as KNMI. It will seek effective coordination to avoid imprudent investments and it will promote the efficient use of the facilities. The committee will include representatives from the knowledge coalition partners.

In contrast to the current situation, in which investment decisions are made by various ad hoc committees, the new committee will devote ongoing attention to investment opportunities which will enhance the research infrastructure. Resources from direct and indirect government funding will be applied in an effective and fully transparent manner, whereby synergy will be sought with the investments made by the institutes of applied research. This approach is based on the recommendations of the Advisory Council for Science and Technology's advisory report *Maatwerk in onderzoeksinfrastructuur* ('A custom-made research infrastructure').

We shall request universities and research institutes to provide accountability for their use of infrastructural funding, to follow the recommendations of the roadmap as closely as possible, and to submit regular reports. This will also reveal the exceptional costs incurred in maintaining the (technical) research infrastructure, such as the Reactor Institute in Delft, which will assist the permanent commission in arriving at a fully integrated consideration of the investment requirement.

Financial resources made available in the form of indirect funding are intended to support the upgrading of the research infrastructure. They will be allocated by NWO in consultation with the permanent commission. The government intends to examine if and how the Toekomstfonds ('Future Fund') can also be used to support investments in facilities for both fundamental and applied research.

There is to be a system of 'pooling', with the national resources allocated in respect of infrastructure linked to the resources at regional level and those of the research institutes, private parties and organisations undertaking applied research. This is in the interests of maximum synergy in both investment and the actual use of the infrastructure. The Permanent Committee will maintain contact with all parties, seeking their input and informing them of developments.'

The committee's commission contains the following elements:
- (Commissioning) the drawing up of a Landscape analysis that details both the availability of and the need for large-scale research facilities. The Landscape analysis contains all of the facilities of universities, scientific institutes, applied knowledge institutions (TO2) and national institutes (e.g. KNMI). For this analysis, the availability of facilities outside of the Netherlands that are available for Dutch researchers must also be identified. The identification of 'white spots' is also part of the analysis.
- The drawing up of a Dutch roadmap for large-scale scientific research facilities with broadly supported strategic frameworks. The roadmap will focus on scientific research facilities. The roadmap will contain existing facilities as well as the need for new facilities that are vitally important for the development of science in the Netherlands.

- During the drawing up of the Dutch roadmap the committee will, among other things, take the following into consideration:
  a the importance of a facility for the development of the science disciplines concerned in the light of the expected developments in these science disciplines;
  b the size and international position of the science disciplines concerned in the Netherlands;
  c the importance of a facility for the answering of societal questions and the economic impact, with a view to increasing the valorisation of knowledge;
  d the policy frameworks and the scientific priorities that have been or will be drawn up in the Netherlands and Europe (Dutch National Science Agenda, ESFRI);
  e the progress in the construction, the added value and the continuity of the facilities on the previous road-map;
  f the possibilities for the use of facilities abroad.

- Advising about and/or formulating conditions for the organisation of a science discipline in terms of collaboration and the formation of networks, which will make optimal use of a future facility by that discipline possible and with that justify an investment.
- Advising about issues that are important for enabling the infrastructure to become a success, such as management, business plans, funding modalities, the possibilities for public-private partnership, and accessibility. For this, the committee will follow internationally available best practices wherever possible.
- Advising about the balance in infrastructure needs of the different science domains: social sciences/ humanities, life sciences/medical, and physical sciences/engineering.
- Exploring possible financers at a regional, national and European level, encouraging the use of different national and European possibilities for funding, and encouraging the use of new ideas to acquire funding.
- Advising about how a Dutch national IT research infrastructure can best be realised considering the National Roadmap.
- Advising about the long-term use of the resources for the Dutch roadmap for large-scale scientific research facilities, so that undesirable loss of capital is prevented and room remains for new developments.
- Advising about the entering into or ending of international commitments by the Netherlands.
- The committee may also choose to independently signal wishes and gaps in facilities in science disciplines and may inform researchers or institutes about these.

The Permanent Committee will submit the roadmap to the NWO Executive Board and will also advise the NWO Executive Board. The Executive Board will not finalise the roadmap until consultation has taken place with the Ministry of Education, Culture and Science and the Ministry of Economic Affairs. Based on the recommendations from these two ministries, the Executive Board will finalise the frameworks for assessing the specific proposals for facilities of the Dutch roadmap for large-scale scientific research facilities.

This assessment will take place in a committee that NWO will appoint separately. The frameworks established by the Executive Board will guide the activities of the evaluation committee. The evaluation committee will advise the Executive Board of NWO about the distribution of the resources for large-scale research facilities.

APPENDIX 3
LRI plans

This appendix outlines the LRI plans of each of the nine Groups. It contains a selection of the highest priority LRI plans (from the Group or in cooperation with LRI from other Groups) that are of strategic and national importance. In the narrative part of this Roadmap (see Chapters 4, 5 and 6), the nine Groups described how the LRI plans contribute to scientific innovation and break-throughs and how they relate to current strategic sector or action plans. The Groups also indicated which of the plans have priority for the next five years. Where relevant, they also described how each of the LRI plans relates to international (ESFRI) initiatives.

This appendix gives a more detailed account of the Groups' top-priority LRI plans for the next ten years, without ranking them. As described in Chapter 1, LRI plans can either be plans for individual LRI or joint plans for multiple LRI from the identified Groups and Cross-Group or Cross-Domain initiatives. The appendix includes both LRI plans that are seeking Roadmap funding in the near or distant future and LRI plans that do not (or no longer) need funding. Each LRI plan gives a brief outline of the plan, the outcomes for users, the partners involved and a brief outline of the possible impact.

ASTRONOMY & PARTICLE PHYSICS

APP

LRI plan: **AstroParticle Physics Facilities – GRAND, GCOS, CTA**
Acronym: **APP**

General description

A next-generation, global, ultra-high-energy, cosmic messenger observatory (GRAND/GCOS) will be required to study and understand the sources and propagation of the highest energy particles in the Universe. It will also offer unique complementary opportunities to find physics beyond the Standard Model in an energy regime that cannot be tested otherwise. The Cherenkov Telescope Array (CTA), presently under construction as a unique global facility for gamma-ray research, will most likely require a substantial upgrade after 5–10 years of operation to remain the leading facility. Actively taking part in the construction and operation of these facilities, including the neutrino telescope KM3NeT already funded in the roadmap, gives the expertise needed to position the Dutch astroparticle physics (APP) research community prominently in the international cosmic multi-messenger research community.

Impact

The Dutch research community is leading in the preparation of the next-generation, global, ultra-high-energy, cosmic particle observatory (GRAND/GCOS). The investment is required to maintain leadership in the execution of that research programme. The CTA investment will be required for specific enhancements of its capability, inspired by its first years of operation. The results will considerably deepen our understanding of the high-energy Universe. Traditionally, cosmic ray physics has a large impact on outreach and education, for example with the HiSPARC project and modules for secondary school education.

RADIO

LRI plan: **NL Radio astronomy facilities and international participation – EVN/JIVE, LOFAR2.0, SKA**
Acronym: **RADIO**

General description

Radio telescopes play a decisive role in tracing the formation of galaxies in the early Universe, help understand the physics of explosions that produce gravitational waves and identify the nature of fast radio bursts, to name just a few. ASTRON operates LOFAR (Low Frequency Array) on behalf of an international partnership and also participates via the Westerbork facility in the European VLBI Network (EVN). The Joint Institute for VLBI ERIC (hosted at ASTRON) is the central user support facility of the EVN and runs innovation programmes to advance the very-long-baseline interferometry (VLBI) technique. ASTRON's Science Data Centre will support the Square Kilometre Array (SKA), of which the Netherlands is a founding member, and that will start science operations in this decade. A significant upgrade to the LOFAR/Westerbork facility is foreseen after 2025 comprising the deployment of SKA dishes to deliver VLBI observations with unparalleled spatial resolution and sensitivity and this will increase LOFAR's processing power to produce ultra-deep maps at very low radio frequencies.

Impact

This LRI plan for the national facility is central to the Netherlands' continuing participation and leadership in radio astronomy in the areas named above. Dutch companies will contribute to this LRI and SKA construction in a manner similar to what they do for LOFAR – producing high-performance, complex signal processing systems, photonic technology, and high-performance calibration and imaging software. Dutch astronomers have played an active role in defining the scientific priorities of these instruments and will be ready for the scientific exploitation phase. They will train people to the highest level, which will increase the talent pool in signal and data processing in astronomy and in society at large.

DDN

LRI plan: **Neutrino physics and detection of dark matter – DARWIN/DUNE**
Acronym: **DDN**

General description

DARWIN and DUNE comprise the next generation of highly sensitive detectors for the search for dark matter and the study of neutrino properties. DARWIN will extend the sensitivity of current dark matter searches by more than an order of magnitude, and will search for axion-like particles, neutrinoless double beta decay, and rare neutrino interactions. DUNE will measure neutrino oscillations using the world's most powerful neutrino beam in order to make a first detection of charge-parity violation in neutrinos and determine the neutrino mass hierarchy. DARWIN and DUNE share much of the detection technology and complement each other in neutrino physics. The LRI will allow Dutch scientists to make leading contributions to the design and construction of the detectors, data acquisition and software, and get access to the data.

Impact

The discovery of a dark matter particle will transform our understanding of the building blocks of matter and provide access to physics beyond the Standard Model of elementary particle physics. Similarly, the discovery of charge-parity violation in neutrino interactions changes our understanding of the asymmetry between matter and antimatter in our Universe. Significant contributions to DARWIN and DUNE secure the leading positions of Dutch scientists in this high-profile research.

ELT

LRI plan: **Extremely Large Telescope instrumentation**
Acronym: **ELT**

General description

With its light-collecting power and super sharp imaging, the European Southern Observatory's (ESO) Extremely Large Telescope (ELT) will revolutionise our understanding of the Universe, from unravelling the formation and evolution of stars and galaxies to the characterisation of exoplanets, key topics of Dutch astronomy. Optical and infrared instrumentation of unprecedented sophistication is being developed in Europe with significant involvement of Dutch scientists, knowledge centres and industry. One of the first three scientific instruments is METIS, an innovative imager and spectrometer working at mid-infrared wavelengths for which the Netherlands (NOVA) is the Principal Investigator. Future-generation instruments of high interest to the Dutch community include a multi-object optical/near-IR spectrometer, MOSAIC and a high-contrast imaging instrument, EPICS. Through involvement in ELT instrumentation, the Dutch astronomy community will gain preferred access to the telescope ensuring leadership roles in the scientific exploitation of the largest optical-near infrared telescope on Earth.

Impact

The ELT and its instrument suite will enable scientific breakthroughs in virtually all areas of astronomy, from planets around nearby stars (including planets where life may exist) to the most distant faint galaxies at the edge of the observable Universe. The necessary technological developments are done in close collaboration with partners in different universities, technology institutes and industry, ensuring knowledge transfer. The challenging technical demands are important drivers for innovations with prime examples in medical imaging and precision engineering. The expected groundbreaking discoveries will serve as inspiration to the general public and attract many young people to the exact sciences.

GW-ET

LRI plan: **Gravitational waves – Einstein Telescope**
Acronym: **GW-ET**

General description

The Einstein Telescope (ET) will be a new observatory, designed to observe gravitational waves from the entire Universe. The ET will put Europe at the forefront of gravitational waves research, being the first and most advanced gravitational-wave observatory of a new class. It aims to provide observational capacity of cataclysmic events like mergers of black holes, neutron stars or supernova explosions for most of the 21st century. Thanks to the unprecedented sensitivity of ET it will be a unique tool to probe the fabric of space-time itself, which will advance our knowledge of the least understood fundamental force in nature: gravitation. It will enable breakthroughs as well as discoveries in fundamental physics, astrophysics and cosmology. ET will facilitate multi-messenger astronomy by combining gravitational-wave observations with measurements of radio, optical, IR, UV, neutrino and cosmic ray observatories.

Impact

In the last few years, the discoveries by LIGO and Virgo of gravitational waves from merging black holes and neutron stars have literally opened up a new revolutionary window to explore the Universe: gravitational-wave astronomy. The required sensitivity levels for ET are mindboggling, and hence technological innovation is a crucial aspect of ET. The chance to host ET (partially) in the Netherlands is unique. It allows the Netherlands for the first time to realise a global big-science research infrastructure attracting the world's top researchers for many decades to come.

