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Moving the Digital Life Sciences in Norway towards increased innovation

Lessons from international innovation practices

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Preface

This is the second report in a project called "A roadmap for academic research-intensive innovation", commissioned on behalf of the Digital Life Norway (DLN) project by the University of Oslo. The project is in three parts. The first report (labelled "AS IS") discussed DLN and its context in the Norwegian research and innovation system and pinpointed issues and weaknesses in the system that could be improved to increase the innovation rate from academic research. This second report (with the working name "TO BE") involves looking at and learning from good examples internationally and is intended to inform DLN's work in devising its own roadmap. A subsidiary goal is to inform relevant parts of research and innovation policy in Norway. DLN will produce a third report in the form of a road map and action plan.

The AS IS report found that the Norwegian innovation system relevant to life science and convergence-based innovation was in many respects strong, but also that DLN faces significant challenges:

- Links between research and the demand side as well as with broader innovation ecosystems are weak
- Innovation skills and culture are deficient in the university system
- The TTO system is narrowly focused on traditional, patent-based ways to exploit new knowledge so that universities' knowledge exchange activities as a whole are impeded
- For different reasons in different sectors, R&D and innovation capacity in DLN-relevant industry in Norway is limited, and it is harder to extend links to industry abroad than at home
- The difficulty of linking research to the demand side is not limited to the obvious direct users of knowledge but is complicated by the need to address well-functioning value chains.
- DLN has limited means to steer its research portfolio towards the needs of the demand side

Following the completion of the AS IS report, we built on the AS IS results to construct a list of R&I-related domains relevant to generating DLN's road map. We used these domains to structure our analysis of international practice in this report. The domains cover the challenges identified in the AS IS such as building interdisciplinary capacity, sources of funding and investment, the role of innovation ecosystems and the demand side, culture, incentives and the operationalisation of RRI in innovation support.

We selected thirteen examples of good and interesting practice relating to these domains in DLN's four focus sectors: biomarine; food and agriculture; healthcare; and industrial biotechnology. This report contains our synthesis of the detailed lessons for each domain and concludes with a set of higher-level indications, in general and for each of the seven domains, intended to contribute both to DLN's future practice and to Norwegian policy more widely.

This volume is structured in two parts. **PART 1** presents the higher-level lessons from the study for both DLN and the policy level in Norway. It can be read as an extended summary. **PART 2** explains our methods and presents the more detailed findings of the study. We present the **case studies** on which the study is based in a separate volume.

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PART 1 LESSONS FROM INTERNATIONAL PRACTICE

1 Lessons for DLN and the Norwegian innovation support system

Norway has an ambition to build a strong sector within digital life sciences. This report examines international practice in supporting research-based innovation and entrepreneurship, based on several case studies. **PART 1** summarises lessons for DLN and the Norwegian innovation system more widely. **PART 2** describes how we researched this report and presents results from the study in more detail. PART 1 will be followed up in a separate action plan. The case studies that underlie this report are available in a separate volume.

We split our subject into seven domains to structure our analysis of international practice. Together they tackle the challenges identified in the earlier stage of this project. The domains are:

- D1 Digital life capacity, transdisciplinarity and convergence
- D2 Research and innovation funding and capital investment
- D3 Operating within innovation ecosystems
- D4 Forging producer-user relations in knowledge production and use
- D5 Innovation culture and practices in research-performing organisations
- D6 University innovation support and commercialisation systems
- D7 RRI – Responsible Research and Innovation

Some of the lessons that emerged relate to the overall system level. We first discuss these, then tackle lessons from each domain in turn.

1.1 Lessons at the system level

Norway needs to build a complete innovation system that covers every step in the innovation process, from idea to application and support the whole spectrum of activities needed to produce value from research. Several of our case studies point the way towards such a holistic approach, which needs to ensure that there are measures or actors working with the needed expertise at all the key points in the research and innovation process. Today there is an apparent lack both of funding (see Domain 2) and knowledge support in the early innovation phase translating research into commercial (or non-commercial) concepts for application. Filling this "gap" is crucial for Norway to be able efficiently to increase the innovation rate from academic research.

Each support organisation should focus on a defined part of the innovation process, optimise it and collaborate with other actors on the other parts. No individual support organisation can handle all the different parts of the innovation process alone. There is a clear pattern among our case study organisations that when they focus, they focus on a small number of related or adjacent steps and optimise them. Since different parts of the knowledge exchange mission require different skills and resources, it is natural to create specialised entities to address different functions. Individual support organisations, such as TTOs, incubators, business clusters etc. should therefore be given or define their role based on an understanding of the need in the whole system and collaborate closely with the actors in the innovation system responsible for other parts. Smaller and more focused organisations may be highly effective in their niches, but if the system perspective is lost, their 'local optimisation' behaviour can cause sub-optimal behaviour at the systemic level, as to some extent is the case with the Norwegian TTOs today. Large organisations, like KUL, WUR and Imperial College more easily can take a systemic perspective and internalise more of the various phases or steps of the innovation process which small organisations may need to access through outsourcing or partnerships.

The academic institutions – the universities – play an important role in this innovation system fostering many great ideas. The role and mandate of the universities within the innovation system depends on the other actors that are present and what role they pursue. A university can insource or outsource functions or – as is in many cases necessary – coproduce them, as long as it is aware of its ownership and responsibility for the process as a whole. It must therefore carefully consider what tasks and mandates that should be held within the university and what should be outsourced to external TTOs or other organisations. Any reorganisation of the TTO role in Norwegian universities should take account of the needs of the innovation system as a whole, and not only focus on how best to perform the TTO function in isolation.

Thematic specialisation is needed to succeed. The way research and innovation are done, and their relationships to users and markets, differ among branches, markets, and technologies. Therefore, those supporting innovation need specialised knowledge and specific network relationships to operate well. Our case studies show that thematic specialisation is important in many aspects of knowledge exchange and in innovation support. Specialisation is observed in all phases from the research process through the provision of research funding and innovation support. Incubators tend to be specialised, especially within health sciences, where the IP strategy, regulatory affairs, long timeframes, high risk and large costs, differ from many other sectors. Seed and capital investors specialise on sectors of industry where their knowledge and networks give them superior information. Since knowledge exchange and innovation works differently also between the various scientific disciplines, branches, and sectors, the need for specialisation also applies to research and innovation activities and facilities in the universities. Different research fields need different models and processes to reach into the innovation ecosystems.

The universities have to make sure that the «third mission» fits into their total responsibility and make space for it. University knowledge exchange systems should cover the whole of the third mission and internal specialisation and division of labour are needed to pursue this mission at high levels of quality and efficiency. However, its structure and governance should be arranged to avoid competition among activities, allow thematic and case-by-case optimisation of knowledge transfers and build sustainable connections between all three university missions. The knowledge exchange function of the universities needs to have the intelligence and flexibility to make decisions – such as choosing between patenting or having a long-term research relationship with a company[1] – that optimise at the university level, rather than locally at the level of an individual function. Knowledge about innovation must be built seamlessly into education and research activities and connect the third mission to the other two. Nationally-determined regulations and incentive systems for universities, including funding programmes, should take into account these principles.

Major initiatives should connect to national and regional policies to succeed. Several of the case study organisations work within the framework of a national or regional development plan

[1] It follows that management and monitoring systems need consistent design across the university. For example, TTOs' typically KPI count intellectual property and licence income, while Norwegian universities' institutional research funding depends partly upon contract research income. These indicators can in many cases be in conflict with each other

or policy. Some, like the UK ones, are tied into medium-term roadmaps or strategies with clear objectives and an explicit time frame, to strengthen the aquaculture cluster, establish a leading position for the UK in the science and application of synthetic biology, and so on. The Flemish examples are older but nonetheless are connected to building a relevant research system and well-functioning innovation ecosystems. These cases appear to be strengthened by the fact that they play roles in bigger, more systemic strategies that build innovation communities, rather than operating as lone entities in fragmented landscapes, or only focusing on research.

For policy, it is important to note that creating these centres involves (top-down) thematic prioritisation at both national and university level as well as linkage to actual and potential industry partners. They do not arise spontaneously, solely based on bottom-up research funding. There is a need for a continuous focus on building a workforce of talent, training, and access to relevant and necessary infrastructure need to be ensured.

1.2 D1 Digital life capacity, transdisciplinarity and convergence

Organisations that are problem-orientated and regularly work in interdisciplinary ways are good homes for convergence research and innovation activities. Initial conditions seem to be important for organisations starting to research and innovate in the new and interdisciplinary fields of interest to this study. These organisations tend to value problem orientation, and regard interdisciplinarity as 'business as usual'. They are likely to be technological universities, more general universities that have a strong interest in engineering and technology or applied research institutes.

Starting to work with convergence requires effort, investment, and a plan. While none of the case study organisations has the same stated intention as DLN to work in the convergence of the life sciences and the data sciences, some were moving in that direction because of organisation-wide decisions to strengthen capabilities in digitalisation based on an identified need. That tended to mean setting aside a specific budget, devoting the time of a dedicated support group, and internal training as well as investing in and sharing new equipment needed for convergence to be possible and succeed.

Building e-infrastructure strengthens the organisation's ability to work in convergence and makes it more attractive to potential research and innovation partners. Digitalisation of life sciences requires not only new competences but also extensive e-infrastructure to store, analyse and share data. Some of the case study organisations have set up e-infrastructures by themselves to make this convergence between life sciences and data sciences possible. The e-infrastructures and data they produce from their own research, are sometimes made available to external parties as well as internal researchers, adding value to the organisation's 'offer' to the research community and the 'demand side'. Data sharing opens opportunities for new research and new projects as well as for identifying needs and potential innovations.

1.3 D2 Research and innovation funding and capital investment

A continuous funding programme with subsequent partly overlapping instruments is needed. Like Norway, the countries in which the case study organisations are located have wide-ranging research and innovation funding systems. These tend to have individual instruments that focus on single functions or phases of the research and innovation process. When combined with funding instruments available through the case organisations themselves, the funding programmes seem capable of covering most steps or phases of the innovation process. Norwegian public funding sources should strive for the same, providing support that spans all the early steps in the innovation process. The instruments must be complementary, possible to combine and have some degree of overlap to secure continuity for projects with clear ambitions and potential to innovate and commercialize. Individual innovation support organisations can add value by exploiting and integrating these schemes to build a pathway to innovation for the projects and companies they support.

Specific funding instruments are needed to handle the first 'valley of death', when going from a research idea to an idea with verified innovation and/or commercialisation potential. There is a huge need for financial instruments with the capacity to bridge the first valley of death, going from a research idea to an idea with verified use and market potential. This is the most critical phase where most innovative research ideas die because the activities needed to develop the idea further cannot necessarily meet requirements either for research excellence or for commercialization. Therefore, traditional funding instruments are not applicable. Specialised instruments must be set up which are tailored to support this deep valley of death. Many of the case organisations have good examples of how such instruments can be set up, often in combination with providing business development expertise to the ideas. Once past this important phase, the ideas can be further funded by private investors, used as a basis for a start-up, or incorporated into collaborative R&D with a company that may then use the results in their own innovation processes.

Funding needs to come in big enough lumps to make it possible to reach significant milestones. Too-small grants make it hard to achieve expensive objectives, as objectives often are in the life sciences. Small grants tend to fragment the process of innovation, easily introducing funding gaps and preventing projects from reaching a point where they provide a return on the investment. The size and organisation of funding needed is context dependent, with pharma projects usually needing much more funding over a much longer time than is the case for more technology-orientated inventions in for instance the marine and food sector. There are even examples where small grants are useful (for example in some places in synthetic biology, in ICT projects or in very early stages where a quick check out of the innovative potential is needed) but most of the examples suggest that the main risk is under-, not over-, funding. Large grant contracts should nonetheless link payments to clear milestones, to secure progress and success.

Innovation support organisations benefit from being able to offer grant funding. Innovation support organisations which offer funding from their own resources can more tightly manage commercialisation and innovation than those which do not have such funding. They may nonetheless depend on external sources for much of the funding needed. However, being able to spend their own money also entails a risk of becoming committed to funding and re-funding failing projects and not being able to terminate in time. For this reason, and to retain the trust of the research community, the few case organisations that do invest their own money tend to leave the decisions on which projects to fund to external, often very specialised, organisations to get high-quality, independent judgements, avoiding the risk that earlier commitments of work and money cloud the investment decision.

1.4 D3 Operating within innovation ecosystems

Innovation ecosystems require active, collaborative contribution from individual support organisations. Innovation ecosystems are key channels through which innovation support organisations can have impact. To get to that stage, they must demonstrate that they are part of and contribute to the ecosystem in which they are embedded. Most of the case study organisations deliberately operate within innovation ecosystems. To be accepted, innovation support organisations need visibly to contribute to the functioning of the ecosystem by offering things like services, advice, networking support, access to funding, equipment and expertise, R&D collaborations, problem identification, road-mapping, and dissemination of useful research results.

Design policy interventions that involve innovation support organisations in programmes to promote clusters, networks, and other kinds of innovation ecosystem. Since innovation ecosystems do not normally arise because of the efforts of innovation support organisations, there is a case for more deliberate integration of these knowledge providers in the design and use of policy instruments that promote ecosystems, such as those of RCN, the regions, and Innovation Norway. This can be done in a variety of ways, including organising cluster networks, disseminating information about research and innovation, promoting collaborative research, offering industrial extension services, including support organisation in funding schemes and so on.

Co-location of different actors within the innovation ecosystem lowers the barriers for collaboration and increases innovation activities. Several of our case studies show examples on how geographical proximity promotes and facilitates collaboration and innovation across disciplines and sectors. Countries and regions with strong industry and a prosperous SME sector usually have closer collaboration with academia and a better functioning innovation system. Mixing actors from different parts of the ecosystem, e.g. start-ups, large industry and academia together with support functions, seems to be most successful. Especially if the mixing can happen not only in the same region but even within the same physical facilities, the impact seems to be even greater. In some cases, universities or other support organisation have non-traditional types of buildings and equipment both to accommodate an effective innovation culture and support co-production of innovations. This means creating more open facilities for interacting with industry, collaboration, thematic and sector specific incubators and accelerators for academic spin-offs and new activities such as maker- and hackspaces.