GW-LISA

LRI plan: **Gravitational Waves – Laser Interferometer Space Antenna**
Acronym: **GW-LISA**

General description

The Laser Interferometer Space Antenna (LISA) has been selected as ESA's L3 flagship mission, currently scheduled for launch in 2037. LISA consists of a constellation of three satellites, connected by lasers in a heliocentric orbit, and will significantly increase the range of Gravitational-Wave (GW) detection. It will allow detection of a rich variety of new sources such as supermassive black hole mergers, stellar mass binaries, and extreme mass-ratio in-spirals. LISA will probe how supermassive black holes form, address fundamental questions such as the formation of elements in the Universe, allow detailed tests of General Relativity in nearby systems, and search for signatures of inflation in the very early Universe. SRON, together with Nikhef, TNO and the Dutch scientific community are developing crucial detectors and optical instrumentation to enable the mission. These developments will guarantee preferred access to LISA data for the entire NL community.

Impact

Gravitational-Wave research is a national priority for both the Dutch physics and astronomy communities. When combined with ground-based instruments such as the Einstein Telescope, participation in the LISA mission will strengthen the leading role of the Dutch science community in this highly competitive field. The technology development required to enable the LISA mission brings together unique expertise from SRON, Nikhef, and industrial partners such as TNO. These developments will provide Dutch scientists with an excellent understanding of the data when it arrives as well as the opportunity to take leadership roles in key LISA science.

HL-LHC

LRI plan: **High-Luminosity Large Hadron Collider instrument improvements – LHCb, ALICE, ATLAS**
Acronym: **HL-LHC**

General description

The Large Hadron Collider (LHC) at CERN in Geneva is the most important instrument to examine the Universe at length scales far below the atomic size. In the middle of this decade, it will be upgraded to have far more luminous beams. The Netherlands participates in the ATLAS, LHCb and ALICE experiments, and in each of these it plays a leading role through the collaboration and coordination that Nikhef provides. The LRI plan provides for the Dutch part of the necessary upgrades of the experiments. For ATLAS, these upgrades enable the highly precise scrutiny of the Higgs boson and the exploration of the TeV scale in search of new particles and inter- actions. For the LHCb detector they give much higher sensitivity to the asymmetry of matter and antimatter. Finally, they vastly improve the tracking capability of the ALICE experiment and thereby characterise the drops of quark-gluon plasma that form in the detector.

Impact

These upgrades are crucial to fully exploring the physics questions that the HL-LHC opens the door to. The Netherlands is a CERN member state and through its focused participation, has always had an outsized impact and influence in these CERN experiments, through the high quality of its hardware contributions, of the participating scientists, and its high reputation for reliability. The technological benefits of the upgrade of the LHC, its experiments and its computing infrastructure are substantial, and travel back to the Netherlands through contracts and through internships for university, HBO and MBO students.

MATERIALS

DXCP

LRI plan: **Dutch X-ray Characterisation Platform**
Acronym: **DXCP**

General Description

The Dutch X-ray Characterisation Platform is the next step towards a national X-ray characterisation platform that is fully integrated with a series of different LRI across the country. Following a pilot study in NC2SM, DXCP will build the next generation of X-ray instruments based on new laboratory X-ray sources developed in HFML-FELIX and XNL. X-ray instrumentation will be integrated into, for example, RID and HFML-FELIX to link orthogonal techniques such as neutrons and intense infrared and THz radiation. There will be a special emphasis on time-resolved experiments. In addition, at NanoLabNL, surface-sensitive X-ray instruments will be developed for in situ characterisation of model systems and thin films during fabrication, growth and processing. Using mobile sample environments and vacuum transport holders, reliable sample characterisation will be possible at multiple instruments and LRI. A national user community will be established for X-rays, synchrotron and free-electron lasers (FEL). The focus on machine learning and artificial intelligence will continue, ultimately leading to rational materials design.

Impact

The Dutch X-ray Characterisation Platform will yield a stronger Dutch portfolio for materials characterisation. By integrating DXCP into relevant LRI, the Dutch materials science community will have access to the full spectrum of state-of-the-art fabrication and complementary materials characterisation by neutron, photon and high-magnetic-field techniques, ensuring that the Netherlands remains competitive and world-leading in this field. This combined and integrated approach, like time-resolved laboratory characterisation, will be unique worldwide and will undoubtedly lead to new technical approaches and knowledge relating to new materials.

ESS

LRI plan: **European Spallation Source**
Acronym: **ESS**

General Description

The European Spallation Source ERIC (ESS) is an international research infrastructure with the goal to build and operate the world's most powerful neutron source, enabling scientific breakthroughs in research related to materials, energy, health and the environment, and addressing some of the most important societal challenges of our time. The ESS will deliver a neutron peak brightness at least thirty times greater than the current state of the art, thus providing the much-desired transformative capabilities for interdisciplinary research in the physical and life sciences.

Thanks to its unique flux and pulse flexibility, the ESS will bring about a revolution in science, as was previously the case with fourth-generation synchrotrons. The long pulse, coupled with optimised moderators, will create peak- and time-averaged neutron fluxes much higher than the neutron fluxes at other spallation and reactor sources, especially in the cold neutron region (wavelengths longer than 0.3 nm). This will benefit a wide range of topics related to energy and health, including soft matter, dynamic biochemical research, protein crystallography and new hydrogen storage materials. The ESS will offer new opportunities for real-time kinetic experiments or pump-probe single-shot experiments in, for example, biological systems.

Impact

The well-being and development of our society depend on addressing major challenges in the areas of energy, environment, global warming, healthcare and information technology. Progress in every area depends on the development of new materials and processes. This requires an understanding of structure and dynamics at the nano, atomic, molecular and macro scales. Neutrons are one of the most powerful and precise tools for studying these properties.

Due to dwindling fossil fuel reserves, there is an urgent need for renewable energy sources, more efficient engines, materials with less heat loss and energy wastage, and greener processes for industry. Neutrons are an important analytical tool that will provide more knowledge and help us to develop promising new materials for solar and fuel cells, batteries, thermoelectric materials for waste heat recovery and cooling, and reversible hydrogen storage materials to safely use hydrogen as an energy carrier. For example, the use of neutron scattering facilities has been identified by the BATTERY 2030+ initiative as essential for progress.

HFML-FELIX

LRI plan: **High-Field Magnet Laboratory – Free Electron Laser for Infrared eXperiments**
Acronym: **HFML-FELIX**

General Description

The High Field Magnet Laboratory (HFML) and the Free Electron Lasers for Infrared eXperiments (FELIX) laboratory together form a large-scale research infrastructure unequalled anywhere in the world. It allows us to push the boundaries of modern technology for molecules and materials with respect to both the field strength of static magnets (up to 45 T) and radiation intensity in the infrared and terahertz (THz) ranges of the electromagnetic spectrum. HFML-FELIX is the world's only facility to link static high-magnetic fields to infrared/THz free-electron lasers.

Research can be done into a broad spectrum of physical, chemical and biological phenomena. Researchers from the Netherlands, from across Europe and beyond, come to Nijmegen to study, control and manipulate materials in virtually every state – solid, liquid and gaseous – with a strong emphasis on materials for the energy and healthcare sectors.

Over the next ten years, the HFML-FELIX development programme will comprise new instrumentation for advanced imaging, ultra-fast dynamics and extreme sampling environments, optimisation of IT infrastructure and magnet/laser operation, and an upgrade of the magnet capacity and cooling system, allowing the building of magnets optimised for FEL light scattering experiments and for coupling with laboratory X-ray sources.

Impact

Materials can be examined under extreme conditions with unprecedented precision and, by exposing them to previously unknown conditions, new functions may emerge. HFML-FELIX makes a vital contribution to the Dutch research portfolio, facilitates an important partnership with industry, educates large numbers of students and responds to societal challenges in the fields of health, energy and smart materials.

HFML-FELIX contributes to the research activities of most Dutch universities and research institutes and attracts hundreds of top researchers from around the world to the Netherlands every year. It has strong links with powerful European networks, such as the European Magnetic Field Laboratory (EMFL), FELs of Europe, LaserlabEurope and the League of European Accelerator-based Photon Sources (LEAPS).

NanoLabNL

LRI plan: **NanoLabNL – the national open-access infrastructure for nano research and innovation**
Acronym: **NanoLabNL**

General Description

NanoLabNL, the Dutch facility for nanotechnology, is one of the leading consortia of its kind in Europe. The open infrastructure for nanoscale R&D is used by more than 1300 researchers and over 90 businesses. NanoLabNL is coordinated as a single infrastructure, but its facilities are spread over five cities: Groningen, Enschede, Amsterdam, Delft and Eindhoven. Each cleanroom at NanoLabNL is a hub where nanoscientists such as quantum engineers, smart materials designers and medical scientists from academia and industry come together to fabricate, characterise and experiment with nanodevices for the purposes of fundamental research and product development. Over the next ten years, NanoLabNL will invest in new instrumentation and advanced tools for the fabrication of new nanomaterials and nanodevices to address fundamental research questions related to the challenges facing our society and the associated transitions.

Impact

Science and technology harnessing the power of the small – including quantum technology, photonics and advanced materials science – are at the heart of some of the enormous transitions the world faces: transitions to clean energy, a safer world, more effective and affordable healthcare, and sustainable agriculture to feed a growing population. Many scientists and engineers working on key technologies conduct research and development at the nanoscale to address these transitions. They do this because they need the "special effects" that can only occur at such a tiny scale, for example because they want to manipulate a material at its most fundamental level, or simply make miniature versions of devices and parts. Nanotechnology is therefore a primary driver of scientific and technological progress.

NanoLabNL is a gateway to this, both nationally and internationally. In 2017, NanoLabNL collaborated with French, Swedish and Norwegian sister organisations to establish EuroNanoLab. This European network currently offers an online one-stop-shop and open access to nanotechnology research facilities in 44 cleanrooms in 15 countries. NanoLabNL plays a central role in many ecosystems within the Netherlands, such as quantum technology, photonics and materials science in general.

NC2SM

LRI plan: **National Characterisation Centre for Sustainable Materials (NC2SM) – X-ray Characterisation Center**
Acronym: **NC2SM**

General Description

The National Characterisation Centre for Sustainable Materials is to become a leading national facility for advanced X-ray characterisation of the materials that will feature in the technological solutions to broad-ranging problems in the area of sustainability (energy, circular economy, health, etc.). The absence of a synchrotron or beamline in the Netherlands limits its competitiveness in the field of materials characterisation as a whole. The core of the Centre consists of a virtual institute based at three universities, namely the University of Groningen, Utrecht University and Eindhoven University of Technology. Investments are proposed in X-ray absorption/emission/photo-electron spectroscopy, X-ray scattering and X-ray imaging allowing the measurement of detailed structural and electronic properties, at various length and time scales, during the synthesis and functioning of a wide range of materials (e.g. inorganic and biological materials, polymers). This will include pilot research into new X-ray sources in laboratories (at XNL and HFML-FELIX) and combined orthogonal technique approaches (with RID and HFML-FELIX), as well as mobile sample environments and vacuum transport holders (with NanoLabNL).

Impact

The NC2SM centre will provide leading research services in the field of X-ray characterisation of sustainable materials in laboratories, including operando experiments. Increased knowledge about the operando structure and electronic performance relationships will lead to the rational design of materials and processes for energy and sustainability (e.g. catalysis, energy research, but also more broadly in other fields such as biomaterials, art restoration, etc.). The development of laboratory (operando) X-ray techniques will yield state-of-the-art instruments and experiments, turning NC2SM into an international leader and driving force in the laboratory X-ray field. The X-ray facility will ensure the international competitiveness of Dutch materials science as a whole and strengthen the competitive ability of Dutch researchers to gain access to synchrotron and FEL beamlines around the world.