1.5 D4 Forging producer-user relations in knowledge production and use

Understanding the demand side is key in innovation and commercialisation. Researchers and research organisations need to have a thorough understanding of the specific characteristics of the industries (or, indeed, public service functions), sectors and branches to which they aim to transfer technology. Ideas that are developed without an understanding of the needs, requirements, and behaviours of the end users and how the relevant industries and communities' work, rarely succeed. Successful innovation must be built on active engagement with the demand side to gain information about needs and opportunities and channels for connecting research results with existing demands, both in public and private sectors. While the wider international shift in research and innovation policy towards addressing societal challenges is not the subject of this study, it is nonetheless worth noting that it, too, implies a need for further engagement by research in society.

Building and maintaining relationship with industry is important for the universities to fulfil their third mission. Long-term research-industry relationships are powerful sources of, and supports to, innovation. They can also be used to develop wider cooperation, for example about training, skills, and labour supply and generate a basis for future grant and contract research income. Such relationships can be informal, but research centres such as SFIs, support organisations, industrial clusters and formal strategic project or partnership agreements also have important roles to play. Large-scale, formal projects and partnerships can be used to support and develop university strategy, in addition to making relations with companies more sustainable in the longer term. Such relationships are not much present within Norwegian life sciences today, partly because of the lack of relevant industry (as discussed in the AS IS report). Innovation ecosystem participation can be used to facilitate contact between the knowledge producers and the demand side and to help academia build relations with industry and companies that will outlast the funding of the individual innovation support organisation or programme. Sustaining deep relationships with industry requires the academic partner to develop a detailed understanding not only of technology but also of markets and future market development, industry practices and behaviour. This in turn requires a multi-disciplinary approach, such as a mix of technological, business studies and economics disciplines.

Build relations with companies that will outlast the funding of the individual innovation support organisation or programme. 'Hands-on' innovation support, such as that by the university innovation centres discussed in this report, tends to have time-limited funding. It is therefore important to build relationships that sustain beyond the funding period, including relationships to support organisations, for innovation to be self-sustaining.

Central coordination of universities-industry collaboration can improve quality and outcome for the universities. Industry collaboration can benefit from being channelled through one coordinating function at the universities because it helps ensure transparency, avoid conflicts of interest, and secure a proper handling of IP for all parties. KU Leuven and Cambridge University (not used as case in this study) are good examples on how such centralisation can be implemented.

Nurture the different roles of start-up support and incubators when engaging with industry. While long-lasting research-industry links are important for research-performing organisations with long-term commitment to specific fields of research and innovation, they can be less so for organisations that focus solely on start-up support and incubation. These organisations need repeatedly to initiate links between new firms and new demands.

1.6 D5 Innovation culture and practices in research-performing organisations

University management must take the lead in the process if the university aims to change its culture to be more innovation friendly and supportive. In our search for cases relevant for learning how to develop innovation support practices in Norway, we found ourselves looking at organisations that already had strong innovation cultures, largely based on their institutional histories. Creating such cultures does not happen overnight and requires several changes. The university management must take the lead in the process if the university aims to change its culture to be more innovation friendly, and they must include the support organisations such as TTOs, incubators and business clusters in the university sphere where relevant. Universities, in collaboration with the national government, should investigate the possibility of reviewing the internal incentive system to ensure that there are incentives for the third mission. Measures are also needed to combat the belief in some parts of the university system that involvement with innovation is 'dirty' or otherwise socially unacceptable.

Easily accessible innovation funding may lower the barrier for innovation. Making early-stage funding (like the one from LRD at KU Leuven) available for innovation projects at the university can be a powerful "learning by doing" way of building an innovation culture.

Universities should build variety into internal innovation sub-cultures, based on the needs of individual sectors. The way knowledge exchange normally works with industry differs between science-based and engineering-based industries and varies in a more detailed way by sector. Universities should aim to take active part in relevant innovation ecosystems at all levels, from university managers to individual researchers and students.

Innovation, entrepreneurship, and collaboration skills requires training and education. The universities and research communities must acknowledge that innovation and entrepreneurship is a discipline, requiring education and training. Classical research training does not really teach PhDs to collaborate with industry. Several of our case study organisations identified benefits from industry PhD schemes, industrial placements (both in education and for faculty members) and arrangements where industry people collaborate in research with the university as ways to improve innovation culture and mutual understanding. Long experience with degrees where one year is spent in industry, and with collaboration with industry in competence centres (such as the SFIs), similarly indicates that working together increases the effectiveness of longer-term collaboration and knowledge exchange. Other mechanisms such as Professor 2 appointments have similarly positive effects. Mobility programmes and fellowship with industry and public sector organisations can thus be a good way of changing the innovation culture. In addition, innovation and entrepreneurship training must be offered at all levels at the university – from undergraduate to faculty/professors' level and should be an integrated part of other education and training. Universities also need to recognise that most PhD candidates will eventually work in business or the public sector, outside academia. Graduate degrees that incorporate industrial or practical experience increase their employability and build a foundation for them to be future innovation partners of the university.

Focus on career incentives rather than financial ones to promote innovation. All the case study organisations except UBI are in countries that have abandoned 'professor's privilege' and have Bayh-Dole inspired legislation. Financial rewards from patents, licensing, and spin-offs, do however seem to have a limited effect on researchers' entrepreneurial behaviour and desire to do R&D in collaboration with industry. More widely, researchers tend to respond to career incentives, rather than financial ones. Incentive payments seem to be mostly of interest to young researchers whereas more senior researchers place greater value on the potential of income to support their research or their research team. Therefore, incentives might have to be differentiated to attract different categories of researchers and thus need to be properly embedded in human resource management and promotion criteria.

1.7 D6 University innovation support and commercialisation systems

Because others were active in the area, we intentionally devoted limited effort to studying TTO functions in this study. Our main message in this area is that **TTO functions should be better integrated into a holistic set of knowledge exchange practices, to prevent a local focus on patents and licensing from reducing the overall effectiveness of university knowledge exchange and the dynamics of the innovation ecosystem.** What tasks and mandates should be held in house within the academic institutions and what should be outsourced to the TTOs or other organisations should in any way be carefully considered. A potential reorganisation of the TTOs must be based on a complete understanding of the innovation system, both nationally and regionally and should not be limited to the current role and mandate of the TTOs. The example of LRD at KU Leuven is a good one. It is integrated and organised in a way that allows it to trade off the costs and benefits of alternative knowledge exchange mechanisms on a case-by-case basis rather than having to prioritise the classical TTO approach. TTO functions and competence are nonetheless important within such an integrated whole, and TTOs can be valuable supporters of innovation culture within the universities.

Based on the findings from our case studies, there seems to be several success factors to consider when setting up innovation support, independent of the exact role and mandate of the organisation and which part of the innovation process that will be supported. These are:

- **Be clear about who you are and which role you aim to take on and make sure not to mix roles.** For instance, incubators generally do not invest their own capital in companies. They can support development with their own money but never or very seldom take shares – they are consciously careful not to mix roles and be both an investor and innovation support. Instead, they hand over to private capital once the idea is sufficiently developed. Similarly, TTOs which are run as private companies struggle to support the early phases of innovation where the cost and risk is too high.
- **Involve a mixture of research and business expertise in the governance** to ensure focus on both technical and commercial viability.
- **Recognise your own limits and make use of external expertise where needed,** whether it is IPR, business planning, regulatory matters, or capital investment**.** This reasoning aligns with the recommendations in the beginning of this chapter, saying that no single organisation can support the full process and that focus and specialisation are needed. These should go hand in hand with collaboration within the eco-system, and underlines the importance of knowing what you do not know
- **Embed the organisation in networks that provide information about demand**. This can be done in a variety of ways, including by setting up company clubs, by providing technical services, organising cluster networks, disseminating information about research and innovation, doing collaborative research, and offering industrial extension services.
- **Absorptive capacity varies among different sectors and the innovation support system, so processes need to be shaped for each of them individually.**
- **Offer easy access to research infrastructure.** Access to specialised instrumentation, facilities and infrastructures is often crucial for research projects in life sciences and for optimisation of R&I activities for commercial development. Norway should benefit from a coordinated effort to get an overview of all available research infrastructure within the DLN field and find practical solutions to make them accessible for Norwegian academic researchers and entrepreneurs.
- **Treat the industry and private capital investors as your customer if you aim to support commercialisation**

Our case studies, along with DLN's experience during its first five years of operation, also point to a number of success factors for creating and running successful innovation projects, and for developing them into viable start-ups or industrial innovation. Those can be summarised as follows:

- **Always involve the demand side in the process when evaluating innovation projects.** Only accept ideas which propose solutions to an existing problem or need for which someone is willing to pay.
- **Innovation projects should not be staffed with PhD students, to avoid conflicts between publishing and confidentiality.** Using PhD students in innovation projects can cause conflicts between objectives and between the priorities of publishing or patenting. To meet the requirements of a PhD, the work needs to be published. Many DLN projects encounter difficulties in setting up projects which should both serve as a platform for PhD projects and at the same time foster innovation. Many DLN project leaders have expressed a wish to employ researchers if the focus is on innovation only.
- **Always keep the inventors/PIs in the process but make sure to use their competence in the right way.** The inventor behind an idea is important for the process of developing the project into an application, a process, or a commercial product. However, what role the inventor

should have must depend on the wishes of that person. Not all researchers are willing to take the risks of entrepreneurship. Further, few researchers have the set of business and managerial skills needed to do so and are therefore also need to be trained and educated. In those cases, the inventor or PI should be given the role as scientific or technical expert to be kept in the process whereas someone else can be engaged to run the business. If the inventor wishes to start the journey of innovation and entrepreneurship, then there must be a support system in place which can help and guide them along the way. To summarise – there seems not to be one answer. What is important is to keep the persons in the process and assign them a role they are comfortable with and where their competence can be used in the best way for the project to succeed.

1.8 D7 RRI

Important features of RRI coincide with established good practice in research and innovation. This applies to RRI's focus on inter- and transdisciplinarity, which is generally necessary to work in a problem-orientated way and the need to interact with demand, needs and values, without which it is hard to innovate successfully. Working in inclusive networks or ecosystems is a way to achieve this interaction and enlarge the circle of those involved from the 'usual suspects' in research and innovation policy (the universities, institutes and companies) to include regulators, educators, the state more widely as well as citizens, supply-chain members and non-government organisation increases the quantity and quality of information available to guide innovation processes in socially desirable directions.

Coupling RRI to funding policy instruments is a powerful way to embed RRI principles in research and innovation practice. As the UK Synthetic Biology Programme shows, the legitimacy that money brings is beginning to change research and innovation practice, influencing companies as well as university researchers. The fact that the programme has a common theme, funding and governance creates the space for reflexivity and learning through the network of centres involved.

The tension between public and private interests in innovation remains, requiring pragmatic solutions to provide benefits to both public and private actors that justify their involvement. Paradigmatically, innovation involves creating temporary and profitable monopolies – often including monopolies of knowledge – that eventually collapse as advantages spill over to others and under the pressure of economic competition. Not withstanding the inherent tensions between RRI-informed approaches and traditional norms of science, the British case studies suggest that practices that build trust, dialogue and increased end-user engagement mitigate this tension and point to alternative partnership solutions. The collaborative and contract research communities have long coped with this tension through contracts that regulate IPR ownership, secrecy, and publication, and these can also be used by the growing RRI community. Case study experience suggests that the conditions of such agreements can evolve over time in more RRI-friendly directions.

Like other platforms, RRI platforms can leverage their funding and the legitimacy it brings to attract further funding and activity that will in turn be influenced by RRI. Both SynbiCITE and UK CMSB have examples of this.

Standardisation may have the potential power of enabling research and innovation if treated carefully. While the importance of standardisation in supporting research and innovation varies, the synthetic biology examples discussed here show the potential power of standardisation in enabling research as well as development and innovation. Standardisation is two-edged – it can benefit both the monopolist and society more broadly – so it is important for RRI advocates to be involved in standardisation debates and processes to pursue the societal interest.

PART 2 THE FINDINGS OF THE STUDY

2 Introduction

This is the second report in a project called "A roadmap for academic research-intensive innovation", commissioned on behalf of the Centre for Digital Life Norway (DLN) by the University of Oslo. The project is in three parts. The first report (labelled "AS IS") discussed DLN and its context in the Norwegian research and innovation system. It was partly descriptive (to provide a basis for comparison with other examples of research-intensive innovation) and partly diagnostic, to understand strengths and weaknesses of the context in which DLN operates. This second report (with the working name "TO BE") involves looking at and learning from good examples internationally and is intended to inform DLN's work in devising its own roadmap. A subsidiary goal is to inform relevant parts of research and innovation policy in Norway. The third part to come is an action plan with pilot activities to be tested on the portfolio of research projects that are associated with DLN over the next four years.

The AS IS report concluded that DLN is in a position to capitalise on strengths in the Norwegian national research and innovation system but also faces important challenges. There is a potential to build on a large amount of high-quality Norwegian research across digitalisation and the life sciences that has the potential to underpin technological advances and innovations in industry and society. The Norwegian system has some good research capacity in these areas and DLN is contributing to increase that capacity further. In general, the R&D and absorptive capacity of industry is increasing, and this should over time reduce the barriers to its take-up of new, research-based knowledge. Research and innovation in Norway are underpinned by a strong, well-funded, state-provided support system, which nonetheless suffers from gaps in supporting the transition from research to innovation and support for early-stage spinouts. This is the gap that DLN Innovation is aiming to bridge and support, but in doing that, the AS IS study also found that DLN faces significant challenges:

- Links between research and the demand side as well as with broader innovation ecosystems are weak
- Innovation skills and culture are deficient in the university system
- The TTO system is too narrowly focused on traditional, patent-based ways to exploit new knowledge so that universities' knowledge exchange activities as a whole are impeded
- For different reasons in different sectors, R&D and innovation capacity in DLN-relevant industry in Norway is limited, and it is harder to extend links to industry abroad than at home
- The difficulty of linking research to the demand side is not limited to the obvious direct users of knowledge but is complicated by the need to address well-functioning value chains. The problem is not binary but systemic
- DLN has limited means to steer its research portfolio towards the needs of the demand side

Following the completion of the AS IS report, the combined DLN and Technopolis/Faugert team (see the list of authors at the start of this report) spent some time discussing and building on the AS IS results to construct a list of R&I-related domains relevant to generating DLN's road map. We used these domains to structure our analysis of international practice in this report, aiming to learn both domain-specific and systemic lessons that could be used in the road map. The domains cover not only the challenges identified in the AS IS report but also cover building interdisciplinary capacity, sources of funding and investment, and the operationalisation of RRI in innovation support.

The domains are:

- D1 Digital life capacity, transdisciplinarity and convergence
- D2 Research and innovation funding and capital investment
- D3 Operating within innovation ecosystems
- D4 Forging producer-user relations in knowledge production and use
- D5 Innovation culture and practices in research-performing organisations
- D6 University innovation support and commercialisation systems
- D7 RRI – Responsible Research and Innovation

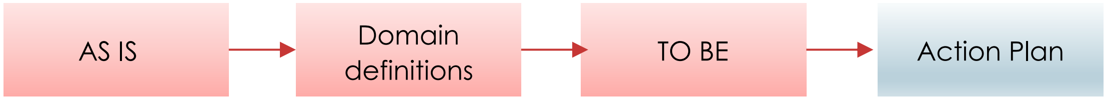
We expand on the issues pursued in these domains at the start of the respective analysis sections from Section 5.3 to 5.9.

- To produce this (TO BE) report, we compiled a long list of 55 potential case study subjects, including those already identified in the AS IS report, through a mixture of Internet searches and the team members' knowledge. All the potential case study organisations addressed at least one of DLN's four sectors: biomarine; food and agriculture; healthcare; and industrial biotechnology. Using further desk research, the long list of potential case studies was reduced to a short list of twelve cases spanning the four sectors that appeared collectively to offer lessons across the seven domains. Subsequently, we added a thirteenth case to strengthen our coverage of RRI. There is a bias towards synthetic biology in the cases because that was a field where there is real interest in RRI – in most other places, little attention is paid to RRI. Our choice of cases was also affected by accessibility, language and willingness for those involved to devote time to this study.
- We developed a case study template that was used for all cases. The template contains a description of each case study organisation followed by issues to be explored for each domain. Not all the domains are relevant to all the cases, so in effect each case handles some of the domains, but collectively the case studies handle all the domains. Each case study was done by, first, using secondary sources to find information. We then sent requests for an interview to each case organisation and made case-specific interview guides to make sure we addressed questions and filled information gaps which could not be covered from the desk research, and to verify information found from public sources. Interviews were conducted by pairs of interviewers from DLN and Faugert/Technopolis. Following the interviews, all the collected information was summarised and sent to our interviewee(s) for verification. Our subsequent cross-analysis of the case studies forms the body of this report. The completed case studies are available in a separate volume.
- The approach used and described above has some limitations. While our impression is that the case study organisations are successful, we were not able to evaluate them, nor is there a dataset available that would allow us to assess their performance. Further, we are looking at a small number of organisations, so we must be careful not to over-generalise from their behaviour. We lean on the wider scientific literature on research and innovation to make sense of what they do (Chapter 3). For example, the literature regards innovation as typically being coproduced in various kinds of networks, clusters, or ecosystems. This makes sense of the case study organisations' tendency to try to operate within wider collectives, rather than to act alone. In the next section, we therefore set out some 'stylised facts' from the literature on research and innovation that provide a context for the case studies. The

third section briefly describes the case study organisations. Thereafter, the fourth section contains most of our analysis of the cases, presenting findings and referring to examples of interesting practice, which the reader is free to explore in more detail in the Appendix. Finally, the fifth section draws lessons for DLN and for wider policy in Norway.

- The bigger project of which this report forms a part has as a next step the development and implementation of an action plan by DLN colleagues. The plan will selectively decide whether and how to operationalise practices identified in the case studies, based on their relevance, feasibility, (Frey & Luks, 2016)cost, and likely impact on DLN innovation performance. Figure 1 illustrates our overall process.

Figure 1 Steps in the overall study



3 The relationship between research and innovation: some stylised facts from the literature

As we point out in our introduction, we want to learn from international practices in connecting research with innovation. However, we are not able to evaluate the case study organisations as a basis for understanding the successfulness and validity of their practices. Rather, we rely on their visibility, reputation, and ability to survive over a period; and the extent to which their practices are consistent with what we know from the research literature about the links between research and innovation. This chapter tackles the second issue. The reader familiar with the relevant literature can safely continue to chapter 3.

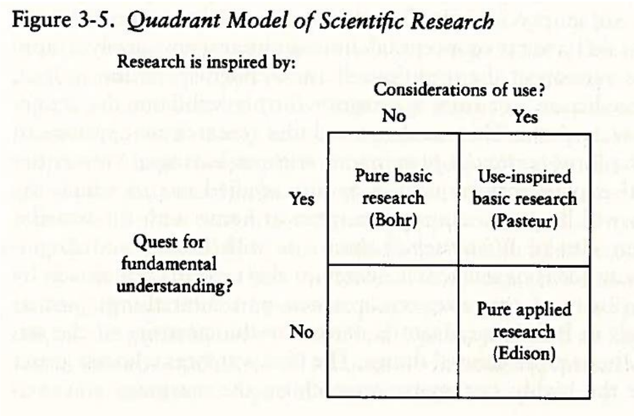
This year, the US National Science Foundation (NSF) has been celebrating the 75th birthday of Vannevar Bush's famous 1946 report to the US president *Science, the Endless Frontier* (Bush, 1945). In his role as Director of the US Office of Scientific Research and Development, Bush had overseen the Manhattan Project that developed nuclear weapons, and like many scientists of his generation he was horrified at the result. His report proposed that responsibility for science should be taken away from society and given to the scientific community, which should decide what science to do. He assured the president that this would produce results that would be good for society and the economy. A five-year battle followed, in which the US Departments of State refused to part with their research budgets, on the argument that if the scientists were in charge there was no guarantee that they would get the research results they needed to meet their 'mission' responsibilities for health, energy, defence and so on in a timely way, if ever. In the end, it was decided to set up the NSF, where the scientific community was indeed in control of the money and the choice of research topics, while the rest of government research stayed firmly under the control of society via the Departments of State.

NSF, and the science foundations or research councils started up in other countries during the post-War years, fund what Bush called 'basic' research – meaning not only that it is in some sense fundamental but also that funding for it is allocated under the control of the research community in response to proposals made and judged by researchers, not society. However, the idea that researcher-initiated and -governed research is **necessarily** fundamental is obvious nonsense. Not only the USA but also most other countries these days have science foundations or research councils, governed by researchers, which in practice fund a mixture of basic and applied research. Stokes (1997) shows that conflating research looking for fundamental understanding with research done purely out of curiosity is wrong (Figure 2).

Some fundamental research is indeed done out of pure curiosity – Stokes refers to Niels Bohr's work as an example – but a lot is done because the researcher has a reasonably good idea where they want to use the new knowledge generated. Louis Pasteur's work on vaccination and microbial fermentation was fundamental, but with some very clear ideas of what problems it might help solve. This contrasts with pure applied research, which in Stokes' example of Thomas Edison involved focus on finding out how to make something (light bulbs) work while devoting no more attention to underlying knowledge than was necessary.

Stokes originally set out his idea of quadrants in a short paper, which he then expanded into a book, where he remarks that the more he looked at the history of science, the more striking it was how much 'basic research' work turned out to be in Pasteur's rather than Bohr's quadrant. This is also where most if not all of the more fundamental work done in DLN projects is situated.

Figure 2 Stokes' quadrant model of scientific research, Source: (Stokes, 1997)

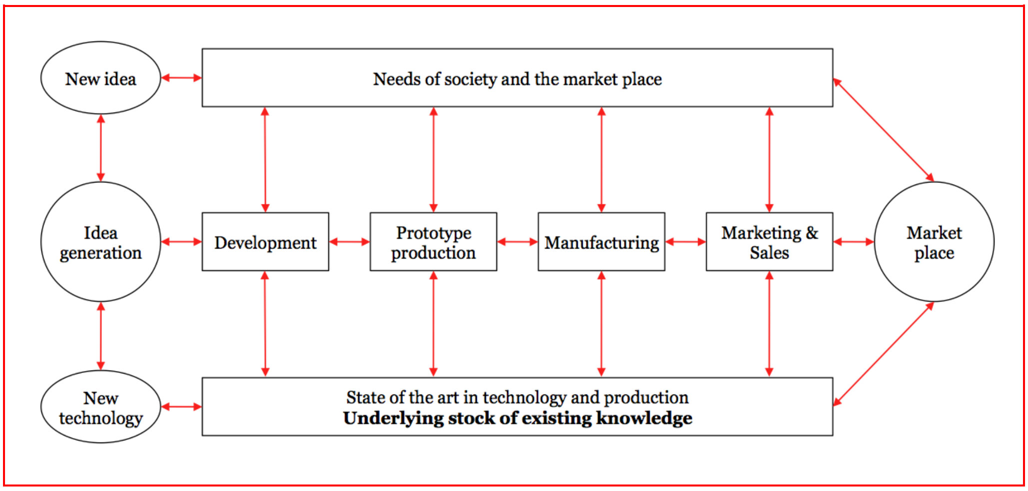


During the 1950s, Bush's claim that science produces useful results in society (without ever really saying when or how these would come) was simplified in policymaking to what we now call the 'linear model of innovation", namely the idea that there is a **causal** connection between basic research and (positive) societal impact. That idea had a massive impact on increasing funding for research in the post-War period, and it has three important properties. First, it is simple, and we always prefer simple theories. Second, it is a powerful way to attract research funding; again, we tend to like that. Third, it is wrong. Or, more precisely, while it seems to be true in the aggregate and the long term (we are after all surrounded by science-based innovations that drive both positive and – unfortunately for Bush, also negative – impacts), it is not true in the particular. Curiosity-driven research generally cannot be managed to solve specific societal needs within a specific time frame. This is why the mission Departments still have research budgets.

From 1962, the newly formed OECD campaigned against the linear model, trying to gain more societal control over research so that it could be directed towards innovation and economic growth. More generally, the 1960s saw an explosion of technology and technological optimism, and interest in innovation driven economic growth. Some researchers proposed an alternative linear model, in which needs 'pull' by users drags results of science. By the early 1970s, the new field of innovation research was producing results that showed the importance of producer-user relations and therefore customers in successful innovation. In 1979, Mowery and Rosenberg (1979) declared both linear models to be dead in a (very funny) paper that said successful technological innovation resulted from the 'coupling' of scientific and technological opportunities with market demand, i.e. needs backed up with the ability to pay to have them satisfied). The linear models were superseded by various non-linear ones, such as that shown in Figure 3 where a trigger for innovation can arise anywhere in the system and where the knowledge used in innovation is not necessarily new. (In fact, innovation surveys tend to show that most innovation is based on existing knowledge.)

Even later, in the 1990s, these non-linear models were developed further, introducing agile methods very often originated within software development, but now widely used in all fields. In these methods terminologies and methodologies such as customer development (Blank, 2020), lean start-up (Ries, 2011), Business Modelling (Osterwalder & Pigneur, 2010)) and Hackathon (Frey & Luks, 2016) all have in common the assumption that innovative ideas and start-up companies should build products or services iteratively to meet the needs of early customers. This to reduce market risks and sidestep the need for large amounts of initial project funding and expensive product launches and financial failures. The methods have lately been tested and developed also to be used within life sciences (Engel & del-Palacio, 2011). Another increasingly popular methodology introduced in innovation processes, is the Design Thinking, which is an iterative process used to understand users and customers, challenge assumptions, redefine problems and create innovative solutions to prototype and test. Design Thinking is considered very useful to tackle problems that are ill-defined (wicked) or unknown (Brown, 2009).

Figure 3 Modern 'Coupling' Model of Innovation



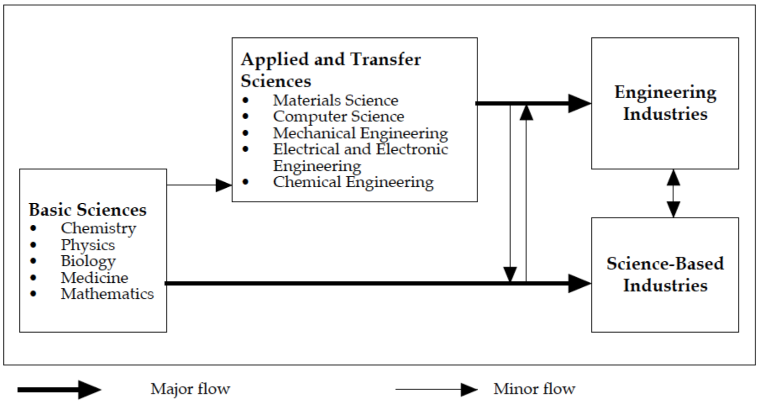
. **Source**: Modified from Rothwell (1994)

Looking back, these discoveries seem trivial – but they jhad a big effect on policy, leading many countries to set up 'innovation agencies' alongside their science foundations or research councils. Today, most if not all countries take a portfolio approach to research funding. They bet some money on researcher-initiated 'basic' research with unpredictable (but often long-term and big) impacts; some on more predictable 'mission' needs; and some on research for innovation, which is also risky, but a proportion of which should produce short-medium term benefits.

Further research on research and innovation has tended to replace the idea of 'heroic' individual inventors with a systemic perspective, which sees innovations as being 'co-produced' in 'system of innovation' (Lundvall, 1985), where innovation is a social process. It is rarely done by one person or organisation acting alone but tends to happen more where there are agglomerations of related people and organisations. It requires specialised knowledge and skills. Hence, it is easier for it to happen where agglomerations are specialised, whether that is in the form of Marshall's 'industrial districts' (Marshall, 1919), Porter's 'clusters' (Porter, 1990), networks, business, knowledge, various kinds of 'ecosystems', or whatever. These will contain specialists working at different stages in value chains, including on capital equipment, research, and other specialised inputs, but also competitors, specialised labour markets, common understandings of supply, regulation, and demand, and a social context in which even "the secrets of industry are in the air" (Foray, 1991). Both these kinds of agglomerations and innovation systems have individual histories, where institutions co-evolve, shaped not only by the nature of the knowledge used but also of many other factors. They tend to be unique and can best be understood by insiders.

However, there appear to be systematic differences among branches of industry in how innovation relates to fundamental and other kinds of research. Figure 4 presents a simplified picture of the results of a study about how established companies get knowledge inputs from scientific publications (Arundel, et al., 1995). It suggests that there is a group of 'applied and transfer sciences' that tend to feed into the engineering industries and a different group of basic sciences that feed into science-based industries (pharma, petroleum, chemicals and instruments)[2]. However, innovation based on the applied and transfer sciences involves a great deal more cooperation and transfer activity than basic science-based innovation. This is especially important to DLN, because it aims to address a mix of engineering- and science-based industries.