RID

LRI plan: **Reactor Institute Delft**
Acronym: **RID**

General Description

The RID (Reactor Institute Delft) operates a 2.3 MW research reactor producing neutrons used in beamforming instruments for materials research. The high-energy gamma-ray field close to the core is also used to produce positrons that are extracted to specialised positron research instruments. A selection of these instruments will use a cold source (the OYSTER project), a device to alter the characteristics of the neutron beam for higher sensitivity and resolution (in use from October 2022). Therefore the remarkable sensitivity of neutrons and positrons to certain elements (neutrons: hydrogen, lithium, boron, etc.) can be even better utilised, with the main applications being catalysis, hydrogen storage, research into lithium-ion batteries, self-repairing materials and steel research. The RID is a facility with low-threshold access, available to Dutch materials scientists. Its scientific and technical staff provide access, data acquisition, analysis and interpretation, as well as software tools and laboratory space.

Impact

The development of new materials and processes plays an important role in making progress on all of the major societal challenges. This requires more knowledge about structure and dynamics at the nano, atomic, molecular and macro scale. Studying the way in which these new materials scatter neutrons is one of the most powerful and precise tools we have for exploring these properties.

From a national perspective, the infrastructure is important because the Netherlands has no facilities of this type and is not yet a member of a facility in another country.

Encouraged by the OYSTER project, RID is growing in its role as a national portal institute for Dutch scientists, especially for ESS. RID offers space to prepare measurements and approaches and is ready to accompany Dutch researchers to ESS, to help optimise measurements and experiments there (at Lund in Sweden: the world's most brilliant neutron source).

TECHNOLOGY

SolarLab NL

LRI plan: **SolarLab NL**

General description
SolarLab NL focuses on the challenge of developing efficient electricity generation from sunlight (photovoltaics, PV).

Solar cells are semiconductor devices that convert solar energy directly into electricity. Module efficiency is currently around 20%. New advanced cell designs allow efficiencies of 30 to 40%. A global race is on to push the conversion efficiency of solar cell technology to these super-high levels. To achieve this, every component of the energy conversion process needs to be perfected, including light absorption, extraction of electrical charge carriers with semiconductor materials, interfaces and contact layers. All of these components must eventually be combined in a solar cell, with the engineering of the solar cell architecture determining its performance.

Disciplines involved in researching and designing high-efficiency solar cells are optics, materials science, semiconductor devices, nano/microfabrication and multiscale modelling. In all of this research, along the entire chain from material to application in a working PV system, state-of-the-art research infrastructure is essential.

The SolarLab NL cluster in the Netherlands consists of the PV research infrastructure and scientific groups at TU Delft, Eindhoven University of Technology, University of Twente, University of Groningen, Radboud University, Utrecht University, NWO Institute AMOLF and TNO Energy Transition, and works with Imec, Forschungszentrum Jülich and Hasselt University. Together, these partners form a strong PV research cluster that plays a leading role in Europe in researching and developing the PV technology of the future.

The planned large-scale research infrastructure will be a central shared facility for spectroscopy, microscopy, fabrication and testing of new PV materials, and application of new PV designs in PV systems. Satellite facilities at the various knowledge institutions will focus on individual aspects according to their own specialisation: new PV concepts based on novel materials, including development of scalable fabrication methods, and new applications of PV technology in systems, built environment and landscape.

Impact
PV will be one of the primary suppliers of renewable energy (electricity) in the future. Reaching the multi-terawatt (TW) level is necessary to meet the ambitious CO_2 reduction targets set out in the Paris Agreement and the European Green Deal, as well as the related national targets in the National Climate Agreement of the Netherlands.

Energy Conversion

LRI plan: **Energy Conversion**

General description
The LRI Energy Conversion focuses on the challenge of developing fossil-free chemical building blocks by designing efficient conversion technologies from electricity to fossil-free chemicals and fuels or energy carriers.

For sustainable production of fossil-free chemical raw materials and fuels, new chemical conversion technologies will need to be added to the traditional thermochemical conversion routes. The fluctuating supply of renewable energy from sun and wind also plays an essential role. The efficiency of conversion processes (from electricity to chemical energy carrier and possibly back) needs to be greatly increased. To do this, we need to understand and be able to influence (electro)chemical processes and multiphase/multimaterial flows from the atomic up to meso and macro scale. This also requires the development of catalysts that can be manufactured at lower cost from non-scarce materials.

Entirely new concepts such as spin-controlled or light-controlled chemistry also offer new opportunities.

An additional challenge is the need to integrate these processes at the terawatt scale. This requires a system integration of all processes, from atomic scale to the scale of a working system. This technological challenge poses new questions for fundamental energy conversion research.

We seek to develop a national research infrastructure that provides an environment where groundbreaking concepts and solutions can be designed, fabricated, and tested at the system scale. It will explore the fundamental limits and possibilities of new chemical conversion systems driven by renewable energy, in combination with chemical pre- and post-processing and the accompanying control systems (e.g. for power and flow). The centralised, plug-and-play research facility will be supplemented by several "satellites" providing components for the entire system. The partners will include TU Delft, Eindhoven University of Technology, University of Groningen, University of Twente, NWO Institute DIFFER and TNO.

Impact

Increasing conversion efficiency and integrating system-level research with research into functional (electro) catalytic materials, components and material flows will lead to new energy systems. Not only will these perform optimally on their own, but they can also be incorporated into larger integrated processes. They will be suitable for scaling up and operation under intermittent conditions. By focusing on the energy source and conversion, they provide an excellent basis for supporting the energy transition in many sectors of society, such as construction, mobility and manufacturing.

GEOSCIENCES

ATMOS-NL

LRI plan: **Dutch skies: the integration of Ruisdael Observatory, NSAO and C-MetNet**
Acronym: **ATMOS-NL**

General description

Gas and aerosol emissions are changing many atmospheric processes. How these changes will manifest themselves on a regional scale is a major scientific question. Landscape variations, urbanisation and proximity to large wetland areas lead to marked local differences in interactions between land and atmosphere, resulting in huge uncertainties in climate models. The integration of Ruisdael Observatory, NSAO and C-MetNet will create a finely meshed system for monitoring and model simulations over land, the Randstad conurbation and the North Sea. This will enable us to:

- **Accurately characterise emission sources and sinks;**
- **Improve modelling of small-scale atmospheric processes, thus improving the accuracy of regional climate projections and of weather and air quality forecasts.**

The universities of Delft, Wageningen, Utrecht, Amsterdam and Groningen support ATMOS-NL, as do KNMI, TNO and RIVM. ATMOS-RI-NL consists of a monitoring network in the Netherlands and in the North Sea. The monitoring data, model output and software tools are freely available.

Impact

Local and regional atmospheric processes play a major role in climate change but are also a prime source of uncertainty in climate models. ATMOS-NL greatly reduces this uncertainty by enabling accurate projections of the future regional climate. Better forecasts, for example of extreme rainfall or air quality, lead to a safe and healthy society. Accurate predictions of sun and wind will be used to optimise renewable energy production. The Dutch atmospheric research community is a global leader. It is especially well equipped to convert the ATMOS-NL data into new knowledge and products. This strengthens its position even further: ATMOS-NL will be able to take a central position in the European Destination Earth programme.

Ocean Observation Utilities NL

LRI plan: **Innovation for future-proof ocean research**
Acronym: **OOU-NL (Ocean Observation Utilities NL)**

General description

The ocean's influence on our society – through sea levels, biodiversity (green life sciences) and climate – is becoming increasingly clear. At the same time, the pressure on our oceans is rising disproportionately. We need to study ocean processes in a new, innovative and autonomous way. This will allow us to observe linked ocean-atmosphere changes as they happen, even in hard-to-reach places such as the deep sea.

For this, we need innovative sensors for physical, chemical and biological parameters. This LRI plan seeks funding to purchase and develop instrumentation that can expand the parameters to be monitored and the monitoring resolution (in time and space), including real-time access to ocean data. Multidisciplinary monitoring (e.g. combining mobile and anchored platforms and vessels) is central to this. Together with the new research vessel, this equipment and data will be available to the Dutch oceanographic community (universities, institutes, NGOs and industry), enabling the Netherlands to maintain its leading role in international science.

Impact

A clear understanding of ocean processes is necessary for accurate predictions of climate change and for the sustainable use of the oceans and related resources. The current instrumentation is outdated and unsuitable for observations and sampling of processes at the relevant spatial and time scales. With an expanded and modernised set of instruments, the Dutch oceanographic and green life sciences in the domain of biodiversity, ecology and living environment will be able to carry out state-of-the-art research. This will also address the objectives of the Dutch Research Agenda Blue route: water as a pathway to innovation and sustainable growth and help to keep us at the forefront of international science.

DANUBIUS-NL

LRI plan: **Supersite for sustainable deltas: infrastructure for observation, experiments and modelling of rivercoast systems**

Acronym: **DANUBIUS-NL**

General description

Deltas are created by complex process interactions between water, sediment and biota, driven by rivers, waves and tides. At the same time, they are a "filter" for flows of nutrients (C, N, P) from the continental land mass to the sea. Climate change and human intervention will have a major impact on deltas in the course of the next century. However, the long-term response of deltas and their ecosystems cannot yet be accurately predicted. This is due to a lack of knowledge about bio-morphological processes, critical thresholds and tipping points in system behaviour, and the natural resilience of deltas. Observations and process knowledge at the delta scale are needed. DANUBIUS-NL infrastructure supplies these to users via:

a   A delta-wide monitoring network (river branches, Rhine-Meuse estuary, sand coast) to determine long-term system changes;

b   Instruments for targeted surveys during extreme events (peak discharge, storm surge);

c   Indoor and outdoor experimental flow, wave and tidal facilities for process research into water-sediment-biota interactions;

d   Resulting datasets feeding numerical models.

The partners involved are eleven Dutch universities and knowledge institutions, organised within the Dutch Centres for River and Coastal Research.

Impact

DANUBIUS-NL opens up the Dutch delta as a globally unique supersite for delta research, embedded in ESFRI DANUBIUS. The infrastructure allows fundamental scientific breakthroughs in understanding the system behaviour of deltas, their ecosystems and biodiversity, and their role in the continent-to-ocean transfer of sediment, carbon and nutrients. This knowledge is the basis for sustainable delta management for safety, shipping, raw materials use, biodiversity, food supply and the innovative solutions required in these respects. The infrastructure will further strengthen the international prominence and impact of Dutch delta research and bolster the competitive position of the Dutch water management and consultancy sector in delta regions worldwide.

eNLarge

LRI plan: **The deep subsurface – bridging scales and boundaries**
Acronym: **eNLarge**

General description

Future investment in deep subsurface research will focus on two aspects.

1. We urgently need to better understand the large-scale effects of human exploitation of the subsurface and its natural processes. This requires new facilities to help translate small-scale laboratory experiments to the scale of, for example, natural earth resources or areas prone to earthquakes. Specifically, it calls for:

   a. Expansion of the Delft Urban Energy Lab, with subsurface facilities to directly monitor the effects of geothermal heat production and storage.

   b. A test borehole at the TNO Rijswijk centre for sustainable geo-energy, crucial for bridging the gap between laboratory and field scale.

   c. Expansion of the KNMI geomonitoring network in the Caribbean Netherlands, a risk area for earthquakes, landslides and volcanic eruptions.

   d. Laboratory equipment for TU Delft and Utrecht University to image the determining physical processes of the subsurface as they happen.

2. A leading role in the sustainable delivery of the European infrastructure for the solid earth sciences (the European Plate Observing System, EPOS). This means ensuring the availability of unique research facilities and data for future research.

Impact

Safe use of the deep subsurface plays an important role in tackling climate and energy issues. The proposed investments will allow scientists to examine both the effects of such subsurface exploitation and the natural risks of the Earth, both on the relevant spatial scales.

This will enable them to identify and calculate the processes that determine risks, for the purposes of risk analysis and knowledge sharing with government and society. A sound international data and facility infrastructure is essential for this. Dutch knowledge institutions already coordinate part of the European EPOS infrastructure. Continuing investment will guarantee a functional infrastructure for sustainable use and reuse of existing facilities and data, in the spirit of open science.

GREEN LIFE SCIENCES

NIEBA-ARISE

LRI plan: **Netherlands Infrastructure for Ecosystem and Biodiversity Analysis:**
Authoritative and Rapid Identification System for Essential biodiversity information
Acronym: **NIEBA-ARISE**

General Description

NIEBA-ARISE is a globally unique infrastructure employed to identify and detect all of the multicellular species (including flora, fauna and fungi) in the Netherlands. For a complete picture of Dutch biodiversity, the infrastructure combines DNA barcoding, image and sound recognition and analysis of radar data. The partners in ARISE are Naturalis Biodiversity Center (the national institute for biodiversity information and research), the University of Amsterdam, the Westerdijk Institute (a centre of expertise for mycology that focuses on major societal issues in agriculture, health and industry (WI-KNAW)) and the University of Twente. ARISE is also directly linked to the ESFRIs DiSSCo, LifeWatch and MIRRI. This integrated infrastructure provides Dutch researchers, conservation organisations, governments and industry with access to a state-of-the-art, near-real-time identification service for biodiversity monitoring and species tracking. This creates new opportunities for understanding the functioning of ecosystems, discovering trends and integrating biodiversity more effectively into major societal challenges such as the circular economy, nature-inclusive cities and circular agriculture. The Netherlands is at the forefront of international collaboration in the field of species knowledge and biodiversity, and ARISE will strengthen this position in science.

Impact

Biodiversity is the foundation of humanity's future on earth. A better understanding of ecosystem complexity will provide important scientific insights and the knowledge needed to tackle the major challenges of our time, such as climate change, the spread of diseases and vectors, food supply, invasive species, and creating a healthy living environment. Dutch biodiversity research is world-class but still lacks the technology for a complete understanding of ecological networks and functions. ARISE combines modern techniques (DNA barcoding and metabarcoding, artificial intelligence, sound and image sensors, radar and data science) that will make this possible and is in line with EU ambitions (EOSC, ESFRI, Green Deal).

LTER-LIFE

LRI plan: **The fundamentals of biodiversity: synergies between long-term biodiversity data (eLTER-NL),**
environmental data (NEMNET), FAIR data storage and open analysis methods (LifeWatch).
Acronym: **LTER-LIFE**

General Description

Preserving biodiversity and crucial ecosystem services requires fundamental knowledge of how ecosystems function in response to the rapid changes that are so characteristic of our times, such as knowledge based on the analysis of plant and animal population data and of the changes in the natural environment. This requires integration of long-term plant and animal data collected by eLTER-NL, with a focus on eLTER sites (currently the Wadden Sea, Veluwe and Delta), and data from the RIVM monitoring networks (NEMNET) for soil, water and air, plus further network development. With this integration, LTER-LIFE will create a unique research infrastructure with catalogues of methods, FAIR data sources, modern linking methods for (often heterogeneous) data, and scalable computing and storage platforms. This will enable teams of researchers and stakeholders to build virtual research environments flexibly and quickly, based on an open LifeWatch architecture. As a result, LTER-LIFE will offer entirely new opportunities for research into the fundamentals of biodiversity and the resilience of natural and semi-natural systems.

Impact

There is no doubt that creating "A Safe Operating Space for Humanity", in which biodiversity plays a decisive role, is one of the greatest challenges of our time. Sustainable use of our living planet requires effective mitigation measures to preserve biodiversity and ecosystem services. Long-term systematic population data and environmental data are needed to identify or predict changes in trends, and to assess whether measures are having the intended effect ("bending the curve") and are cost-effective. With LTER-LIFE, long-term and current data will be integrated with external sources (e.g. ARISE, remote sensing) to give effective workflows answering crucial questions about how to preserve and strengthen biodiversity. This approach enhances the Netherlands' position in Europe, such as the cooperation between LifeWatch ERIC and eLTER (ESFRI roadmap), and links the latter to data generated in European cluster projects (ENVRI-FAIR, EOSC-FUTURE) and to the future European framework for biodiversity monitoring (EuropaBon).

XL-EFES

LRI plan: **Large-scale Experimental Facilities for Ecosystem Simulations**
Acronym: **XL-EFES**

General Description

Experimental ecosystems are a powerful tool for studying the effects of biodiversity and climate change at ecosystem level under controlled conditions. The impact of stressors such as nutrients, foreign substances, plastics and nanoparticles, light emission and invasive exotic species can also be determined under realistic conditions.

The Netherlands currently has on-campus experimental systems for land and water research (e.g. limnotrons, flumes, test ponds, test ditches, soil ecotrons and mesocosms) as well as on-site experimental field locations in a number of ecosystems (CLUE fields, NutNet site, exclosures).

XL-EFES takes an essential next step. By coordinating the setting up of large-scale experimental outdoor facilities (on campus and on site), we will be able to answer complex questions concerning ecology, environment and climate under controlled conditions. To this end, existing experimental facilities will be linked and new facilities created in all relevant ecosystems for the Netherlands: ranging from natural to urban systems and to energy landscapes. In addition, a direct link will be created with artificial intelligence and machine learning. This will allow actual simulation of complex ecosystems by means of digital twinning. The partners are the Netherlands Institute of Ecology (NIOO-KNAW, lead), Royal Netherlands Institute for Sea Research (NIOZ), Naturalis, Westerdijk Institute (WI-KNAW), University of Twente and a number of universities with an ecology department (Wageningen University & Research, Leiden University, Utrecht University, University of Groningen, Radboud University, University of Amsterdam and VU Amsterdam).

Impact

Ecosystems are characterised by complex interactions between organisms and with their living environment. They provide services such as oxygen production, carbon storage and sustainable water and food supplies. Human activity has an enormous impact on the composition and functioning of ecosystems. Many of the consequences are the result of non-linear processes, which cannot be accurately predicted using small-scale laboratory experiments. Conversely, many field situations are too complex to discern cause-and-effect relationships. The use of large-scale experimental ecosystem facilities in combination with artificial intelligence and machine learning for digital twinning will allow us to conduct simulations using data on complex ecosystems. This will enable us to predict the consequences of biodiversity and climate change more accurately and focus on preserving key ecosystem services.

With XL-EFES, the Netherlands is taking a big step towards integrating experimental ecosystems and AI, in a way that fits in well with new European developments (including AQUACOSM-plus, ANAEE.EU and ECOTRON-Hasselt).

UNLOCK

LRI plan: **UNLOCKing Microbial Diversity for Society**
Acronym: **UNLOCK**

General Description

Microorganisms are team players by nature, and microbial communities are essential for a multitude of natural and biotechnological processes and applications. Together with Wageningen University & Research and TU Delft, NWO is investing in UNLOCK, a research facility offering full integration of all necessary expertise in four complementary platforms. The Biodiscovery platform serves to discover and characterise novel microorganisms. In addition, biomolecular analyses can characterise biological samples in a fully automated procedure. The Modular Bioreactor platform facilitates research into sustainable solutions to environmental issues, such as the breakdown of (micro) pollutants, renewable energy generation and recovery of raw materials from complex waste streams. The Parallel Bioreactor platform enables users to perform dozens of experiments simultaneously under varying conditions in reactors. The FAIR data platform stores, processes and interprets the large volume of data from the experimental systems in a cloud-based infrastructure designed according to FAIR principles.

Impact

Microbial communities are essential for a wide range of natural and biotechnological processes and applications. UNLOCK provides the necessary infrastructure to analyse and resolve major societal challenges in the coming decades, in the areas of food production, health, environmental protection, climate change and sustainable biotechnological production of chemicals. UNLOCK offers solutions for the far-reaching integration of the various subfields of the research, a development that researchers studying microbial mixed cultures have been awaiting with great anticipation. UNLOCK is open to users from universities, research institutes and industry in the Netherlands and abroad, and enables research and development at an unprecedented pace and with new resolution.

NPEC

LRI plan: **Netherlands Plant Eco-Phenotyping Centre**
Acronym: **NPEC**

General Description

NPEC is an integrated national research facility hosted jointly by Wageningen University & Research and Utrecht University, with financial support from NWO. NPEC facilitates large-scale, high-resolution analysis of plant responses, thus advancing the understanding of plant performance in a changing biotic and abiotic environment. The influence of interaction with neighbouring plants, microbes and other organisms as well as factors such as the quality of the light, soil and atmosphere can be accurately mapped within NPEC in six different modules (Ecotrons, Plant-Microbe Interaction, MultiEnvironment, High-Throughput Controlled Environment, Greenhouse, Open Field) at different organisation levels. This gives a realistic picture of the effect of biotic and abiotic interactions on the plant phenotype. NPEC provides its users with experimental scale-up, higher resolution and new forms of data, and also guarantees well-structured metadata stored according to FAIR principles in a cloud environment including data visualisation and analysis tools.

Impact

Plants are essential to our future; a future in which more and more of our food, animal feed and various other products will be made from plants. NPEC allows the development of new, robust crops and optimal cropping systems needed for future food production and food security. NPEC offers a unique integrated facility that strengthens both the leading Dutch knowledge institutions and industry in the field of plant genetics, plant-microbe interactions and ecology. NPEC will attract talent from other fields and from beyond the Netherlands. Automated phenotyping can contribute greatly to better methods for efficient crop breeding and sustainable crop production.

BIOTECH-NL

LRI plan: **An integrated proposal for the system-oriented use of synthetic biology to develop tailor-made biocatalysts in Industrial Biotechnology (BIOTECH-NL), led by IBISBA-NL with linkages to SMART-FABRIC, UNLOCK and WI-KNAW.**

Acronym: **BIOTECH-NL.**
Brings together the IBISBA-NL and SMART-FABRIC plans, plus parts of the plans of the Westerdijk Fungal Biodiversity Institute.

General Description

The transition from the current linear, petrochemicals-based economy to a circular economy based on biological starting materials and processes is essential for a sustainable society and planet. It also requires responsible stewardship of available natural resources and the environment. Industrial Biotechnology (IB) is a crucial key technology in this respect. BIOTECH-NL delivers an IB infrastructure aimed at unravelling the fundamental design rules of microbial systems and predicting behaviour and underlying functions at different scales. It also aims to exploit this knowledge to restore, design, and redesign natural and synthetic systems in biotechnology and sustainable production. BIOTECH-NL is committed to the Design-Build-Test-Learn approach for tailor-made biocatalyst development in IB. Central aspects are the FAIR generation and handling of (heterogeneous) data and its AI applications for experimental design, redesign, interpretation and prediction. BIOTECH-NL provides access to advanced multidisciplinary services allowing us to answer a variety of scientific questions about microbial lifestyles, metabolism, robustness, interactions and evolution. BIOTECH-NL accelerates the end-to-end development of new and existing bioprocesses and contributes greatly to the development and implementation of low-carbon technologies with a low environmental footprint for a wide range of industrial applications. BIOTECH-NL builds on the IB infrastructures IBISBA-NL (associated with ESFRI-IBISBA) and SMART-FABRIC (food and biobased domain) and draws on the virtually inexhaustible wealth of diversity found in fungi (WI-KNAW) and other microbes (ESFRI-MIRRI; UNLOCK). BIOTECH-NL is open initially to any scientist from European academia and research institutes. Access is easy and efficient through a one-stop-shop (with scientific quality being a decisive criterion). This gives users access to many resources and services that are organised in a standardised manner and yet are focused on the user's needs.

Impact

Dutch science and industry have an excellent reputation and a long tradition in the field of IB and sustainable production. IB is the key to the biobased economy, as it enables sustainable production of bulk, semi-bulk and fine chemicals, nutraceuticals, pharmaceuticals, materials, food and feed, using renewable biomass and energy sources. Lack of access to robust, efficient infrastructures is currently a major bottleneck in generating scientific knowledge and translating it into market processes and products. This is especially true for knowledge institutions and SMEs, while bigger established industries often lack the flexibility to experiment with innovative new concepts due to their larger structures. Therefore, industrial biotechnology needs to combine its R&D forces, accelerate the development of bioprocesses, shorten lead times and link fundamental R&D in the biosciences to industrial reality. BIOTECH-NL will thus further enhance the Netherlands' top position in the field of sustainable technological innovations.

LIFE SCIENCES & ENABLING TECHNOLOGIES

LRI component 1: **Deep molecular analysis using omics**

General description

The omics technologies offer a unique opportunity to understand the molecular building blocks of life, explaining the underlying mechanisms of disease, health and new treatments. To achieve this, we aim to further develop analytical techniques of sequencing, mass spectrometry and bioinformatics and to link these high-quality omics analyses with functional imaging, phenotypic and other research data.

Impact

The Netherlands' pioneering role in the development of mass spectrometry technologies will be extended to ultra-sensitive metabolic phenotyping. This will allow the consequences of post-translational protein modifications and abnormal biochemical patterns in cells and tissues to be identified and translated into more sensitive and personalised clinical biomarkers.