Figure 4 Knowledge flows in technological problem-solving



Source: (Arnold, et al., 1999), based on analysis of data from (Arundel, et al., 1995)

Unlike the linear model, which implied that companies rather passively absorb and then used new knowledge in innovation, the current view is that they actively search for the knowledge that they need and require specific skills to make use of it. Companies wishing to innovate using external sources of knowledge need to have the 'absorptive capacity' to look for technological opportunities and to couple them to their business needs (Cohen & Levinthal, 1989) (Cohen & Levinthal, 1990). To deal with all but the simplest kinds of external knowledge, that means that companies need technical expertise. The more advanced or fundamental (or less ready-to-use) the external knowledge is, the greater the need for companies to have research skills and therefore to have an R&D department. The big contribution of Cohen and Levinthal is to show that acquiring knowledge for innovation is a search-based activity, and not a passive process of absorption as was suggested by the original linear model. Different companies have different amounts of absorptive capacity, and this helps explain the need for a range of different ways to help them discover and exploit knowledge-based opportunities to innovate (Arnold & Thuriaux, 1997).

This account has the following implications for linking innovation to research.

- Since, over time, technological and scientific progress are interdependent, innovation incentives need to be able to reach all the way into basic research
- Links from Bohr's Quadrant to innovation are unlikely to result directly from contact with users and markets and more likely to occur via the mediation of more applied research interests

[2] This picture needs to be taken with a pinch of salt, especially as – since Arundel et al did their study – there has been a trend to increased 'sciencification' of R&D everywhere

- Since innovation involves an information problem, it will occur more easily in environments that are rich in relevant information, such as focused networks or ecosystems. The more steps in the innovation chain that are involved in the environment, the more useful the information flow is likely to be in supporting innovation
- Organisations and networks that are 'joined up', in the sense of understanding as much as possible of the 'innovation chain' (ie all the discrete types of activity from Bohr's Quadrant to manufacturing and sales) have an advantage in identifying and exploiting innovation opportunities
- Given the differences between science- and engineering-based innovation and industries, such networks will have branch or technology-specific characteristics
- Since research-based innovation depends on old as well as new knowledge, organisations working with existing as well as those working with new knowledge will be needed
- Thematic research and innovation policy foci need to be consistent with capabilities and needs along the whole innovation chain. This affects the connection between specific research and innovation activities on the one hand and national policy priorities on the other

4 The case study organisations

When selecting cases for this study we based our choice on the role of DLN within the innovation system where the centre operates, and the issues we have identified in the AS IS study. DLN innovation mainly plays a role in the early phases of innovation and not further downstream. Therefore, we have chosen cases working in the same phases of the innovation process to be able to gain insights and knowledge that the centre can use to explore and test new ways of operation. We have not attempted to explore examples of organisations whose focus is venture or other forms of capital investment, nor have we sought out examples of traditional technology transfer offices (TTOs) since the way such organisations conventionally work is well documented and is outside the set of skills and resources that DLN could reasonably command. We made one exception to this and included LRD at KU Leuven among the cases because KU Leuven is widely regarded as having world class TTO and incubation activities, which we believed would give us useful knowledge.

Table 1 lists the organisations we studied. Our cases involve:

- Two Norwegian state-owned research institutes – the Norwegian Institute of Marine Research (IMR) and Nofima
- Five university innovation centres, in the sense of groups funded within existing university structures to connect university research with industrial R&D and innovation. Two of these – Synbiochem and the UK Centre for Mammalian Synthetic Biology (CMSB) – were selected because of the central role of RRI, so the descriptions of their activities are less complete than those of the other three centres, the Industrial Biotechnology Innovation Centre (IBioIC), the Sustainable Aquaculture Innovation Centre (SAIC) and SynbiCITE
- Three specialised, free-standing, incubators, two of them – adMare and the BioInnovaton Institute (BII) – owned by independent foundations, as opposed to universities, and one - Umeå Biotech Incubator (UBI) - partly owned by the university
- Three large-scale research-performing organisations that internalise a wide range of knowledge exchange activities – Vlaams Instituut voor Biotechnologie (VIB), Wageningen University & Research (WUR) and KU Leuven

The inclusion of IMR and Nofima may seem counterintuitive. DLN is a project essentially based in Norwegian universities, so it was natural in this study to look abroad for university-related examples of good practice from which to learn. However, we observed that the Norwegian universities seemed to be poorly embedded in Norwegian clusters and 'innovation ecosystems' in addition to having poor links to industry. We suspect that this connects to the history and structure of Norway's research infrastructure, in which the institutes play a large role and the universities a smaller role than is the case in many countries. Norway has a fairly complete set of institutes, handling a large proportion of contract research. The obvious gap is in medicine and health[3] – a field where practitioners and industry almost everywhere get their knowledge direct from universities. In contrast to the universities, the Norwegian institutes are deeply embedded in their respective sectors, so it seemed sensible to try to learn from their experience.

There are two kinds of research institutes in Norway: research and technology organisations (RTOs) like Nofima, whose job is to support innovation in industry; and government laboratories

[3] However, there are strong institutes in public health

like IMR, whose primary function is to provide the government with the information needed to legislate and regulate, but whose work is often also very relevant to that of industry. We therefore explored one example of each type.

Table 1 Case studies in this report

Case	Type	Country	DLN sector
IMR	Research Institute: Government Lab	Norway	Biomarine
Nofima	Research Institute: RTO	Norway	Food and agriculture
IBioIC	University innovation centre	Scotland	Industrial biotech
SAIC	University innovation centre	Scotland	Biomarine
SynbiCITE	University innovation centre	UK	Industrial biotech
Synbiochem	University innovation centre	UK	Industrial biotech
CMSB	University innovation centre	UK	Industrial biotech
adMare	Free-standing incubator	Canada	Healthcare
BII	Free-standing incubator	Denmark	Healthcare
UBI	Free-standing incubator	Sweden	Healthcare
VIB	Inter-university research institute	Belgium	Industrial biotech
WUR	University and RTO	The Netherlands	Food and agriculture
KU Leuven	Knowledge exchange manager, including TTO and industrial liaison	Belgium	All

Synthetic biology is strongly represented among our cases, partly because this is an expanding part of industrial biotechnology and partly because it involves ethical issues that have attracted the attention of the responsible research and innovation (RRI) community in both social and physical sciences as well as among funders. In the Synbiochem and UK CMSB cases, we focused on RRI issues. While some of the others were to some degree concerned with RRI, this did not appear to play a very central role in their behaviour, so we used these two cases to explore RRI more deeply. Given time and resource constraints – not least that while our interview partners were helpful and willing, they also had limited time and wanted to get on with the day job – that meant that we were not able to learn so much about other innovation dimensions from them.

The commercialisation of university-generated knowledge is advanced in the USA and has been encouraged worldwide by the example of the US Bayh-Dole Act of 1980, which abolished the traditional 'professor's privilege' of personally owning intellectual property rights (IPR) to their inventions by assigning ownership of all IPR from government-funded research to the institutions at which it is performed. However, institutional arrangements in the USA reduce the relevance of comparisons with European countries. (There is also little US interest in RRI.) We have therefore focused our case work on North-West Europe and Canada, where relevant framework conditions tend to be closer to those in Norway than elsewhere.

Research Institutes

The Institute of Marine Research (IMR)

IMR is a Norwegian government research institute answering to the Ministry of Trade, Industry and Fisheries and is one of the largest in its field in Europe. It maintains a research fleet of 7 vessels and several field stations around Norway. Its main tasks are

- To give research-based advice to the Ministry of Trade, Industry and Fisheries, the Directorate of fisheries, Norwegian Food Safety Authority and other relevant authorities in questions concerning governance and exploitation of marine biological resources
- To make data and research available for the public administration, other research institutions, the marine sector, and society
- To deliver relevant research that contributes to knowledge-based development of the marine sector

The ministry provides funding of just over a billion NOK; IMR obtains about as much again from the Research Council of Norway; and there is a small income stream from selling services to industry. IMR is therefore essentially a government laboratory. Its responsibilities include understanding seafood markets and demand, in addition to providing information for regulating fishing and aquaculture and supporting Norway's position in international fishing treaties. It is of interest to this study because of its internal approach to digitalisation, innovation, and its need to maintain strong links with industry and understand its needs.

Nofima

Nofima is a research and technology organisation (RTO[4]), i.e. a research institute dedicated to supporting innovation in industry and elsewhere outside government. Its origins are in the canning industry's research association (1931) and later the research association of the fish meal industry. In its current form, it results from a merger between four research institutes relevant to aquaculture, food science and seafood, which comprise its three major divisions today. Nofima has no formal role in advising government or monitoring regulations. Nofima is owned by the Ministry of Trade, Industry and Fisheries (56.8%), a foundation for agri-food research and a company owned by the Møre og Romsdal region that has a mission to invest in research institutes. It is today a non-profit company with a mission to support seafood and agri-food production, which it does based on substantial core funding from the state, income from research funders especially RCN and the EU, income from research levies on fish and agricultural products, contract research and technical services funded by industry. Many of its projects will be partly funded by the state and partly by industry. Most of them address short-medium term, industrial issues such as reducing the use of plastic packaging, increasing yields, animal health and food safety and require an intimate understanding of industry needs and markets. It is of interest to this study as an example of an organisation working close to end-users' specific needs doing research.

University innovation centres

IBioIC

IBioIC is one of eight centres in the Scottish national Innovation Centre Programme (ICP). It focuses on industrial biotechnology for the circular bioeconomy, especially sustainable

[4] For more information on RTOs see the web site of the European Association of RTOs Earto https://www.earto.eu

feedstocks, biocatalysis/biotransformation, cell factory construction and process physiology, downstream processing, and integrated bioprocessing. Although it is formally based at the University of Strathclyde, IBioIC is in practice run by an academic network over several Scottish universities and has a wider network of over 120 companies and NGOs. IBioIC runs calls for proposals and brokers collaborative projects (typically in the range TRL 4-7) between industry and relevant Scottish universities, using its ICP funding to part-fund them. It provides technical services and advice from the academic network and offers scientific training from Higher National Diploma[5] to PhD level. It does not have its own incubation facilities but can broker access to scale-up facilities at Strathclyde and at Herriot-Watt University.

The Sustainable Aquaculture Innovation Centre (SAIC)

SAIC is located within the Institute of Aquaculture – one of the four institutes of the Faculty of Natural Sciences at the University of Stirling. SAIC operates as an autonomous unit within the University and receives public sector funding grants from the Scottish Funding Council (SFC), Scottish Enterprise (SE) and Highlands and Islands Enterprise (HIE), as one of eight centres in the national Innovation Centre Programme (ICP). SAIC aims to facilitate collaborations between academia and industry to drive commercial success and economic growth. It is not a legal entity or an organisational entity within the university, but is integrated into the Institute of Aquaculture, in effect as a large project.

SAIC does problem-orientated collaborative R&D projects with industry (typically in the range TRL 4-7), runs dissemination events and provides aquaculture-relevant training from apprenticeship to PhD level. To do this, it uses people and resources from the Institute of Aquaculture supplemented with additional SAIC-specific funding from UK and EU sources. It is an active participant in the Scottish aquaculture ecosystem, maintaining a network of over 200 organisations, including other Scottish universities and international aquaculture networks. SAIC co-funds start-ups through Scottish Edge and provide funding that could be defined as incubation.

SynbiCITE

SynbiCITE is located at Imperial College, a leading UK university of technology that is among the leading UK universities in integrating innovation and high-level research. It is the UK's national centre for the commercialisation of synthetic biology and was one of seven Innovation and Knowledge Centres (IKC) Funded by UK research and innovation councils[6] in 2013-18. It is run by two of the prime movers in synthetic biology research, who also have experience of growing their own companies. It builds on the more academically focused Imperial College Centre for Synthetic Biology (IC-CSynB), set up in 2008 and currently involving 36 research groups across 6 Departments from the Faculties of Engineering, Life Sciences, and Medicine. It maintains a large network of researcher organisations and companies. It offers small amounts of funding for proof of concept and developing prototypes, and brokers access to laboratory facilities and the London Biofoundry, which has the equipment necessary to do synthetic biology in practice. It provides access to scientific training at Imperial College and runs its own short courses on entrepreneurship in synthetic biology, especially a so-called 4-day 'MBA'. It provides coaching for relevant start-ups and is engaged in developing industrial standards

[5] Equivalent to a foundation degree or the first two years of a bachelor's degree

[6] Engineering and Physical Sciences Research Council (EPSRC), Biotechnology and Biological Science Research Council (BBSRC) and Innovate UK

needed to support the growth of industry based on synthetic biology. It emphasises RRI and is a member of various national RRI networks.

Synbiochem

Synbiochem is a centre funded as part of the UK's £100m Synthetic Biology for Growth programme[7], which also involved a road map and national strategy to strengthen research and industrialise synthetic biology in the UK. Like other UK activities in synthetic biology, it has a strong focus on RRI, which is the focus of our case study. Complementing SYNBIOCHEM, the University of Manchester was awarded a new £10m grant in 2019, the 'Future Biomanufacturing Research Hub' (FBRH).[8] Compared to SYNBIOCHEM, the FBRH is focussed on scale-up and commercial uptake of bio-based processes, and consequently also has a greater focus on collaboration with industry. For this study, we have focused on RRI, which is given much higher priority at Synbiochem than in most of the other cases.

UK Centre for Mammalian Synthetic Biology (CMSB)

The UK Centre for Mammalian Synthetic Biology (CMSB) was established at the University of Edinburgh in 2014 with funding from the UK research councils BBSRC, EPSRC and MRC under the £102m Synthetic Biology for Growth Programme aiming to 'stimulate innovation' by building research capacity and diverse expertise. At CMSB, the initial aim is to build tools for engineering cells to develop innovations in the biomedical field. CMSB provides opportunities for industry to access facilities, in-house training, collaborative projects, consultancy services, and licencing opportunities.

CMSB is based on longstanding multidisciplinary collaboration focused around the Centre for Synthetic and Systems Biology (SynthSys), which does more fundamental research. SynthSys was founded in 2007 based on another centre-of-excellence grant from the UK research councils.[9] For this study, we have focused on RRI at CMSB, to which – like Synbiochem – CMSB gives much higher priority than most of the other cases.

Free-standing incubators

adMare

AdMare BioInnovations is a pan-Canadian organisation funded by public and private actors focused on building the national life sciences industry. The enterprise was formed in 2019 through the merger of the Centre for Drug Research and Development (CDRD) which was Canada's national life sciences venture based in Vancouver and the NEOMED Institute, a not-for-profit R&D organisation building an innovation ecosystem in Montréal. Accel-RX, a Canadian health-science seed investor, joined in early 2020. AdMare provides early-stage investment – from seed corn to scale-up – access to research labs and facilities, and four levels of training, developing commercialisation and start-up skills at undergraduate, post-doc, and established scientist levels, and leadership skills for people running young companies. It also does foresights and scouting proactively to identify ideas and people to support, for example by maintaining relations with university TTOs.