By coupling multi-omics analyses with imaging, and especially by doing so in a functional way over time, we can read metabolism in useful detail, gaining a better understanding of life processes at the cell and tissue level. This will provide a strong basis for understanding disease processes, leading to the development of better medicines. We will generate a Dutch functional genome database within the European 1 Million Genome Project using high-volume genomics and metabolomics platforms. Building on existing Dutch cohort data, we will gain a detailed understanding of the genotype-phenotype relationship in health and disease, thus laying the foundations for prevention.

LRI plans

The LRI clusters X-omics, M4i and BDC aim to develop and perfect techniques to study the function of molecular building blocks (DNA, RNA, protein, metabolites) and their variants in their natural environment for a better understanding of health and disease. Single-cell omics, spatial fluxomics and mass spectrometry imaging will be used in combination with digital pathology and image analysis. The LRI Proteomics Center focuses on techniques to study post-translational modifications of proteins and their consequences in diseases.

The LRI NPC, NMPC and M4i aim to develop ultra-sensitive mass spectrometry techniques to better understand the structure of proteins and metabolites and their function in life sciences. This includes single-molecule and single-cell proteomics/metabolomics, de novo sequencing, analytical and functional annotation of millions of protein and metabolite variants, characterisation of higher-order structures of proteins, as well as integration with other structural biology platforms such as EM, NMR etc.

DGCD, X-omics and NMPC plan to generate a Dutch genome database within the European 1 Million Genome project to gain a detailed understanding of the genotype-phenotype relationship in health and disease and lay the foundations for prevention. This will be done in consultation with the LRI group Health Sciences.

LRI component 2: **Visualisation of dynamic processes in life sciences**

General description

Complementary imaging techniques allow us to visualise molecules and proteins in their biological environment with the highest possible resolution and to understand their function in (sub)cellular processes. To achieve this, we aim to strengthen the foundations of imaging techniques, push the boundaries of achievable resolution, and connect different technologies within and across LSET components. Coupling the various forms of imaging expertise with omics analyses to monitor steady and changing functions of intracellular processes over time will allow better understanding and manipulation of life processes at the cell and tissue level, using toolboxes and models developed within the LSET group.

Impact

Combining the various forms of imaging expertise within the LSET group will create a unique integrated infra-structure to enable moonshot challenges in life sciences, materials science, medicine, biotech and agri-food. Visualisation of protein structures and functions using high-throughput techniques will allow quantitative analysis and manipulation of cellular processes. Bridging the various imaging and omics techniques (visual omics), combined with the development of AI-driven data analysis, will lead to an accessible national infra-structure for all Dutch researchers and to groundbreaking discoveries and applications. By developing imaging techniques that push the boundaries of achievable resolution, we can determine the structures of molecules and proteins in cells and tissues, preferably in their natural environment. This will lead to a revolution in fundamental insights and to innovative applications for the development of biomarkers, vaccines and personalised medicine for complex diseases such as cancer, obesity and neurodegenerative diseases.

LRI plans

The national LRI cluster NL-BioImaging aims to visualise, quantify, and manipulate molecular processes in living cells, tissues, and organisms through high-content screening combined with tools developed within the LSET. In collaboration with the biomolecular imaging LRI AMICE, we aim to push the boundaries of our understanding of life and disease processes, leading to innovative therapeutic applications. To study the molecular metabolism in a single cell, the LRI M4i will develop a bridge between molecular imaging and mass spectrometry, focusing on immunological applications. The national LRI cluster NEMI will expand the development of accessible, ground-breaking resolutions to resolve issues within the fundamental and applied life sciences. The national cluster uNMR will develop the use of ultra-high-field NMR to its full potential in order to study processes in chemistry and biology at the highest resolution. Like NEMI, it will develop innovative (bio)materials necessary for the energy transition and a more sustainable society.

LRI component 3: Development of unique tools and integration with application models

General description

The omics and imaging LRI will be able to thrive thanks to cross-fertilisation with the tools and models devel-oped within the LSET group. For example, unique tools will be developed to study biological processes from the level of molecules to living cells, ultimately leading to pharmacology in living organisms. Various large-scale infrastructures will also be developed and used to study highly infectious pathogens, cancers, metabolic conditions and ageing-related diseases, leading to biomedical applications. All of these activities are closely interlinked with the omics and imaging LRI components within LSET, including data management and AI data analysis.

Impact

Within the next few years, we aim to map the "druggable genome". This will be done by developing a chemical toolbox to visualise processes in cells and tissues and relate them to specific genetic and metabolic character-istics. In addition to genetically determined characteristics in the proteome, an infrastructure will be developed for determining changes in glycan structure and biological characteristics in organisms. We will integrate this within the developed omics and imaging platforms, and extend this to applications within various unique research models with infrastructures for research using highly virulent pathogens, disease-related studies in laboratory animals and preclinical metabolic studies in humans.

LRI plans

Using new facilities, the LRI CPC will develop a comprehensive chemistry toolbox for the omics and imaging LRI, focusing on activity-based probes to measure enzyme activity in cells and tissues, and on drug-profiling screens to allow new discoveries and applications including novel drugs. The aim of the LRI Glycoenable-NL is to create a unique toolbox and infrastructure for the study of glycans. The various metabolism-related innovations by different LSET LRI will lead to applications at the LRI MRUM for multi-day metabolic studies looking at metabolic diseases in humans. This will allow the linking of detailed molecular phenotyping and deep metabolic pheno-typing in order to test cellular and preclinical findings in humans. The LRI MCCA2.0 enables researchers to carry out preclinical in vivo studies in the field of cancer and ageing, while the LRI BSL3 facilitates and conducts studies involving highly pathogenic (class III) microorganisms in controlled environments.

MEDICAL SCIENCES

AT&MS

LRI plan: **Advanced personalized Therapies & human Model Systems**
Acronym: **AT&MS**

General Description
Innovative stem cell technology is the foundation for understanding, monitoring and influencing life processes in both the sick and healthy. Stem cells are essential in order to create realistic tissue models (MS) and to develop personalised medication and cell and gene therapies (AT). The AT&MS plan combines the forces available in the Netherlands. The intended infrastructure, divided between the LRI AT: ICAT (formerly Utrecht CTF), NECSTGEN, NPORT, hDMT INFRA, RMU, includes centres of excellence for stem cell technology, developmental biology, organ-on-a-chip and organoid technology, developmental laboratories, and translational and GMP expertise. The partners include all Dutch University Medical Centres (UMCs) and universities of technology, Utrecht University, Leiden University, Maastricht University, University of Groningen, Hubrecht Institute, TNO, Princess Máxima Center, Utrecht Science Park, Province of South Holland, RegMedXB, hDMT, the city of Leiden, Leiden BioScience Park, CCRM, UCL and IZI Frauenhof Leipzig.

Impact
With the AT&MS plan, the Netherlands aims to maintain its global lead in the field of stem cell technology and human organoid and organ-on-a-chip models. Based on molecular biology, cell biology and genetics, the plan will lead to a fundamentally new understanding of the causes of diseases and individual differences, laying the foundations for personalised treatments. The plan will accelerate scientific breakthroughs and the fundamental new insights obtained will lead to the right therapy for each individual. In addition, the plan will have a major societal impact by increasing the effectiveness of drug development, lowering medicine costs, accelerating the availability of medicines and reducing animal experiments. The AT&MS plan is in line with the European Organ-on-Chip roadmap and, with the infrastructure, will enhance the Netherlands' innovative capacity and appeal for scientists and life sciences businesses both at home and abroad.

PIGI

LRI plan: **Precision Imaging and Image-Guided Intervention**
Acronym: **PIGI**

General Description
Imaging techniques are a crucial navigation system in almost every phase of clinical intervention and contribute to "personalised therapy" with optimal effectiveness and minimal side effects. It plays a role in initial diagnosis, staging, monitoring and prognosis: which disease is it, where is it localised, how severe is it, is the intended therapy effective? Imaging techniques are involved in the planning and targeted implementation of treatment or drug delivery, whether by surgery, irradiation, chemotherapy, immunotherapy, cell therapy or nanotherapy. With advanced technology spread across the LRI DYNAMIC, CIS, Spinoza, Scannexus, Radboud Imaging Center, MITeC, HollandPTC and Amsterdam Molecular Imaging Center, PIGI aims to gain a better fundamental understanding of pathological processes and conditions regarding their anatomical, physiological, metabolic and molecular aspects.

Impact
Targeted effective treatment ultimately leads to lower costs. The Netherlands is an international leader in medical imaging thanks to strategic investments in high-field MRI, molecular tracers (PET) and image-guided interventions spread across centres of expertise, amongst others. The results of this top-class research are translated to clinical settings and exploited commercially by businesses, mostly Dutch-based.

HEALTH SCIENCES

CONNECTION

LRI plan: **Broadening data collections**
Acronym: **CONNECTION (CONtiNue vErnieuwend CiTIzens jOurNey)**

General description

By linking existing administrative data, population cohorts and clinical data, and enriching these data with relevant data collections, e.g. Statistics Netherlands data, data on living and social environments, personal health environments (PHE) data as well as data on lifestyle and exercise collected by citizens themselves, the phenotypic depth (environment, behaviour, lifestyle, biomedical data, disease and health) of existing collections can be increased.

Impact

Scientific research that can make use of the above infrastructure will lead to a better understanding of the various psychosocial and societal effects that, in combination with genetic predisposition, play a role in maintaining optimum health. This approach will enable us to map the incidence and natural progression of many common conditions and gain insight into the causes and mechanisms of these conditions, leading to prevention and treatment options. Conversely, acquiring knowledge about the residual effects of diseases and the interacting effects of multiple diseases (multimorbidity) in later life will also yield unique new opportunities that can be translated into action to help maintain and improve health.

DEEP

LRI plan: **Deepening data collections**
Acronym: **DEEP (DEEp Phenotyping)**

General description

DEEP focuses on enriching the data set in the Dutch cohort infrastructure at individual level through additional data collection. This will be achieved, in part, by making research facilities available that enable deep phenotyping of citizens or patients, such as DNA sequencing and imaging. The goal is to characterise biological samples and patients in far greater detail via these measuring infrastructures for "routine" deep phenotyping so that environment, lifestyle and behavioural data (exposome) can be seamlessly related to biological changes (microbiome, metabolome, proteome, epigenome, genome) and health.

Impact

In combination with advanced data analysis (AI) techniques, the even richer phenotyping provided by this component of the LRI plans will enable new scientific research leading to the reliable identification of causes of disease and factors that promote health, better biological insights, opportunities for pharmacological and lifestyle interventions, and better predictive models for disease and health. By operationalising the deep phenotyping infrastructure, the research field in the Netherlands will take a giant step forward in answering complex health questions.

This will also provide an opportunity to identify small subgroups in the real world that may be eligible for a specific, innovative, research-based intervention.

LIDI-NL

LRI plan: **Continuous data collection over time (longitudinal approach)**
Acronym: **Lifecourse Data Integration Netherlands (LIDI-NL)**

General description

The Netherlands has collected a vast amount of longitudinal data (recurring measurements over time for each study participant) over the past 10–30+ years, concerning living circumstances, behaviour and health in various populations: cross-sections of the young, elderly, families, twins, and people from different ethnicities and geographic locations throughout the country. Provided privacy is guaranteed, these prospective cohort data can be linked to data flows collected from GPs, hospitals and government bodies such as Statistics Netherlands. Some of these cohorts also collected biological material and omics data at recurring intervals. LIDI-NL aims to coordinate the integration of data from these richly phenotyped and recurring measurements, and also an extension to harmonised new data collections in relevant cohorts. Optimal use of existing data and new, current data requires a framework of activities to link a continuum of observations over the life course, to identify and trace missing data, to optimise new (dynamic) data collection and sampling of cohorts and to collect data in flexible ways. This requires tight control over participants' involvement and ways of systematically feeding results back to participants in an understandable form.

Impact

Integrating relevant cohorts and new data collection in LIDI-NL will allow us to determine the influence of biological factors, behaviour and environment on health outcomes throughout the life course. Using this knowledge, it will be possible to optimise health outcomes via individualised health interventions and associated recurring measurements. This concerns outcomes of chronic diseases such as diabetes, obesity and multi-morbidity, and the response to sudden-onset diseases such as COVID-19 and other infections. It also concerns the effects of preventive and clinical treatment. This initiative will be guided by a national network of practical and theoretical methodological and epidemiological expertise, in order both to guarantee the design and analytical quality of the studies, and to develop and implement innovative study designs.

DAPHNE

LRI plan: **FAIRification & data integration**
Acronym: **DAPHNE (DatA Pooling tHe Next lEvel/ DatA Pooling tHe NL lEvel)**

General description

The Netherlands is rich in high-quality health data from large-scale population and clinical cohorts. Bringing these data together in a federated analytics environment is the next step to increase efficiency through both the associated economies of scale and the FAIRification of data. Appointment systems, methodologies and tooling are needed to i) link data from existing cohorts (data harmonisation), ii) enrich them with data from registries (NKR, NIVEL, PALGA, etc.), healthcare institutions (hospitals, pharmacies, GPs, municipal health service, mental healthcare etc.), government bodies (Statistics Netherlands etc.) and other relevant data collections (NIFER, etc.), and (iii) expand these with new, prospectively harmonised data collections in a standardised, reusable manner. The privacy of participants and patients must be guaranteed in all of these activities.
This infrastructure comprises the following essential components:
- a platform for data requests and controlled access to data from all cohorts;
- retrospective and prospective harmonisation of cohort data;
- an app store for questionnaires, measuring methods/SOPs;
- generic informed consent in line with privacy legislation (GDPR) with maximum opportunities to link data and conduct innovative new research;
- generic data storage and data analysis facilities enabling federated analysis.

Impact

Supporting harmonised data collection and data integration holds out new opportunities for unravelling the determinants of health and disease. Scaling up offers unprecedented new research opportunities to better understand the complexity of behavioural, environmental, psychosocial, socioeconomic and biological inter-actions in maintaining health and in the development of disease. Newfound knowledge can be translated into more effective, more precise prevention options at the population level, e.g. with a focus on gender differences. In addition, the systematic implementation of DAPHNE will provide the high-quality data that is key to large-scale application of federated machine learning and other AI techniques in Dutch healthcare research, as further implemented in the fifth LRI component MoMaSim. Lastly, DAPHNE will enable us to identify and invite citizens or patients to participate in adaptive or innovative studies.

MoMaSim

LRI plan: **Machine learning, modelling & simulation**
Acronym: **MaMoSim**

General description

The rich data set that can be jointly accessed via the Federated Dutch Cohort Infrastructure provides a basis for major scientific breakthroughs. This will require the analysis of large volumes of often high-dimensional data. AI techniques are especially powerful in identifying relationships between such high-dimensional data. Investment will be needed to make the data from the Dutch cohort infrastructure AI-ready, i.e., make the data machine-accessible in order to apply AI analyses. For a fundamental understanding of the causes of disease processes, we also need to develop causal, mechanistic models. This requires models across the full spectrum (from molecule to organism), with the option of integrating models at different levels. The models we envisage will be personalisable: a model with person-specific parameters can be constructed for each individual, serving as a basis for new technological applications and individualised treatment pathways.

Impact

Facilitating the analysis of data from the Federated Dutch Cohort Infrastructure using AI and mechanistic models is not only innovative but also represents a next level in data analysis and can thus lead to fundamental new insights in the health and life sciences. It may also lead to prevention and treatment based not solely on correlative and instantaneous observations, but on a complex, causal model incorporating personalised para-meters. This has great potential for patient-specific treatment pathways (e.g. in obesity), new technology (e.g. closed-loop systems for cardiovascular applications and brain-machine interfaces) and drug development. It also provides a unique opportunity to connect with citizens.

Required investment

This digital infrastructure requires investment in:
1   Modelling, simulation and AI software and accessibility for scientists (FAIR-compliant models/software with rich metadata);
2   Accompanying high-performance computing facilities and development of a modelling, simulation and AI software infrastructure for users;
3   Software to translate federated datasets into models and AI analysis;
4   Software and computing capacity for retrograde and anterograde testing of models against observations, allowing models to be validated and improved;
5   Software and computing capacity to apply models with a view to individual treatment pathways and new technological applications;
6   Dashboards for citizens to use their data and resulting models for personal life-journey planning, prevention and public awareness.

SOCIAL SCIENCES & HUMANITIES

SSH-INFRA- COMPUTE

LRI plan: **Secure High-Performance Computing for the Social Sciences & Humanities**
Acronym: **SSH-INFRA- COMPUTE**

General description
ODISSEI & CLARIAH have brought about huge improvements in the interoperability of data. This enables the linking of diverse datasets to answer new questions. Doing so can be highly impactful in terms of both science and society but presents two challenges that are unique to social sciences research.

1   The data are more complex when linked. They traverse multiple layers and link different types of data subjects in complex contextual data models. These models are so complex and rich that they are increasingly referred to as a digital twin of Dutch Society.
2   The data are more sensitive when linked. For example, employment data is both personal and potentially sensitive but when this is linked to health records, the sensitivity of the data increases further.

SSH-INFRA-COMPUTE will address the sensitivity and complexity of SSH data by providing researchers with high performance, secure and flexible analytical environments.

Impact
New data providers, such as publishers and private companies require various security requirements and computational configurations in order for their data to be brought into the SSH data landscape in the Netherlands. In collaboration with SURF, the SSH-LRI will develop computational solutions that will enable the comprehensive exploitation of the data within ODISSEI, CLARIAH and beyond. The ODISSEI Secure Supercomputer has provided a simple and initial basis for this and what is possible but further expansion of the computing facilities for SSH would allow new levels of complexity to be encapsulated, and further scientific and societal questions to be addressed.

SSH-INFRA- DATA

LRI plan: **Federated data collection platform for the Social Sciences & Humanities**
Acronym: **SSH-INFRA- DATA**

General description
ODISSEI, CLARIAH, NICAS and EHRI collect and process a vast range of complex and multi-layered data ranging from social surveys and tax records through to handwritten seventeenth-century texts and social media data. To capture the deep, diachronic context of such data requires investments in new data collection infrastructure to make use of new technologies and reduce the long-term costs of ingesting data into the various SSH infrastructures. Specific needs include but are not limited to:

1   New infrastructure for harvesting, processing and archiving the exponentially increasing amount of digital content that is available online;
2   Adapting survey data collections to a fully online future, allowing for rapid and low-cost data collection while maintaining the quality and continuity of collections;
3   A platform for the engagement of huge numbers of participants in online experiments and citizen science projects, expanding and enhancing the PaNL project.

Investing in new technologies and coordinating data collection activities across the domain requires a federated infrastructure for data collection.

Impact

The SSH-INFRA-DATA Infrastructure will lead to the coordinated, ex-ante alignment of high-dimensional and rich data collection efforts across the domain. This coordination will enable SSH to participate in international infrastructures including SHARE, ESS, GGP, CLARIN and DARIAH but will also increase the further integration of these data collections, facilitating interdisciplinary research. For example, the infrastructure will further invest in and align the collection and processing of textual and audio data, which is vital across the social sciences and humanities. The enhanced scale of operating across the domain will also increase the capacity for new innovations and new research lines.

SSH-INFRA-FAIR

LRI plan: **FAIR Implementation for the Social Sciences & Humanities**
Acronym: **SSH-INFRA- FAIR**

General description

FAIR implementation is a fundamental challenge across the sciences and an obstacle to the realisation of the European Open Science Cloud. This challenge is shared by all infrastructures in the SSH domain, but there is a desperate need for investment, collaboration and further integration of efforts. DANS has been active in the development of the ODISSEI portal and the CLARIAH's interoperability standards but there remain significant needs for the realisation of a fully FAIR SSH cluster by 2030:

- Monitoring and enforcement of FAIR standards across the SSH domain in cooperation with DCCs and individual data providers;
- The integration and mapping of metadata standards from non-scientific data providers, such as private companies, museum collections and government agencies;
- The alignment and mapping of SSH standards with those of other domains, particularly in the life sciences and environmental sciences;
- The development and deployment of FAIR Implementation tools to assist local data stewards and data auditors.

Impact

The successful implementation of FAIR across the SSH domain will enhance the return on investment in a wide range of existing projects and infrastructures. At the heart of both the social sciences and humanities are a shared set of underlying data subjects (people, organisations, places, etc). FAIR data standards are needed to document these as digital objects and support interoperability. When these standards are published and accepted across the domain, it will make research workflows machine actionable and greatly increase the efficiency, impact and scope of scientific research. Furthermore, it will allow for the social dimension to be exported and incorporated into other domains such as the environmental or life sciences.

SSH-INFRA-TOOLS

LRI plan: **Toolbox for the Social Sciences & Humanities**
Acronym: **SSH-INFRA-TOOLS**

General description

SSH Researchers need tools, software applications and services aimed at digitising, annotating, analysing and reporting research data. The last 10 years has seen a nascent community of research software engineers develop in the social science and humanities communities, demonstrating the growing potential and demand for such tools. Currently the expertise of this community is spread across KNAW-HUC, the eScience Centre, Centerdata and SoDA team. This community of research software engineer's needs:

- common standards for the development of such tools;
- a common network for knowledge exchange and the pooling of development expertise;
- the transferability of skills and qualifications to enable the circulation of expertise between centres;
- investment in the career pathways of research software engineers and the recognition of their scientific work;

The Social Science and Humanities Toolbox will support the development of new tools by integrating and reinforcing this increasingly vital scientific community so that they can, in turn, facilitate groundbreaking research.

Impact

High-quality tools have the ability to transform research. They enable researchers to perform tasks faster, more efficiently and more accurately. Using an enhanced and integrated SSH toolbox as provided by research software engineers, researchers will be able to search, edit, analyse and present large amounts of data and pose research questions that could not be answered before, for new scholarly insights. The Netherlands is at the cutting edge of digital humanities and computational social science, but the SSH toolbox would be the first such community in the world and would turn the SSH cluster in the Netherlands into a centre of excellence in these closely related fields.

SSH-INFRA-TRAIN

LRI plan: **Expertise Hub for the Computational Social Sciences & Digital Humanities**
Acronym: **SSH-INFRA-TRAIN**

General description

ODISSEI and CLARIAH have developed some of the most complex and advanced research infrastructures in the social sciences and humanities to be found anywhere in the world. The success of these infrastructures is dampened by their inaccessibility beyond those with a very specific set of technical skills. They need to be opened to the wider research community who lack the skills, expertise and support to make use of the infrastructure. Researchers need support in being able to:

• Learn how to find the right resources;
• Learn to work faster and more effectively with resources;
• Use or develop possibilities to apply tools and data in education;
• Look at use cases for inspiration and to refine research questions;
• Quickly gain insight into how certain tools and datasets can work together;
• Use a structured approach to analysis or processing of research material through multiple tools;
• Work through common research steps more efficiently and effectively.

SSH-INFRA-TRAIN will invest in the use of existing infrastructures and the significant upskilling of researchers in the Netherlands to make use of the infrastructure.

Impact

The impact of SSH-INFRA-TRAIN will be the development of a highly sophisticated and effective national community of researchers which will cement the Netherlands position as the leading centre for social sciences and humanities in the digital and computational age. The challenges the social sciences and humanities face in developing new curricula and retraining generations of leading scientists are shared across the domain. SSH-INFRA-TRAIN will provide scale and flexibility to meet this challenge so that the research communities can make full use of the infrastructures available to them. The work within SSH-INFRA-TRAIN will also greatly increase the return on investment of the infrastructures which the community use.

APPENDIX 4
National Roadmap 2016:
16 clusters and 17 individual infrastructure[11]

Domain Social Sciences & Humanities

CLARIAH-PLUS	The digitisation of analogue sources of text, image and sound improves researchers' access to large amounts of data. CLARIAH-PLUS develops smart, user-friendly techniques to structure collections and make them accessible.
ODISSEI	Open Data Infrastructure for Social Sciences and Economics Innovation (ODISSEI) is an integrated, flexible infrastructure. It was established to gather, integrate, store and create access to data from the social sciences.