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[7] https://bbsrc.ukri.org/research/programmes-networks/synthetic-biology-growth-programme/

[8] https://gtr.ukri.org/projects?ref=EP%2FS01778X%2F1

[9] BBSRC and ESPRC funded six Centres for Integrative Systems Biology

BII

The Bioinnovation Institute (BII) was established by the Novo Nordisk Foundation in 2018 and became independent of Novonordisk in 2020. It provides incubation services in health technology, therapeutics and bioindustries, with separate incubation programmes for early-stage start-ups and for companies with proof of concept and a business plan which need to find capital. A third programme is a faculty programme for strategic research. The first two involve giving the start-up convertible loans, which can be repaid or converted into equity to be held by BII. The latter involves grants. BII provides premises, training and coaching to the companies. It maintains partnerships with universities and drug companies as well as providers of capital and professional services,

University knowledge exchange

Umeå Biotech Incubator AB (UBI)

UBI is one of three specialised life incubators at the University of Umeå and supports medical innovators. It has a thorough step-by-step incubation process, able to take inventors at the university though to finding investors and starting to scale up. It provides seed money at the early stages, partly from internal sources and partly via external funding. Identifying and connecting to business angels and venture capital is a key part of the incubation activity.

VIB

VIB (Vlaams Instituut voor Biotechnologie) is a non-profit research institute that is spread across and operates in partnership with 5 Flemish universities. It is one of several inter-university institutes established during the rapid development of the Flemish RTI system from the 1960/70s onwards. Its main role was to build critical mass in biotechnology across the Flemish research system by building research capacity and providing shared infrastructure. It provides technology watch services and supports commercialisation via incubation, providing space for experimentation and start-up. It sits within several Flemish innovation and life sciences ecosystems. Thereby maintaining relationships with string incumbents as well as new starters.

WUR

WUR results from an operational merger between Wageningen University, the Netherlands' national agricultural university, and Wageningen Research, the national agricultural research institute of the Ministry of Agriculture in 1997. They share a common top management level but, having different legal bases, they formally comprise two different sub-organisations. Support for this collaboration hinges on 5 science groups – Agrotechnology and Food Sciences Group; Animal Sciences Group; Environmental Sciences Group; Plant Sciences Group and Social Sciences Group - that connect the work done at the university and research halves at WUR. A science group consists of a Wageningen University department that is integrated into the organisational structure of appropriate Wageningen Research institute(s).[10]

WUR has a technology transfer office (TTO), which is part of the university organisation (unlike the Norwegian pattern of the TTO sitting outside the university organisation as a profit centre). WUR also does industrial liaison, student start-up, and provides incubation services and entrepreneurial education. It is a key node in the Food Valley ecosystem.

[10] WUR (2019). Annual report Wageningen University & Research 2019. Available at: https://www.wur.nl/en/show/Annual-report-WUR-2019.htm

KU Leuven R&D (LRD)

Leuven R&D (LRD) at the Catholic University of Leuven (KU Leuven) in Flanders is the university's technology and knowledge transfer office. It is an autonomous division within the university. Its missions is "Promoting and supporting knowledge and technology transfer between university and society". LRD organises a rather complete set of services in support of the third mission, including acting as a KU Leuven's TTO.

- Provides a classical TTO function, scouting and managing invention disclosures, advising, and assisting in taking out patents, and managing and marketing KU Leuven's portfolio of intellectual property
- Manages research collaborations between the university and external organisations
- Manages KU Leuven's industry PhD programme
- Acts as an incubator, supporting staff in setting up spin-out companies developing business plans and finding a team
- Helps staff at KU Leuven find and apply for Flemish and Belgian national funding for research and innovation
- Helps staff find and apply for EU and other international research and innovation funding
- Manages the €35m circulating Gemma Frisius Seed Capital Fund
- Supports the Kick centre for student entrepreneurship

It charges a 17% overhead on commercial contracts with the university, half of which goes to the university centrally and half pays for LRD's administrative costs.

5 Findings from the case studies

Our aim in this report is to use international experience to explore how DLN and other actors in Norway can address some of the problems in the Norwegian life science-based innovation system we recorded in the AS IS report. In this section, we begin with some overall and systemic observations of the case study organisations. Thereafter, we comment on differences among the four sectors in which DLN specialises. Then we explore how the case organisations work in the individual domains in more detail.

5.1 General and systemic observations from the case studies

We have analysed the case studies to identify common features that can be used to understand how we can tackle the issues we have identified in the Norwegian system, as presented in the AS IS report. The analysis has been done mainly with the domain definitions in mind. However, we have observed several common features across the cases, which either are on a higher, systemic, level than the domains or cut across several of them.

One such observation is the advantage of thematic specialisation, which crops up in almost every part of the systems we investigate in this study, from the research process through the provision of research funding and capital investment, to the innovation support system. **The way research and innovation are done and their relationships to users and markets differ among branches, markets, and technologies, so those supporting innovation need specialised knowledge and specific network relationships in order to operate well**. For example, the UBI and BII incubators were set up in part because life sciences require specialised knowledge about regulatory requirements and different IP strategies compared to many other fields, mainly because it takes much longer to move from an idea to a product than in other technologies.

No support organisation can be present in all the different parts of the innovation process. Nonetheless, there is a clear pattern among our case study organisations that when they focus, they focus on a small number of related or adjacent steps. University innovation centres focus on interacting with the demand side to understand needs, doing research that helps satisfy them and cooperating with knowledge users so that they can take advantage of the results. TTOs focus narrowly on identifying, protecting, and selling or managing intellectual property. The incubators focus on refining ideas into inventions, starting companies, learning necessary skills, and finding investment capital. The very big organisations – VIB, WUR and KU Leuven – can take a more systemic perspective than the smaller ones, and flexibly trade off the costs and benefits of alternatives, such as choosing between itself owning intellectual property or continuing to take collaborative R&D opportunities together with an industrial partner. Smaller and more focused organisations may be highly effective in their niches, but their 'local optimisation' behaviour can cause sub-optimal behaviour at the systemic level. (This problem is at the centre of the current re-thinking of the TTO function in Norwegian universities.) The large organisations, such as LRD at KU Leuven and BioInnovation Institute in Denmark, are also able to internalise many of the various phases or steps of the innovation process, which small organisations like the adMare incubator and Umeå Biotech Incubator, may need to access through outsourcing or partnerships.

Most of the cases use a mixture of research and business experts in their governance, aiming to ensure focus on both technical and commercial viability. Most are also careful to recognise their limits, using external expertise where needed. These external inputs can include IPR, business planning, regulatory matters, and capital investment. This underlines the importance of knowing what you do not know, and bringing others' expertise to bear, where relevant.

Several of the case study organisations gain strength from playing roles in bigger national or regional strategies that support the development of innovation ecosystems.

- In the UK, the research councils first started to support synthetic biology in about 2007. The Royal Academy of Engineering's Synthetic Biology Inquiry Report[11] from 2009, and later the Synthetic Biology Roadmap for the UK in 2012[12], identified synthetic biology as a key potential driver of the UK bioeconomy.[13] The roadmap contained 5 main recommendations that connected capacity development to needs (including RRI). Following the roadmap's recommendations, the Synthetic Biology for Growth Programme invested £102m in research, including £70.5m in six multidisciplinary Synthetic Biology Research Centres.[14] Individual centres, such as SynbiCITE, have specific, quantified performance targets, underlining the seriousness of the plan
- SAIC was set up in 2014 as one of eight centres in the Scottish Innovation Centres Programme. In consultation with the industry and other research-performing organisations, it commissioned a sector study and innovation roadmap '*Scottish aquaculture: a view towards 2030*[15] together with the Scottish Highlands and Islands Enterprise agency
- IBioIC, another of the eight Scottish innovation centres, was set up as part of the implementation of the Scottish National Plan for Industrial Biotechnology and is aligned with national targets for the industrial biology sector. These targets include generation of more than £400m of IB sales Scotland-wide; creation of 1,500 new jobs in the sector; securing inward investment projects worth more than £140m; creation of more than 25 start-up businesses. IBioIC is measuredf against the targets on an annual basis
- The Flemish cases – VIB, WUR and KU Leuven – all work within a long-standing development policy in Flanders, based on building and strengthening research and innovation in a handful of prioritised sectors. The development policy has driven the creation of strong business and innovation ecosystems.
- BII is in a special position, in that it is a component of a private innovation ecosystem sponsored by the NovoNordisk Foundation. BII was split off from the NovoNordisk Foundation to incubate high-risk opportunities. Successful start-ups can move back into the ambit of NovoNordisk to obtain more capital for scale-up and growth. BII's investment objective is to break even, but the NovoNordisk Foundation will back it up if necessary

Irrespective of whether they focus on entrepreneurship or wider knowledge exchange**, most of the case study organisations take care to embed themselves in networks that provide information about demand.** This can be done in a variety of ways, including by setting up company clubs, by providing technical services, organising cluster networks, disseminating information about research and innovation, doing collaborative research, offering industrial extension services, and so on. Some of the cases go so far as to arrange workshops with groups of potential users to identify problems that could be addressed through innovation.

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[11] https://www.raeng.org.uk/publications/reports/synthetic-biology-report

[12] https://www.gov.uk/government/groups/synthetic-biology-leadership-council

[13] UK Synthetic Biology Start-up Survey, SynbiCITE, 2017

[14] http://www.synbicite.com/news-events/SynbiCITE-videos/creating-synthetic-biology-industry/

[15] Gatward I, Parker A, Billing S, Black K, et al., 2017, 'Scottish Aquaculture: a view towards 2030'.

The UK centres studied tend to follow a similar pattern of research investment within a university over a longer period, focusing either on a promising enabling technology such as synthetic biology or an acknowledged area of national economic importance, such as aquaculture. They build capacity through a combination of university and externally funded project investments, which may include centre-of-excellence funding. This is then strengthened via innovation centre funding, that builds on the established research capability and strengthens and extends its industrial ecosystem. Unlike normal academic grants, those for the innovation centres involve quantitative performance indicators related to activities and outputs, economic outcomes, and job creation. These are reviewed frequently, often annually, with an understanding that inadequate performance will lead to withdrawal of the funding. For policy, it is important to note that creating these centres involves (top-down) thematic prioritisation at both national and university level as well as linkage to actual and potential industry partners. They do not arise spontaneously, solely based on bottom-up research funding.

A final commonality among many of the cases is their stress on training – either in the technological focus of the case study organisation or in entrepreneurship – and often in both. We discuss this further under Domain 5, below.

5.2 Differences among DLN sectors

DLN aims to address four sectors: biomarine, food and agriculture, healthcare, and industrial biotechnology, and our case study organisations were chosen to cover them all (Table 1). The cases tend to confirm our observation in the AS IS report that these sectors have somewhat different characteristics. The first two sectors have historically had low rates of innovation. Their small size relative to the market and the low technological capabilities and absorptive capacity of individual producers – fishers and farmers – mean that R&D-intensity has historically been low. Hence, many countries have operated state-owned research institutes and (in agriculture) state extension services to generate and disseminate innovation. While, today, there are growing numbers of R&D-capable firms in these sectors (and especially in the supply chains providing them with capital goods and other inputs), the state still tends to take a more active role in innovation than in the other two sectors DLN addresses. Thus, Norway still operates levy systems in fishing and aquaculture (Fiskeri og havbruksnæringens forskningsfinansiering FHF) and agriculture and food (Forskningsmidlene for jordbruk og matindustri – FFL/JA) to fund research for the collective good in these branches.

Biomarine innovation in Norway tends to focus to a considerable extent on aquaculture, which is the part of the sector that needs to grow most, faces a rich array of challenges ranging from fish health and treatments, production, environmental issues, diversification and improvement of farmed species, feeds to capital equipment. These concerns are echoed in other countries where aquaculture is important, such as Scotland and Chile. Innovation therefore needs to address a wide variety of needs and diverse types of organisations, including both large established suppliers (for example, in feeds) and many small start-ups addressing small technology niches.

Food and agriculture traditionally contain a mix of large incumbent firms (with varying amounts of technological capability – and in the case of Norway some degree of monopoly power) and small specialists, generally with modest technological capability. As in the rest of the economy, technological capability is generally rising and parts of the sector involve disruptive and increasingly technology-based product innovation, driven by increased consumer interest in vegetable-based foods.

Healthcare tends to have innovation pathways that are well structured and well understood. Healthcare companies, especially in pharma, have high absorptive capacity and can make use of research results at low TRLs, though they often prefer it if someone else bears the cost and risk of moving knowledge up to higher TRLs. IPR and entrepreneurship are very important, and a common business model involves establishing a technology-based company with the intention of selling it to one of the large incumbent firms. Healthcare-related patents drove the growth of university patenting from the time of the Bayh-Dole Act and currently dominate patenting overall at the EPO. The needs of healthcare also drove the way first-generation TTOs work. The healthcare innovation system also benefits from great scale, allowing specialisation in innovation support and investment. Our healthcare cases are in countries with strong national companies and healthcare innovation systems (UK, Denmark and Sweden), so they probably can link to industry and investors more easily than their Norwegian counterparts.

Industrial biotechnology in general is a well-established field, but there is an immense amount of research and innovation activity, especially in synthetic biology, and the bio-economy more generally. These activities are highly relevant in the other sectors addressed by DLN. R&I policymakers can see that these areas contain key emerging technologies and are investing heavily in them. Because these are new technologies, the relevant case-study organisations play important roles in capacity building as well as innovation. The wide range of potential applications means that the innovation ecosystems involved are diverse, containing organisations from many different sectors with different dynamics. Some of the innovations emerging – for example, vegetable-based imitation meats and certain process innovations – are potentially disruptive.

A few important sector differences emerge from the cases.