Domain Science/Technology

ATHENA	Advanced Telescope for High Energy Astrophysics (ATHENA) is a space telescope for the observation of X-rays in the 'hot and energetic Universe'.
CESAR	Measuring and modelling Dutch cloudscapes generates more insight into the origins of clouds and rain and a better understanding of weather, climate and air quality.
DUBBLE	Highly intense beams of X-rays, produced by the particle accelerator (synchrotron) in Grenoble, are being used for both materials research and the physical and chemical research of matter. Researchers can also use the X-ray beams to monitor chemical and biological processes up to the atomic level.
E-ELT	The European Extremely Large Telescope (E-ELT) provides extreme sensitivity in the visible and infrared wavelength range due to its large diameter (39 metres). This optical telescope will broaden researchers' understanding of the formation and evolution of the Universe as a whole, of galaxies and of individual stars and planets. E-ELT will also provide an impetus to the search for extraterrestrial life and the unravelling of the mystery of dark matter and dark energy.
EPOS-NL	EPOS-NL is the Dutch contribution to the European Plate Observatory System (EPOS), the European infrastructure for research in the solid earth sciences. EPOS-NL provides facilities for research that serve the societal needs for the supply of natural resources and for protection against natural disasters. The EPOS-NL facilities will be used to study the safe use of the Dutch subsurface, addressing natural and human-induced earthquakes, sea level change, geothermal energy, subsurface storage of energy and waste products, as well as the future construction of subsurface infrastructure.
ESS	European Spallation Source (ESS) produces neutron radiation that enables researchers to study structures and processes up to the nanoscale in biology, chemistry, materials science and art history.
ET	Einstein Telescope (ET) is the European initiative for a third-generation, underground gravitational-wave observatory, designed to detect gravitational waves from space. South Limburg is a potential candidate for establishing this European facility.

HFML-FELIX	The combination of extremely intense infrared laser light and extremely high-magnetic fields generates surprising discoveries. That explains the draw of the High Field Magnet Laboratory (HMFL) and the FELIX Laboratory cluster – both situated in Nijmegen – on researchers from around the world.
ICOS-NL	With unprecedented precision, Integrated Carbon Observation System (ICOS-NL) is constantly monitoring the exchange of greenhouse gases between land, sea and the atmosphere.
KM3NeT	Studying neutrinos provides us with the opportunity to learn more about the nature of these 'ghost particles'. It also yields information about events taking place in the far corners of the Universe.
LHC-detector upgrades	Protons collide with each other at almost the speed of light in the Large Hadron Collider (LHC), CERN's underground particle accelerator. An analysis of the resulting 'fragments' provides insight into the basic building blocks of matter and energy.
NanoLab NL	NanoLabNL provides researchers from universities and companies from the Netherlands and abroad access to equipment, technologies and expertise for the design and fabrication of materials, components, devices and systems on a scale of a millionth of a millimetre.
NC2SM	Researchers at the National Characterisation Center for Sustainable Materials (NC2SM) are using advanced spectroscopic techniques to make detailed analyses of the structure and behaviour of materials for sustainable applications.
RV Pelagia/NMRF	Compared to our knowledge of the land, seas and oceans are largely undiscovered areas. Dutch researchers and their (international) partners are changing that with the research vessel RV Pelagia.
SKA	The Square Kilometre Array (SKA) will be an extremely sensitive radio telescope that will enable astronomers to look back in time much further than is possible now. They thus hope to gain more insight into the fundamental laws of physics.
Solar cells	In order to achieve the objectives of the 2015 Paris Climate Change Conference the cost of converting sunlight into electricity has to decrease fourfold in the next twenty years. Dutch knowledge institutions, largely united in Netherlands Energy Research Alliance (NERA), are examining different potential paths for achieving that objective.

Domain Medical/Life Sciences

BBMRI	Biobanking and Biomolecular resources Research Infrastructure (BBMRI) makes biomaterials, images and data from (longitudinal) research retrievable, accessible and exchangeable for research on the prevention and treatment of diseases. The latter occurs on an individual basis to the greatest possible extent (personalised health & medicine).
BSL3	In the High Containment Research Facility (HCRF) BSL3 (Biosafety Level 3), scientists can conduct research on infectious diseases with full control of any risks to themselves or the environment. The facility operates at the second-highest possible safety level. Here researchers can examine the agents causing potentially serious infectious diseases.
ELIXIR-NL	As a national focal point in the European network ELIXIR, the Dutch node ELIXIR-NL aims to build the digital environment to make data generated by the life sciences accessible and exchangeable for analysis. The initial emphasis is on biomedical data, as part of the Health-RI initiative, but the plan is to have the infrastructure function as a broad Life Sciences Data Exchange.
ISBE	Infrastructure Systems Biology Europe (ISBE) provides researchers in the life sciences with the expertise and the tools to integrate different types of data into computer models. As a result, they can explain and predict the behaviour of biological systems – from cell to ecosystem.

MCCA	The Mouse Clinic for Cancer and Ageing (MCCA) provides researchers with the opportunity to monitor the aetiology and development of cancer and other age-related diseases with a range of imaging techniques. For this purpose, they use specially developed mouse models and human tissues.
MRI and Cognition	Magnetic Resonance Imaging (MRI) provides researchers and clinicians with data about the structure (anatomy), the functioning (physiology) and the biochemical processes (metabolism) in the brain and other parts of the body. As such, it is an important tool for researching illness and health, behaviour, learning and development.
MRUM	The Metabolic Research Unit Maastricht (MRUM) provides the opportunity to conduct research on the metabolism of the human body as a whole or of organs and tissues in a closely controlled environment.
NEMI	Technological developments have instigated a revolution in the more than eighty-year-old field of electron microscopy (EM). Netherlands Electron Microscopy Infrastructure (NEMI) provides researchers with an opportunity to actually see how individual atoms and molecules behave and organise themselves in biological and non-biological materials. At the same time, Dutch research institutes and companies can continue to operate on the front of the latest developments in electron microscopy.
NIEBA	Netherlands Infrastructure for Ecosystem and Biodiversity Analysis (NIEBA) provides researchers with easy and remote access to an abundance of validated data about life on Earth. The infrastructure also provides options for analysing and modelling, using these data.
NL-BioImaging AM	Netherlands BioImaging Advanced Microscopy (NL-BioImaging AM) develops advanced microscopic techniques to directly observe biological processes in action in cells, tissues and organisms. Moreover, the consortium makes these techniques accessible to other scientists.
NL-OPENSCREEN	NL-OPENSCREEN provides researchers with a library containing tens of thousands of compounds plus the facilities to test their biological impact quickly and efficiently.
NPEC	Netherlands Plant Eco-Phenotyping Centre (NPEC) provides scientists with next-generation growth platforms to enable research designed to unravel to the interactions between plant genes and the environment. These interactions determine the growth, health and other observable characteristics – the phenotype – of plants.
UNLOCK	UNLOCK provides scientists with an opportunity to accelerate how we map microorganisms and their ecosystems from all corners of the Earth. The insights that this will generate will shed light on many potential applications, such as agriculture and nutrition, health and environmental health, and new processes and products in the industry.
uNMR-NL	The ultra-high-field magnets at the NMR-NL facility makes it possible to study complex materials, biomolecules and living organisms in even greater detail than previously.
X-omics	The X-omics cluster (pronounced: cross-omics) provides researchers at universities, academic hospitals and companies with access to advanced facilities to study the building blocks of life in their natural environment: cells, tissues and bodily fluids.

APPENDIX 5
Roadmap grants call 2017/2018 and 2019/2020

Call 2017/2018

ATHENA, probing the hot and energetic Universe

Main applicant	Dr J.W.A. den Herder
Institutions	SRON – Netherlands Institute for Space Research University of Amsterdam Leiden University Radboud University University of Groningen
Amount awarded	€ 19,496,000
Summary	The Athena space telescope is ESA's next large mission (2028). Athena will revolutionise our understanding of how the Universe evolved from a near-homogeneous soup of matter to the highly structured Universe that we observe today. In addition, the X-ray space telescope will finally allow us to determine how supermassive black holes form and help shape the Universe. The Netherlands provides key contributions, such as an ultra-sensitive X-ray camera annex spectrometer. For the first time, astronomers will have an instrument that can produce sharp 2-D images and simultaneously chart the characteristics of gas as hot as 10 million degrees Kelvin.

EPOS-NL: The Netherlands contribution to the European Plate Observatory System

Main applicant	Prof. M.R. Drury
Institutions	Utrecht University The Royal Netherlands Meteorological Institute TU Delft
Amount awarded	€ 12,272,000
Summary	EPOS-NL is the Netherlands contribution to the European Plate Observing System (EPOS), which is the pan-European infrastructure for solid Earth science, for geo-hazards and geo-resources. The objective of EPOS-NL is to develop the infrastructure needed for scientific breakthroughs in the understanding of human-induced geo-hazards, such as subsidence and earthquakes caused by gas production. In addition, the EPOS-NL infrastructure will enable research on new geo-resources such as geothermal energy production and subsurface energy storage.

BSL3: safe solutions for research into global threats by infectious diseases

Main applicant	Dr J.M. Fentener van Vlissingen
Institution	Erasmus University Rotterdam – Erasmus University Medical Center
Amount awarded	€ 4,752,000
Summary	The world is increasingly confronted with new infectious disease problems, and research is essential to be able to predict, detect, treat, control and prevent major outbreaks and pandemics. Special facilities are needed to study the most dangerous pathogens. These must operate according to the highest international biosafety and biosecurity standards. The novel research lab facility in Rotterdam was designed to meet these standards and facilitate research from multiple teams simultaneously, thus providing unique opportunities for excellence in infectious disease research.

The Netherlands Plant Eco-Phenotyping Centre (NPEC)

Main applicant	Prof. M.G.M. Aarts
Institutions	Wageningen University & Research Utrecht University
Amount awarded	€ 11,281,000
Summary	The UN predicts that a 70% increase in global food production will be required by 2050 to meet the needs of Earth's rapidly growing human population, necessitating the development of improved crop varieties with higher yields at less environmental cost. The current bottleneck in developing such new plant varieties is capacity for large-scale assessments of how plant genes (genotype) relate to desired plant traits (phenotype). NPEC provides the necessary state-of-the-art research infrastructure to decipher underlying mechanisms that dictate plant performance.

KM3NeT 2.0: Neutrino Science in the Deep Sea

Main applicant	Prof. S.C.M. Bentvelsen
Institutions	Nikhef TNO Delft University of Groningen NIOZ – Royal Netherlands Institute for Sea Research
Amount awarded	€ 12,730,000
Summary	KM3NeT will comprise a huge underwater neutrino detector capable of identifying sources of high-energy neutrinos in the Universe. These sources will be studied to possibly identify them as the particle accelerators responsible for cosmic rays. The interactions of cosmic rays in the Earth's atmosphere produce neutrinos that can be used by KM3NeT to study the particle physics of the neutrinos. A temperature-sensing array for oceanographic studies and a novel hydrophone array based on a fibre-optic network complement the multidisciplinary science.

Netherlands Electron Microscopy Infrastructure (NEMI)

Main applicant	Prof. J. Klumperman
Institutions	University Medical Center Utrecht University of Amsterdam – Academic Medical Center Leiden University Utrecht University Maastricht University University of Groningen Leiden University Medical Center TU Delft University Medical Center Groningen Eindhoven University of Technology
Amount awarded	€ 17,275,000
Summary	Electron microscopes can magnify an object up to 10 million times. This incredible magnification power is used to study the smallest components of biological and material specimens as well as man-made structures. The Netherlands Electron Microscopy Infrastructure (NEMI) initiative unites the major Dutch electron microscopy labs and invests in innovation to create optimal conditions for top-level research relevant for science, industry and society.

The Ruisdael Observatory for atmospheric science

Main applicant	Prof. H.W.J. Russchenberg
Institutions	TU Delft The Royal Netherlands Meteorological Institute Wageningen University & Research Utrecht University National Institute for Public Health and the Environment Energy Research Centre of the Netherlands VU Amsterdam TNO Utrecht University of Groningen
Amount awarded	€ 18,196,000
Summary	The Earth's atmosphere has structurally changed due to the long-term emissions of greenhouse gases, air pollution and particulate matter. The Ruisdael Observatory will very accurately measure and model these changes above the Netherlands. A permanent measurement network, mobile sensors and extensive ground stations will provide data about the chemical and physical properties of the atmosphere and its interaction with the Earth's surface. A new computer facility will process the data observed into atmospheric models in real time. In this way, the Ruisdael Observatory will provide a detailed description of the changes in the local weather, climate and air quality.