- Industrial biotechnology – and especially synthetic biology – creates innovation opportunities that cross traditional sector boundaries, and therefore seems to require greater effort in innovation support, not least in helping spread understanding of the technologies and the innovation opportunities they provide
- As an important emerging technology, synthetic biology, is also linked to national strategy and programmes. This provided not only programme funding but also wider communities of researchers and innovators, within which to operate
- Synthetic biology and other parts of industrial biotechnology raise issues in ethics and social legitimacy. Most of the work that we found on RRI was concentrated in that field

5.3 D1 Digital life capacity, transdisciplinarity and convergence

The Centre for Digital Life Norway is an ambitious and large-scale initiative to foster and boost transdisciplinarity and convergence between digital and life sciences, to address the rapid developments in biotechnology to do better research and generate more innovation and value for society. The AS IS study found that this convergence is not taking place sufficiently in the Norwegian state-funded research system. Possible causes included lack of data skills and capabilities in Norwegian life sciences, and insufficient e-infrastructure to facilitate the convergence. The universities seemed to find it hard to create cross-disciplinary links and structures between the data sciences and life sciences, which still work in silos. Insufficient understanding of other research disciplines than one's own and lack of common terminology, data norms and standards across different scientific fields were sometimes seen as barriers to transdisciplinary work. One specific underexploited area was the failure fully to utilize Norway's almost unique health-related databases, which are assumed to be a gold mine with regards both to research and innovation.

Domain 1 therefore explores the initial conditions in case study organisation, their approaches to interdisciplinarity and the way they implemented convergence.

Initial conditions, organisation, and skills

Our cases mostly involve problem-orientated organisations. We did not see examples where a general need to solve problems triggered a decision to become more interdisciplinary. Nor were there cases where organisations were fussy about maintaining a distinction or hierarchy between 'basic' or purely curiosity-driven research on the one hand and applied or innovation-orientated work on the other, as is unfortunately still the case in some traditional, Humboldtian universities.

Unlike DLN, none of the case study organisations we selected were examples of organisations making strategic decisions to operate in the convergence between digitalisation and the life sciences. However, in at least six cases, life sciences organisations had set up new sub-groups to strengthen their capacities by increasing the instrumental[16] use of digital techniques in a managed way.

The most relevant case with regards to Domain 1 is Wageningen University and Research, WUR, with their Data Competence Centre, WDCC - a small, centralised support unit that focuses on developments in Big Data, IoT, and data science. It is embedded in the infrastructure of WUR, chiefly collaborating with the different science groups and units. The objectives for WDCC are very broad and cover education, research, and innovation with the purpose to help the two organisations – Wageningen Research and Wageningen University - to benefit from digitalisation both in research and in innovation. WDCC therefore provides digitalisation support to the whole chain from education and research to technology transfer (referred to as value creation) and offer services in data, technology, and analytics. The objective with respect to innovation is to organise a process that takes into account the opportunities for value creation from the outset in the development of new concepts and services based on big data, and to provide industry with opportunities for data science courses. WDCC has two Value Creation Coordinators working with internal and external alliances, networks and coalitions to ensure that WUR is represented in the infrastructures that are involved in digital data, and to facilitate public-private partnerships with industry for the development and commercial application of research. WDCC also has Data Stewards acting as points of contact regarding (big) data policy and developments, facilitating the implementation of the WDCC strategy in WUR. The Data Stewards help transfer knowledge from WDCC to the different science groups of WUR as a facilitator of applying data science rather than a data science research unit.

Role of e-infrastructure and data assets

In at least five of the cases we have studied, the organisations were able to create e-infrastructures in the form of scientific data repositories and make them at least partly available to others outside the organisation. IMR and WUR offer particularly clear examples of task-forcing to develop e-infrastructures that support convergence. Data is key in most of the research and advisory activities IMR do, and the data collection spans everything

[16] While an instrumental approach to digitalisation makes perfect sense from the perspective of groups whose intellectual roots are in other disciplines, it is tempting to speculate on the opportunities that might be uncovered via a less structured meeting between the playful curiosity of an organisation like the Alan Turing Institute (or Simula?) and parts of the life sciences

from mapping and monitoring to experimental studies and modelling. Therefore, it is crucial to IMR to have systems for storage, use and sharing of all their research data. Because of the use of new research methods based on digital solutions and new sensors, the amount of storage need has multiplied and will continue to do so. The organisation therefore has a constant and proactive focus on good and secure storage solutions and efficient methods for data transfer from sampling to storage. It has made its own investments to secure storage capacity for the next four years. Producing public goods in this way also encourages collaboration, signals usefulness to potential users and generates legitimacy within wider ecosystems.

None of our cases offered solutions to the under-exploitation of health data that we see in Norway, and most countries. However, within the marine sector, there were good examples of how large research data sets can be used and shared for both research and innovation. Of course, those data do not present the same issues and difficulties with regards to data security as personal health data records do, but the examples could still serve as inspiration.

Nofima, IMR and WUR additionally collect and make available data about markets and demand, in effect providing public goods (information) in support of problem identification and eventually innovation. These three organisations have wide mandates in which the production of public goods plays an important role. Several of the smaller organisations with a narrower focus also collected demand-side data, using them to guide their actions and identify opportunities both for research and innovation. This information was likely to be most useful to their immediate networks and is made less widely available.

5.4 D2 Research and innovation funding and capital investment

While there are funding mechanisms in Norway that are intended to help move research results towards commercialisation, the AS IS study concluded that they are fragmented and do not offer comprehensive support for bringing ideas all the way from research to a stage where private capital is willing to invest. There are perceived gaps in public funding for use-oriented basic and translational research, and in the phases between research and idea generation up to proof of concept (PoC). Where support is available, the conditions are sometimes seen as onerous, given the amount of funding offered. There is no funding instrument or mechanism for hiring people to work on business development of an existing research project and it is difficult to keep key people such as post-docs in post once the research stage finishes, because they work on fixed-term research contracts.

The AS IS study also pointed out the difficulty of obtaining investment capital for early-stage life-sciences firms in Norway – partly because the Norwegian venture investment industry is small and lacks relevant expertise, and partly because of poor linkage between Norwegian investment opportunities and international investment markets combined with lack of interest in creating such links. There are also few business angels in Norway. Norway suffers from the more general problem that investors tend to avoid the small investments needed early in firms' development, which involve high risks and a high ratio of assessment costs to the total cost of the investment. They generally prefer to invest once start-ups have become established enough to demonstrate their potential, reducing the risk and the ratio of assessment to investment cost. State efforts to support 'seed corn' funding to close this gap appear largely ineffective.

This section explores how and under what conditions researchers and innovators involved with the case study organisations can access funding for commercialisation research within their respective national funding systems and within the case-study organisations, as well as how these organisations help them access early-stage investment capital.

5.4.1 National funding for commercialisation research

The countries where our case study organisations are located have state funding systems that, like Norway's, to some extent support 'commercialisation' or (in medicine) 'translational' research that builds on more fundamental research. We are not able to comment on the adequacy or completeness of these Instruments in the countries where the case-study organisations are located, but it is important to note that the case study organisations do not stand alone – they are backed up by wider, state-run programmes and instruments. Equally, there is a background of – often thematic – state R&D programmes that support collaborative research.

RCN has funding instruments for feasibility studies and for verifying the commercialisation potential of ideas. At later innovation stages, Innovation Norway has a range of grant and loan instruments for start-up and innovation. Similar kinds of support are available in the countries where our case study organisations are based. The UK research councils offer translation and PoC funding to university researchers and to companies via Innovate UK. In The Netherlands, NWO offers PoC grants while RVO in The Netherlands offers PoC loans to companies. Flanders Innovation and Enterprise provides PoC grants to companies while the Flemish Research Foundation funds translational research in medicine but not in other kinds of commercialisation research. Innovation, Science and Economic Development Canada funds translational research through the Natural Research Council of Canada and company R&D via the council's long-running IRAP (Industrial Research Assistance Programme). The Swedish innovation agency, Vinnova, provides funding for collaborative R&D through strategic innovation programmes. However, seed funding does not appear to be well integrated into the research and innovation support system in any of these countries. Nor do the main R&I funders offer funding to strengthen the innovation dimension of already-established research projects.

5.4.2 Funding for commercialisation research in the case-study organisation

Most of the case study organisations offer some funding. Some, like IBioIC, SAIC and SynbiCITE, have individual calls, where the funding is the focus, whereas other organisations like adMare, BII, UBI and VIB, offer funding as part of a comprehensive support package, an incubator or accelerator programme. Independent of the framing of the funding, all organisations seem to have developed instruments to overcome the early hurdles we have observed in the Norwegian system, going from an idea into a concept that is sufficiently developed for private capital to invest. In addition to funding to run commercialisation projects, some organisations have funding to boost collaboration between industry and academia. The most prominent examples are the Scottish centres, IBioIC and SAIC, which largely fund collaborative projects.

Our case study organisations defined as university innovation centres (IBioIC, SAIC, SynbiCITE, Synbiochem and UK Centre for Mammalian Synthetic Biology) are normally based on (fixed-term) grants from research and funding councils. These may fund university projects intended to inform innovation, typically on the mid-range development scale, TRL 3-7, to bring the projects through critical phases such as feasibility studies, PoC studies, scale-up and optimisation. Activities that the funding can support include intellectual property protection, exploitation, freedom-to-operate reviews, legal and professional costs including commercial business plan development and assessment of market size and reach, support for prototype development, manufacturing cost assessment and other aspects required as part of validating a commercial investment decision. Sometimes the money can be used also to pay staff to undertake specific activities to accelerate the commercial opportunity. Along with the money, some of the organisations also offer access to facilities needed to perform the funded activities.

Projects are sometime required to be done in collaboration with industry. The Scottish centres IBioIC and SAIC only fund collaborative projects between industry and academia which address a defined market need and commercial opportunity. The project must also demonstrate an economic, societal and/or reputational benefit to Scotland. Funding offered is typically in the range €50k to €100k and is usually granted to the academic partner. Often, the company must provide a substantial minority of the cost in cash or in kind. The centres' grants allow them in some cases to fund or part-fund commercialisation or translation research and some of the early work involved in a start-up, and they may be able to access other external grant-funding resources to increase the amount of work they can grant fund. These centres have no capital of their own, so while they may help start-ups look for equity investments, they will not themselves provide them.

In contrast to the university innovation centres described above, the three free-standing incubators, UBI, BII and adMare, have a flow of budget funding that they can use to give grants to inventors or start-ups, funding early-stage technical activities and necessary business development, which otherwise is difficult to find money for. Since their business model is primarily to drive company development through equity investment, they all focus their attention on this.

UBI is a very small, stand-alone, specialised life science in health incubator, partly owned by Umeå University. Projects and start-ups entering UBI's incubation process are offered grant funding from the budget income of UBI and from time to time from external programme funding. UBI's involvement with equity investment is limited to the verification phases of the incubation process, helping start-ups develop and verify their ideas and later identify, approach and pitch to potential external investors from various countries in north-west Europe. UBI never takes shares in the ideas it incubates.

BII has a slightly different model. Rather than investing in equity, BII provides start-ups with convertible loans. Therefore, they require the inventors to set up a company as soon as they enter any of their innovation programmes, independent of how early they are in developing the business. At the end of the incubation process, if the start-up fails to reach its targets, BII writes off the loans and closes the company. If the company is successful, it can either repay the loans or convert them into minor equity to be held by BII. (Equally, it is possible to leverage grants into equity, where universities adopt a policy of taking equity in their spin-off companies as a quid pro quo for the university's support, though we did not see an example of that among our case studies.) The terms and conditions of the loans are very generous for the inventor and not intended for BII to make profit. Like UBI, BII is very careful not to take equity in companies they are currently supporting, as that would make it harder to stop projects that are failing.

In contrast, adMare has a vision of eventually becoming self-sustaining through the returns on its investment portfolio. Its current funding streams allow adMare to invest in technology that requires additional validation as well as to support companies via pre-seed capital investments. AdMare focuses on therapeutics and diagnostics but considers AI and digital health as emerging areas. The initial investment from adMare generally ranges between C$500k and C$3m. Further investment can follow at a similar scale. The type of investment used is tailored to the company, but is primarily equity. AdMare can either be the sole investor, or a co-investor alongside venture capitalists, (and prefers to involve other investors as early as possible).

The big research organisations – VIB, WUR and KU Leuven – have larger, more comprehensive, and potentially more flexible knowledge-exchange arrangements and funding. They benefit from institutional and often also external funding that they can invest in translational research and commercialisation grants. In some cases, this comes from foundations associated with the university. The universities tend also to own foundations or funds that risk small amounts of their own money via equity investments. Reflecting the universities' societal missions, these tend to be 'evergreen' funds that reinvest earnings in future start-ups rather than profit-maximising for the benefit of their owners.

VIB, as an example, also runs incubator activities similar to what BII and UBI do, from idea to the phase where private capital can be attracted. The PoC stage of their incubation process includes opportunities to receive investments from the VIB internal PoC Fund. This enables VIB to provide early-stage equity capital for start-ups that are considered interesting and have commercial potential. It has been suggested that the PoC Fund makes it possible to target research with low scientific impact but high commercial potential.

WUR hosts an accelerator, StartLife, which is regarded as one of Europe's leading accelerators for innovative Food and Agtech start-ups. StartLife runs two funding programmes for start-ups: pre-seed funding, and student start-up loans. StartLife pre-seed Funding is available to start-ups admitted to the StartLife Accelerate programme and is composed of a loan of up to €75,000 that is divided into 2 payments: 1) a payment of €25,000 after successful completion of the StartLife Accelerate programme and 2) €50,000 after reaching milestones agreed with the StartLife team. There is also an optional additional one-time investment of €175.000 for start-ups that the accelerator views as having high potential. For each part of the payment the start-up must pitch to a StartLife Review Board composed of agrifood investors and serial entrepreneurs. StartLife student start-up loans are aimed at WUR graduates, within two years of graduation. The Loan is up to €8.000 and is only available to those who have not registered a start-up at the Dutch chamber of commerce during the previous five years.

LRD, the Tech Transfer Office of KUL, offers pre-seed capital through its Centre for Drug Design and Discovery (CD3) and seed capital through the Gemma Frisius Fund (GFF) (further described in the next chapter). The aim is for LRD to be able to provide all the kinds of funds and support needed for the researcher to commercialise research. CD3 capital is co-provided by the LRD and the European Investment Fund (EIF) with three funds, launched in 2006, 2010 and the latest in 2016 (with a capital of €60 million from the LRD and EIF)[17]. In total, CD3 has received €84m.[18]CD3 works with potential drug discoveries, focusing on funding the translation of innovative research into promising drug discovery programmes that are well qualified for further development by pharma or biotech companies.

LRD also manages the KU Leuven Patent Fund which is available to researchers who lack sufficient financing to fund their patent applications themselves. (LRD provides guidelines for researchers about the costs of patenting at different stages to support their decision making.)

[17] KU Leuven (2016). KU Leuven's Centre for Drug Design and Discovery closes 60 million euro fund to turn academic research into new medicines. Available at: https://lrd.kuleuven.be/en/news/ku-leuven2019s-centre-for-drug-design-and-discovery-closes-60-million-euro-fund-to-turn-academic-research-into-new-medicines

[18] Centre for Drug Design and Discovery (2021). Organisation. Available at: https://www.cd3.be/about-cd3/organisation

The fund is supported through contributions from licence income[19], in line with LRD's overall approach of maintaining the self-sustainability of its operations.

LRD also manages governmental funding instruments to realise industrial proof-of-concept studies or produce convincing prototypes for the market. KU Leuven Industrial Research Fund, financed by the Flemish government, supports innovative research & development projects with clear industrial or societal applications. Several specialised incubation instruments were created to finance projects at an early stage of development. Further the LRD's Flemish and Federal Government Funding Department supports researchers in applying for government funding. These applications must be to finance public-private partnerships with an aim to implement research results.

Grants and investments tend quickly to run into the hundreds of thousands of Euros, and sometimes more. AdMare and BII both pointed out that their earlier grants had been small, but that no single grant was then enough to get a company from start-up to having proved both the technical and the business concept or reached another major milestone. This impeded the start-up process, so both organisations decided to work with larger sums of money and changed their models accordingly. At the same time, they are all aware, that innovation is a 'numbers game'. Because of the risk and uncertainty at this early stage of innovation, they need a portfolio of investments to capture a few ideas that will succeed. The amount needed seems however to be context dependent, with pharma projects usually needing much more funding over a much longer time than is the case for more technology-orientated inventions in for instance the marine and food sector. SynBiCITE is the only case organisation going in the opposite direction to adMare and BII, and who after two programme periods have found that more investments of smaller sums have more impact than fewer and larger grants. The rationale behind this is that much of the research within synthetic biology only need small support to de-risk development in synthetic biology, helping projects to reach an investable state at low cost.

Our case organisations also tend to follow the same practice as state funding agencies by running periodic calls for proposals, rather than being ready to accept proposals at any time. That increases the amount of choice they have when making funding decisions. As with state funders, it was important to use transparent application and assessment processes to gain the confidence of the research community. Given the nature of the projects being funded, organisations emphasised the need to have both scientific and business input into funding decisions. Examples of the case study organisations' assessment processes are found in Domain 6.

5.4.3 Access to early-stage investment capital

Capital investors, like the case study organisations themselves, tend to be specialised on sectors of industry where their knowledge and networks give them better information than others. Even within the three large organisations studied, both the innovation support and the capital investors with which they work are in fact specialised. The case study organisations tend to focus on what we might think of as a 'commercialisation gap' problem – that is, either funding and doing the research needed to move from a research idea to one with verified innovation potential, ready to be funded by private investors or used as a basis for entrepreneurship through a start-up, or alternatively incorporated into collaborative R&D with an company that may then use the results in innovation. They use varying mixtures of grants

[19] KU Leuven (2021). KU Leuven Research & Development Advancing the Impact of Research Results. Available at: https://lrd.kuleuven.be/doc/lrd-brochure-2021

and seed-style investments (or help in accessing them) to overcome this commercialisation gap, leaving subsequent investment stages to the markets or collaborating firms. In some cases, it is possible to involve networks of 'business angel' investors. The few organisations that do invest their own money tend to leave the capital investment decisions to external, often very specialised, organisations to get high-quality, independent judgements, avoiding the risk that earlier commitments of work and money cloud investment decisions.

Incubators generally do not invest their own capital in companies – they deliberately avoid mixing roles, such as being both an investor and innovation support. Many therefore subsidise research and translation from their own or others' budgets, as explained in the previous chapter, but hand over to private capital once the idea is sufficiently developed. Both BII and UBI have networks of investors and venture capitalists with whom they collaborate. BII is surrounded by a strong financial system, thanks to the Novo ecosystem. UBI, on the other hand, suffers from not having investment-willing capital in its region. Private capital has to be attracted from elsewhere. UBI is therefore extremely careful about building and maintaining its brand and consider private investors as its customers; they listen to them and adapt their processes and way of working to the needs of the private investors. When the investors realise that UBI does listen to them, their interest to invest increases. It is a matter of building a long-term relationship. UBI also acts as a bridge between a Swedish business angel network and the companies in UBI's incubator, helping the business angels understand the business ideas and the market potential in doing life science investments.

AdMare has a different strategy than UBI and BII and has brought in a pre-existing life sciences seed corn investor, Accel-Rx. This has added both expertise and capability in seed-stage investment and entrepreneur development to adMare, which will further its position as a one-stop shop. Through this partnership, adMare and Accel-Rx can offer funding even further downstream than incubators normally do, reaching past the PoC phase. Together with Accel-Rx, adMare can stimulate co-investment by private investors to provide capital for early-stage life sciences companies.[5]

The large research organisations have a slightly different approach. KU Leuven maintains its own 'evergreen' investment, the Gemma Frisius Fund (GFF) that recycles profits into start-up support. GFF is the seed capital fund designed to stimulate the creation and growth of KU Leuven spin-off companies. The fund is a joint venture between KU Leuven (20%), KBC Bank (40%) and BNP Paribas Fortis Private Equity (40%) and was launched in 1997. GFF entails a combination of knowledge and technology transfer expertise (university) and financial expertise (financial partners). The fund has about €36.5m invested in 58 spin-off companies.[20] GFF focuses primarily on first-round funding. Exceptions can be made for second-round funding if this is necessary to ensure the spin-off's growth. In such cases GFF cooperates with other external investors. GFF funding period generally lasts for 7-10 years. LRD also maintains a network of business angels and investors it has attracted and with which it has had prior dealings. This network of investors is involved in second round funding.

VIB benefits from a close relationship with the V-BIO Ventures fund, which VIB launched in 2015 as an early-stage life sciences investment fund. V-Bio Ventures invests throughout Europe in start-up and early-stage life science companies with high growth potential. The fund focuses on investments in (bio)pharmaceuticals, diagnostics and agricultural improvements. The role

[20] KU Leuven (2020). Gemma Frisius Fund: portfolio. Available at: https://lrd.kuleuven.be/en/spinoff/gemma-frisius-fund-portfolio

of V-Bio Ventures in collaboration with VIB is a twofold one. First, the fund helps VIB get an early perspective from a venture capital investor regarding the market potential of the start-ups they incubate, and secondly, investment from V-Bio Ventures helps attract other investments as the involvement of a venture capital fund is seen as an endorsement to the commercial potential of the start-up.

5.5 D3 Operating within innovation ecosystems

Innovation ecosystems are thematically focused communities of organisations containing many network relations that offer rich contexts for innovation. The significance of using the ecosystem concept, and not only the system concept, is that the analogy with organic ecosystems brings in idea of simultaneous competition and collaboration, symbiosis, evolution and co-evolution among parts of the ecosystem (Moore, 1993). The term innovation ecosystem is therefore often used to describe the system of various actors such as universities, government, corporations, supportive organisations such as TTOs, start-up accelerators, venture capitalists, private investors, foundations, entrepreneurs, mentors, etc. that are critical for innovation to take place and several thematic innovation ecosystems can exist in parallel, i.e. around various value chains. One of the characteristics of an efficient and successful innovation ecosystem is that each player can have a significant role in the process of transforming new ideas into economic and societal value.

Norway has several innovation ecosystems relevant to DLN. However, according to the findings of the AS IS study, they do not generally function as efficient vectors of digital life research results into commercial products and services. Many of the players specialise in a specific sector, but these existing ecosystems seem to be sub-scale and insufficiently specialised to generate useful knowledge transfer and business opportunities. It was also found that relevant partners are numerous but fragmented across multiple ecosystems and therefore are not sufficiently networked to create efficient innovation ecosystems at the national level.

Even though the Norwegian innovation ecosystems include actors relevant for early phase innovation development, such as the Tech Transfer Offices (TTOs) and some incubators and accelerators in addition to early phase venture capitalists, it is found that the sector-specific business clusters, most of them funded through Innovation Norway's cluster programme, play a dominating role. Many of these business clusters are primarily networks of small and large companies, and do not involve research-performing organisations, technology transfer or start-up support, though some focus on innovation. The AS IS study found that there are often poor links between university research and other actors in the innovation ecosystems, in particular the business clusters. The ecosystems thus seem to be most effective in relation to growth and scaling of established businesses. The low level of R&D done by many of the companies is a barrier to innovation. Raising the level of such networks to tackle innovation and become integrated parts of the innovation ecosystems is an important development policy objective, though there is a risk that they can become policy- rather than business-driven.

This domain explores how case study organisations participate in ecosystems, with the aim of increasing the use and commercialisation of research-based knowledge. It describes the types of ecosystems in which they are involved from the perspective of the case organisation and how they and other relevant actors engage with them. Therefore, none of the ecosystems discussed below is described in full detail but only presented based on the understanding of the case organisation. This domain also considers the roles of the research-performing organisations in the ecosystems, the role of infrastructure and services and the development of absorptive capacity among companies, and how the case study organisation makes use of the ecosystems to help them understand user needs and potential demand.

5.5.1 Characteristics of the ecosystems and the role of the case study organisations

The case organisations we have studied come from different countries around Europe – Norway, Sweden, Denmark, Scotland, UK, Belgium (Flanders) and the Netherlands – and from Canada. The national innovation systems of these countries within which our case organisations operate are all slightly different in the way they are organised, and which players are involved. Government's roles in the various innovation ecosystems also vary quite a lot – in some countries, the government has been the initiator both in terms of policy and funding, whereas in other countries the ecosystems have evolved organically over time. Innovation ecosystems are in general characterised with an element of self-organisation compared to other innovation systems, and many of the most successful innovation and business ecosystems have self-organised over long periods.

Canada, is an example where the government has taken initiatives and invested in a Super Cluster Programme to boost innovation and growth in a particular industry. The clusters are areas of intense business activity made up of companies, academia, and not-for-profit organisations that boost innovation and growth in a particular industry. There are currently five Super Clusters in the areas of Digital Technology, Protein Industries, Advanced Manufacturing, Scale AI and Ocean. AdMare, the Canadian case organisation included in this study, is not part of the cluster programme but was created based on the desire of the federal government further to utilise Canada's resources and create a more dynamic and efficient environment for commercialising research and creating world-leading companies.

Denmark, on the contrary, has a very strong life science sector, partly because of the strong life science industry led by the Novo ecosystem consisting of Novo Nordisk A/S, Novozymes A/S, Novo Holdings A/S, Novo Nordisk Foundation and BII. Together with the government funding body Innovation Foundation Denmark and Lundbeck, these organisations form a very strong base for life science commercialisation in Denmark and beyond. (NNF, NH and BII also fund opportunities outside of Denmark.) The Danish innovation system within life sciences now has critical mass, with many actors and funding opportunities that allow university-based life science innovations to be commercialized effectively, in comparison to other European locations. The proximity to Southern Sweden has also given rise to the Danish-Swedish life science cluster Medicon Valley, with more than 200 biotech, pharma and medtech companies, 15 incubators and science parks and approximately 80 contract research and manufacturing organisations.

The Swedish innovation ecosystem, studied through UBI, is something in between the Danish and Norwegian. Life science and innovation are high priorities for the Swedish government, which established a Life Sciences office in 2018, with the task of promoting the development of knowledge, innovation and quality in healthcare, the life science sector and at universities and colleges. The office aims to improve the conditions for life sciences companies that establish themselves and work in Sweden. Sweden also has a strong international life science industry with Astra Zeneca as one of the major players. Unlike Denmark, the Swedish industry has not taken a funding role in the way that Novo Nordisk has done. Instead, Sweden has the Knut and Alice Wallenberg Foundation which is a strong supporter of Swedish research and education and recently donated SEK 3.1 billion to a 12 year research programme in data-driven life sciences. The programme is managed and run by the Swedish national life sciences infrastructure SciLifeLab, consisting of more than 40 different research facilities all over Sweden, offering free services to the Swedish research community. The Swedish system is also quite complex and fragmented, with innovation offices, incubators and holding companies partly connected to the individual universities, and having partly overlapping agendas. In addition, there are the public funding agencies Vetenskapsrådet and Vinnova, several strategic innovation programmes (SIP), various interest groups, trade associations, etc. One major difference between the Swedish and Norwegian system is that Sweden still has 'professor's privilege', giving Swedish researchers full ownership of their findings. Hence, there are no Tech Transfer Offices with automatic ownership rights to researchers' ideas and the innovation offices only work with the good will of the inventors. Another difference is the Norwegian cluster programme which has no equivalent in Sweden today.

The UK innovation ecosystem has been studied from the perspective of synthetic biology and using SynbiCITE as case. This is the UK national centre for industrial translation and commercialisation of synthetic biology and one of seven Innovation and Knowledge Centre (IKC) in UK which are set up to are set up to nucleate new industries, by closing the gap between scientific research and its commercial exploitation within emerging technologies. Synthetic biology is a rather new field which has developed rapidly in UK during the last decade and a complete innovation ecosystem has developed. Several of the important organisations within that ecosystem, like SynbiCITY, are located at Imperial College. In addition to SynbiCITY, which is a collaboration of the UK's leading academic institutions and industrial partners, ranging from MNC's to start-ups and supporting organisations, there is the more academically focused Imperial College Centre for Synthetic Biology (IC-CSynB) which provides strategic thinking and vision for synthetic biology whilst developing an open, inclusive, and collaborative environment for interdisciplinary research and ideas to flourish. There is also the London DNA Foundry which provides state-of-the-art automation of end-to-end design, construction and validation of large gene constructs to prototype new biologically based chemicals, drugs, and materials. Together these three organisations comprise a solid pipeline for the process of going from academic research to a product for the market. Part of the ecosystem are also seven synthetic biology research centres located around UK, of which the three in Bristol, Edinburgh, and Manchester are more focused on entrepreneurship than the others. What is interesting with the innovation ecosystem for synthetic biology is that it all started with the strong belief of a few researchers at Imperial College that the field of synthetic biology was the future. Several influential reports later led to the UK strategy for synthetic biology in 2009 and the Synthetic Biology Roadmap for the UK in 2012, which was the basis for the funding of SynbiCITY.