Netherlands X-omics Initiative

Main applicant	Prof. A.J. van Gool
Institutions	The Hubrecht Institute for Developmental Biology and Stem Cell Research
	Radboud University Medical Center
	The Netherlands Cancer Institute / Antoni van Leeuwenhoek Hospital
	Leiden University Medical Center
	Leiden University
	Utrecht University
	University Medical Center Utrecht
	University Medical Center Groningen
	Erasmus University Rotterdam – Erasmus MC
Amount awarded	€ 17,334,000
Summary	The splendour of the chemistry of life lies in its unparalleled complexity. Yet, this also poses the biggest challenge for biologists and medics as they try to understand how diseases arise and how these can be detected and treated at an earlier stage. This project combines and improves a number of molecular technologies, thus enabling researchers to better observe complex and dynamic processes in cells and tissues. This project will make top scientific research possible in the fields of cancer, Alzheimer and many other diseases.

HFML-FELIX: a unique research infrastructure in the Netherlands Matter under extreme conditions of intense infrared radiation and high-magnetic fields

Main applicant	Dr B. Redlich
Institution	Radboud University
Amount awarded	€ 10,785,000
Summary	HFML-FELIX represents a world-unique research infrastructure on Dutch soil, generating some of the world's highest magnetic fields and infrared/THz radiation with unparalleled tunability. Studying matter under extreme conditions allows materials to be probed with unprecedented precision and even drives them into unchartered territory, potentially revealing new function-alities. This innovative research programme addresses outstanding questions in diverse fields, connects to societal challenges of health, energy and smart materials, attracts world-class researchers to the Netherlands and educates a large number of students.

CLARIAH-PLUS

Main applicant	Prof. A.F. Heerma van Voss
Institutions	KB National Library of the Netherlands
	Max Planck Institute
	Data Archiving and Networked Services
	The Meertens Institute
	The Dutch Language Institute Sound and Vision
	International Institute of Social History
	Huygens Institute for the History of the Netherlands
Amount awarded	€ 13,879,000
Summary	The availability of massive quantities of digital sources (textual, audio-visual and structured data) for research is revolutionising the humanities. Analysis of these huge amounts of data is only possible with the use of sophisticated IT tools.
	CLARIAH-PLUS offers scholars a 'Common Lab' that helps them extract information hidden in these digital data by using innovative user-friendly tools, thus enabling them to carry out groundbreaking research with high potential for contributing to the resilience of society.

Call 2019/2020

The uNMR-NL Grid: A distributed, state-of-the-art Magnetic Resonance facility for the Netherlands

Main applicant	Prof. M.H. Baldus
Institution	Utrecht University
Amount awarded	€ 17,900,000
Summary	Nuclear Magnetic Resonance Spectroscopy (NMR) and Imaging (MRI) exploit magnetic properties of nuclei to study the structure and dynamics of molecules in both living organisms and materials. uNMR-NL was set up with a central NMR instrument with unprecedented capabilities. Now this is expanded to a grid of high-field NMR centres throughout the Netherlands by novel instruments and upgrades, fostering access and exchange between local centres and user groups. This nationwide grid will support diverse research areas ranging from studying disease and the discovery of new medicines to improving crop production and food quality, and novel materials for energy storage and conversion.

FuSE: Fundamental Sciences E-infrastructure

Main applicant	Prof. S.C.M. Bentvelsen
Institution	Nikhef
Amount awarded	€ 12,000,000
Summary	The Nikhef and ASTRON FuSE project will enable Dutch researchers to extract exciting science from the vast amounts of data produced by three of the largest global science facilities, namely the Large Hadron Collider (LHC at CERN), KM3NeT and the Square Kilometre Array (SKA). The Netherlands invests considerably in all three of these facilities, driven by leading Dutch scientists at our universities and institutes. Each facility runs experiments to explore our Universe and seeks to unravel the fundamental physics that governs it. They share a similar challenge: they produce enormous amounts of complex data. The FuSE project will develop a set of shared computing and data science expertise in the Netherlands. This will ensure that all researchers in the Netherlands are able to fully exploit the potential of these facilities, and convey these discoveries to the public.

Netherlands Infrastructure for Ecosystem and Biodiversity Analysis – Authoritative and Rapid Identification System for Essential biodiversity information (NIEBA-ARISE)

Main applicant	Prof. J.C. Biesmeijer
Institution	Naturalis Biodiversity Center
Amount awarded	€ 13,600,000
Summary	ARISE is a globally unique infrastructure that serves to identify all multicellular species (e.g. plants, animals, fungi) within the Netherlands, and to monitor where and when they occur. This infrastructure enables the research community to improve our understanding of the patterns and trends in Dutch biodiversity and the interactions between species. This initiative, which combines DNA sequencing and machine learning techniques, is also followed with great interest internationally. ARISE will provide policymakers with more reliable information on biodiversity, to allow for more effective measures to halt the loss of biodiversity.

Renewal of the National Marine research Facilities; critical research instrumentation

Main applicant	Prof. H. Brinkhuis
Institution	NIOZ – Royal Netherlands Institute for Sea Research
Amount awarded	€ 10,300,000
Summary	Our seas and oceans are essential for Earth and life in general. Yet, knowledge about them is still limited. The Netherlands has a long and rich history of excellent marine research that relies on the availability of research vessels and specialised equipment. The present 28-year old research vessel is due to be replaced. This Roadmap application concerns innovative scientific equipment to be included on the new research vessel. The main large research facility for which funding is requested concerns autonomous, and remotely controlled equipment for making observations in depth, time and spatially that will help answer fundamental and technological research questions.

HFML-FELIX: A Dutch Centre of Excellence for Science under Extreme Conditions

Main applicant	Prof. P.C.M. Christianen
Institution	Radboud University
Amount awarded	€ 15,100,000
Summary	HFML-FELIX represents a world-unique research infrastructure on Dutch soil, leading in science and technology with magnets and free-electron lasers. Studying matter under high-magnetic fields and intense infrared/THz laser radiation enables materials to be probed with unprecedented precision and to be driven into uncharted territory, potentially revealing new functionalities. In this innovative programme HFML-FELIX and several Dutch universities, institutes, companies and medical centres combine their expertise to create entirely new instrumentation and an indispensable contribution to the Dutch research portfolio. The new experimental capabilities will enable groundbreaking science with societal relevance in the areas of health, energy and smart materials.

ODISSEI: Better Infrastructure, Better Science, Better Society

Main applicant	Prof. P.A. Dykstra
Institution	Erasmus University Rotterdam, Erasmus School of Social and Behavioural Sciences
Amount awarded	€ 9,300,000
Summary	ODISSEI is a shared research infrastructure that will bring together existing data from the social sciences and enrich them with data from government registries and online sources. The infrastructure ensures that Dutch social scientists are well equipped to exploit the opportunities offered by the digital age. By developing innovative analytics and visualisation tools, and offering world-class, secure and ethical data management facilities, ODISSEI will enhance the position of Dutch social scientists as global leaders and enable them to better address the pressing social questions of our time.

UNLOCK: UNLOCKing Microbial Diversity for Society

Main applicant	Prof. H. Smidt
Institution	Wageningen University & Research
Amount awarded	€ 14,500,000
Summary	Microorganisms can perform many processes useful for mankind, such as converting milk to cheese, keeping human and animal intestines healthy, and cleaning our water and environment. So far, we are relying heavily on pure cultures, and have only exploited less than 1% of the microorganisms present in nature. In Wageningen and Delft, the UNLOCK research facility is built enabling the discovery, characterisation, optimisation and utilisation of microbial function-alities in natural and man-made microbial ecosystems to solve some of the major societal challenges facing food safety and production, human, animal and environmental health, and bioresource utilisation and sustainable production of biobased chemicals.

APPENDIX 6
LRI in connection with the ESFRI Roadmap

The scheme below is a starting point to show which Dutch LRI are connected to the ESFRI 2018 consortia (cut-off date of 1 July 2021).

ESFRI – Thematic Domains Roadmap (2018)	ESFRI Name	Status (Project/ Landmark)	Legal status	National Roadmap 2016 (LRI)	National Roadmap LRI 2021 (Group)	National Roadmap LRI 2021 (Domain)
Physical Sciences & Engineering	CTA	Landmark	GmbH	——	Astronomy & Particle Physics	
	ELT	Landmark	IGO	E-ELT	Astronomy & Particle Physics	
	EMFL	Landmark	AISBL	HMFL-FELIX	Astronomy & Particle Physics	
	ESS-ERIC	Landmark	ERIC	ESS1	Materials	
	HL-LHC	Landmark	CERN Convention	LHC-detector upgrades	Astronomy & Particle Physics	**Technical & Natural Sciences**
	KM3NeT 2.0	Project	In formation	KM3NeT	Astronomy & Particle Physics	
	SKA	Landmark	IGO	SKA	Astronomy & Particle Physics	
Environment	ACTRIS	Project	In formation	CESAR/ICOS (Ruisdael)	GeoSciences	
	DANUBIUS-RI	Project	In formation	RV Pelagia/ NMF	GeoSciences	
	ICOS-ERIC	Landmark	ERIC	ICOS-NL	GeoSciences	
	EPOS	Landmark	ERIC	EPOS-NL	GeoSciences	

ESFRI – Thematic Domains Roadmap (2018)	ESFRI Name	Status (Project/ Landmark)	Legal status	National Roadmap 2016 (LRI)	National Roadmap LRI 2021 (Group)	National Roadmap LRI 2021 (Domain)
Environment	DiSSCo	Project	In formation	NIEBA	Green Life Sciences	
	eLTER	Project	In formation	——	Green Life Sciences	
	LifeWatch ERIC	Landmark	ERIC	NIEBA	Green Life Sciences	
Health & Food	EMPHASIS	Project	In formation	NPEC	Green Life Sciences	**Life & Medical Sciences**
	EU-IBISBA	Project	In formation	UNLOCK	Green Life Sciences	
	MIRRI	Project	In formation	NIEBA/ UNLOCK	Green Life Sciences	
	Euro-BioImaging	Landmark	ERIC	MRUM, NL-BI, NEMI	Life Sciences & Enabling Technologies	
	BBMRI-ERIC	Landmark	ERIC	BBMRI-NL	Health Sciences	
	EATRIS-ERIC	Landmark	ERIC	EATRIS-NL, MRI & Cognition	Health Sciences	
	ELIXIR	Landmark	ELIXIR Consortium Agreement	ELIXIR-NL	Health Sciences	
	INSTRUCT-ERIC	Landmark	ERIC	MRUM, uNMR-NL	Health Sciences	
Social & Cultural Innovation	CESSDA-ERIC	Landmark	ERIC	——	Social Sciences & Humanities	**Social Sciences & Humanities**
	CLARIN ERIC	Landmark	ERIC	CLARI-AH-PLUS	Social Sciences & Humanities	
	DARIAH-ERIC	Landmark	ERIC	CLARI-AH-PLUS	Social Sciences & Humanities	
	EHRI	Project	In formation	——	Social Sciences & Humanities	
	E-RIHS	Project	In formation	——	Social Sciences & Humanities	
	ESS2-ERIC	Landmark	ERIC	ODISSEI	Social Sciences & Humanities	
	SHARE-ERIC	Landmark	ERIC	ODISSEI	Social Sciences & Humanities	

ESS: European Spallation Source
ESS: European Social Survey; AISBL: Association internationale sans but lucratif
CERN: Conseil Européen pour la Recherche Nucléaire
ERIC: European Research Infrastructure Consortium
GmbH: Gesellschaft mit beschränkter Haftung

APPENDIX 7
Source of illustrations

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National Roadmap for Large-scale Research Infrastructure 2021

Scientific research is impossible without Large-scale Research Infrastructure (LRI). Scientists use facilities and services such as databases, research vessels, telescopes and book collections to conduct excellent scientific research, both in the Netherlands and internationally. The aim of the Permanent Committee for LRI, established within NWO at the request of the Ministry of Education, Culture and Science, is to create a future-proof ecosystem of Large-scale Research Infrastructure in the Netherlands.

For the purposes of this publication, nine cohesive scientific groups have selected LRI that are vital for scientific innovation and require additional government investment. NWO will organise two new funding rounds for this within the National Roadmap programme.