The Scottish R&I ecosystem, which in this study is represented by the two case organisations, IBioIC and SAIC, is influenced (or inspired) by the triple helix model of innovation (Etzkowitz & Leydesdorff, 1997) to coordinate and optimise the innovation ecosystem. Both IBioIC and SAIC are part of the Scottish national Innovation Centre Programme (ICP) which was established in 2012 with to support transformational collaboration between Higher Education Institutions and businesses. The Scottish R&I ecosystem is rather complex and difficult to navigate, with organisations active across different sectors and policy issues not aligned under a single stakeholder group or authority. Funding bodies for innovation are both decentralised to Scotland as well as present at the national level. The programme therefore aims to enhance innovation and entrepreneurship across Scotland's key economic sectors, two of them being industrial biotechnology and aquaculture, create jobs and grow the Scottish economy. Aligned with the overarching aim, the programme's main objectives are to offer collaborative knowledge exchange and research activities to help solve industry defined problems, co-create innovative opportunities for growth, enhance two-way knowledge exchange between universities, industry and others to realise tangible benefits for businesses while also stimulating and challenging the Scottish research base, to provide an environment that supports the development of the next generation of business innovators, academics and entrepreneurs in Scotland and a culture change towards greater and more effective university/industry collaboration and to simplify the innovation landscape in Scotland through creating conduits to the university knowledge and expertise for all businesses in Scotland.

The Flemish life science ecosystem, represented by KU Leuven and VIB, is noted for its strong international performance in biotech, medtech, pharmaceuticals and healthcare and ranked top 3 in several disciplines such as clinical trial procedure speed and clinical trial application per capita, biotech market capitalisation, pharma and biotech patent applications per capita and the number of (bio)pharma researchers per capita. This has been achieved through a combination of a supportive legislative system and a comprehensive number of different stakeholders that together make up a successful value chain from research to commercialisation within the region. The stakeholders include

- 5 universities (Ghent University; KU Leuven; University of Antwerp; Vrije Universiteit Brussel; Hasselt University) that provide life sciences education and contribute to the emergence of the next generation of scientists, entrepreneurs, and technicians
- 3 research centres focusing on biotech (VIB), nanotech and digital technology (imec) and cleantech and sustainable development (VITO)
- 2 cluster organisations (Flanders.bio and Flanders.health)
- 11 accelerators and incubators
- Science parks, of which two have specific focus on life sciences and health (Tech Lane Ghent and Science Park University of Antwerp)

The ecosystem also contains more than 20 contract research organisations (CROs) offering services for contracted research in life sciences.

Flanders.bio, one of the two clusters in Flanders, focusing on biotech, is a network organisation which functions, more or less, as an innovation ecosystem on its own. The organisation aims to facilitate access to research services, facilities, and training, and encourages research commercialisation, public-private partnerships and engagement between higher education and industry in life science development. Flanders.bio does not perform research but connects different actors in the ecosystem and enables the ecosystem to function. Since its inception the cluster has grown from around 60 members in 2004 to 340 members in 2021.

In the Netherlands, the agri-food sector is one of the "top sectors" of strategic importance to the Dutch economy, with around 5,300 agri/food companies operating in the country and resulting in the Netherlands being the second-largest exporter of agri/food products globally. To facilitate innovation, The Netherlands has a "golden triangle" scheme - a concept used to describe the traditional productive relationships between businesses, the government and knowledge institutes to stimulate innovation. Recently, this metaphor has been broadened to the "Dutch Diamond", which promotes the collaboration of NGOs/civil society in addition to the private sector, government, and knowledge institutions when tackling challenges. In essence, the Dutch Diamond recognises that on an ecosystem level, challenges require multi-stakeholder involvement to account for different perspectives and achieve fruitful public-private partnerships. We have studied the Dutch innovation ecosystem using Wageningen as case organisation, and learned that most institutions, including WUR, are actively taking part in the Dutch Diamond. One of the leading organisations in the Dutch sector for agri-food is the private-public cluster network organisation Food Valley, today comprising more than 15,000 food scientists and engineers, and about 200 companies, both start-ups and large companies like the Royal Friesland Campina, Kraft, Heinz and Unilever, within a radius of 50km from WUR. The Food Valley was established in 2004 and has since then become the leading actor in agri-food innovation and development both in The Netherlands and internationally.

5.5.2 *The roles of the case study organisations and other relevant knowledge organisations*

To be recognised as actors in an innovation ecosystem, organisations, companies or individuals must bring thematically specialised knowledge and resources that add value, such as some form of knowledge and/or technology exchange, capabilities or benefits from agglomeration.

The case organisations we have studied are all parts of larger innovation ecosystems, though their roles within them vary. Many of them like IBioIC, SAIC and SynbiCITE, act as important nodes, or intermediates between industry and academia, connecting actors to do research and innovation together. Both IBioIC and SAIC were launched by the Scottish Government because there was a need for fora for the industry and academia and other relevant organisations to come together to collaborate, to deal with common issues and to do innovation. The centres were therefore established to act as hubs, coordinating interactions and spreading out R&I activities more evenly across the country. The centres link their own members both with each other (sometimes using own funding schemes) and with other funding bodies and support organisation in the innovation ecosystem, to ensure that projects and collaboration activities beyond the scope of the centre still can take place. Both centres also have active roles as advisors for agencies and the government to ensure that decisions concerning their respective sector are evidence-based. Another mission of IBioIC is to spread knowledge about industrial biotechnology among businesses currently not active in the sector, to widen the use of biotechnology into new fields. Similarly, SAIC has an important role in the strategy development for the Scottish aquaculture sector and participates in the Aquaculture Industry Leadership Group, a national group that gathers industry leaders and relevant stakeholders. SAIC is currently responsible for implementing some of the strategy's recommendations. In some cases, the case-study organisations' industry clubs build or strengthen their relationships within the ecosystem. IBioIC runs a Bioeconomy Cluster Builder project, aiming to strengthen the ecosystem. SAIC runs technical advice networks, aiming to strengthen the aquaculture community by sharing knowledge.

Another useful role for intermediaries[21] in ecosystems is to build an interface to regulatory bodies and government. The members and the projects they pursue help build evidence to support this policy advisory function. In this way, SAIC has been able to encourage research councils to set up aquaculture research programmes.

VIB, WUR and KU Leuven are deeply embedded in the various Flemish innovation ecosystems where policy has aligned their development and growth with the needs of significant business sectors. The Flemish government has supported the development of the ecosystems' by providing organisational support, funding, and infrastructures. In effect, Flanders' rapid growth and development since the 1970s has been built on several parallel, sector-based 'smart specialisation' strategies (starting long before that term was operationalised by EU[22]). Both VIB and KU Leuven have played active parts in the ecosystem by strengthening life sciences in

[21] https://en.wikipedia.org/wiki/Innovation_intermediary

[22] https://s3platform.jrc.ec.europa.eu/

Flanders, particularly the biotech sector which has experienced a boom over the past 25 years, growing from less than ten life science companies to over 300 by 2021.

KU Leuven has provided significant investment capital to support the many incubators, science parks, and business centres. Further, the city of Leuven has provided a strong support to the local ecosystems by making sure that permits and local legislation are in place to facilitate establishment of R&D companies in Leuven or supporting new incubators. The local high-tech ecosystem around Leuven, secured by the strong cooperation between universities, industry and the government, together with the international orientation of the city, has enabled KU Leuven to be increasingly involved in European consortium projects and in Knowledge and Innovation Communities (KICs) of the European Institute of Innovation & Technology. Of importance also is that KU Leuven is an active member of its own professional community, the League of European Research Universities (LERU), ensuring that it does not get isolated. LERU shares best-practice and has triggered some joint projects and spin-offs. In addition, membership of the Flanders TTO network entails best-practice sharing and visibility for the tech transfer organisations in the Flemish university landscape. VIB has a significant role in Flanders by offering access to core facilities (see Domain 6) for external researchers from all of Flanders, allowing non-VIB affiliated researchers to benefit from the same opportunities for high-tech equipment that is operating in the cores. At the European level, VIB core facilities are part of the Core for Life (C4L) and EU-LIFE initiatives, where VIB is a founding member.

BII and UBI have slightly different roles in their respective innovation ecosystems, compared with the Sottish and Flemish organisations mentioned above. Both BII and UBI are incubators, or accelerators, aiming to develop research-based ideas into spin-outs ready for private investors. They therefore collaborate with the other actors in the system to get a flow of potential ideas and at the searching for an investor or a big company to which to hand over the spin-offs. BII uses actors from the Novo ecosystem for its due diligence and to exchange scientific and business know-how. However, for final decisions about funding, BII is completely independent of the other organisations in the Novo ecosystem. BII-funded companies can also seek investments from any source and are not limited to Novo Holdings as an investor.

The role of adMare is partly similar to that of BII and UBI, for example that it aims to translate leading academic research into new companies. However, adMare goes a bit further than BII and UBI and engages in scale–up of the company. AdMare depends on stakeholders across academia, industry, the investment community and government to manage this task. Thus, the adMare Innovation Centre hosts more than 20 companies playing key roles in the life sciences value chain. The resident companies offer services in medicinal chemistry, assay development, drug metabolism and pharmacokinetics (DMPK), intellectual property, and strategic recruitment consulting.

In our case studies, R&D collaborations often involve institutes or university innovation centres – sometimes both. The university innovation centres have a core in applied research that is often linked to academic organisations with more fundamental research interests. Institutes can also contain centres with rather fundamental research and do 'boundary work' bringing together scientific knowledge and problem-solving. It is therefore useful for them to be linked to universities, and vice versa. Either can be linked to the wider ecosystem. Nofima and IMR are both research institutes and part of a Norwegian based innovation ecosystems for food production and aquaculture. Nofima's role is to deliver internationally recognised, applied research and solutions in fisheries, aquaculture, and food along the complete value chain. In addition to research and technology development, IMR also delivers monitoring services, data and advice to the public administration and therefore never engages in contract research.

Nofima considers itself as having a bit of the same role as the Scottish centres, IBioIC and SAIC, in bridging the gap between industry and academia, with the major difference that Nofima has no money of its own to stimulate collaboration and must rely on external funding. Both Nofima and IMR collaborate a lot with several of the Norwegian universities on research projects, in addition to working with industry. Collaboration across different organisations within the ecosystem is considered important, not only for development of the best possible research and advice, but also to find and develop good solutions for the future. A commonly used instrument for collaboration between industry, academia and the research institutes in Norway is the RCN-funded centres for research-based innovation (SFI in Norwegian). Another way the institutes collaborate with the universities is through Researcher 2 positions and PhD students. Many of Nofima's staff teach at universities occasionally and they often use master's and PhD students in the projects as well. The same holds for IMR.

Our case study organisations benefit of being part of an innovation ecosystem via access to information about problems and needs on the demand side, building trust and legitimacy by providing public or 'club' goods such as information or equipment-sharing, as well as commercial services, and collecting and disseminating information about innovation opportunities. Continuous contact with the ecosystem lets the case study organisations understand business models and innovation processes specific to the various ecosystems and build relationships with actual and potential customers.

5.5.3 Infrastructure, services, and the development of absorptive capacity

Providing experimental and testing facilities and equipment (see Domain 6) can be a powerful way for centres to be active contributors within ecosystems. For example, Nofima runs the Biotep national pilot facility for marine bioprocessing, allowing companies to develop and test processes; SynbiCITE runs the London Biofoundry; while Synbiochem has developed an automated Design-Build-Test-Learn (DBTL) pipeline to allow rapid prototyping and optimising of chemicals. Innovation centres within innovation ecosystems can serve to legitimate new technologies and tools. For example, the education, dissemination, and collaboration activities of the UK's seven synthetic biology centres help companies appreciate the technology and its potential. A well thought-out and transparent data management strategy can increase companies' trust in the centre, willingness to work in the centre's facilities and to cooperate in research, in the knowledge that private data are safe (SynbiCITE). Also, to ensure that the ecosystem is fit for purpose, IBioIC has established essential research facilities at the request of its stakeholders and is regularly identifying areas in need of coordinated action through strategic projects, such as the Bioeconomy Cluster Builder project or the ICT-Biochain project.

5.5.4 Understanding needs and potential demand

Active engagement and participation in innovation ecosystems can be a powerful way for research organisations to help companies to build absorptive capacity. This can be done through graduate and postgraduate education, and focused training. Once companies hire someone competent from a research-performing organisation they tend to come back for more. Disseminating information and knowledge about innovation opportunities encourages innovation and encourages companies to reach out for help in doing it. A long-term benefit of participating in innovation ecosystems is therefore to build absorptive capacity within the system and hence a demand for increasingly sophisticated forms of technological innovation. Innovation ecosystems do evolve over time and possess different levels of maturity and sophistication. In some cases, they involve rather simple forms of innovation. Increasingly, as the average level of technological capability among the participating firms rises over time, the level of sophistication is high, creating a virtuous circle of interaction between companies that understand and can specify their innovation and technology needs and knowledge organisations that supports innovation and research. Ecosystems are dynamically evolving trough interactions between the actors (Valkokari, 2015) and different stages of maturation of ecosystems have been identified. The role of the actors can thus also vary depending on the life cycle stage of the system (Heaton, et al., 2019).

Universities can support ecosystem development by educating people skilled in the relevant technologies important for the value creation in the system. It is therefore useful if the university produces graduates and post-graduates trained in them (as in SAIC, the UK synthetic biology centres, VIB and WUR). Over time this will not only provide skilled labour needed for ecosystem growth but also strengthen relationships, for example between the university and its alumni working in companies in the ecosystem. This is further discussed in Domain 5.

5.6 D4 Forging producer-user relations in knowledge production and use

One of the issues raised in the AS IS study was the apparently limited extent to which life science groups in universities have long-term research relationships with industry or other knowledge users. Long-standing partnerships and coalitions between research organisations and knowledge users (industry) are internationally an important way to valorise research but according to the AS IS study, such partnerships are not much present in Norwegian digital life research. It was found that researchers have insufficient understanding of the problems and needs of the demand side which can undermine their ability to propose 'relevant' research with innovation potential. This can be because of an inappropriate structure of the Norwegian industry – such as the small size of the biotech industry – so that there is limited demand for digital life technologies and innovations in Norway (Evjen, et al., 2017). The pharma industry is dominated by foreign multinationals which only occasionally scout for ideas in Norway, and only a modest part of the agriculture and food sector is research intensive. In aquaculture and its supply chain there are substantial companies with a great deal of absorptive capacity as well as fish farms that largely work with off-the-shelf technology. Other possible factors included lack of industrial demand for partnership (especially in agriculture) and the low extent to which research and industry are collocated in the sectors where DLN is active. This domain explores how such relationships arise, in the context of the wider role of the case study organisations.

5.6.1 The importance of understanding the demand side for research and innovation

Long-lasting research-industry links occur both within and outside ecosystems. Ecosystems, as discussed in the previous section, provide contexts where researchers and organisations supporting the commercialisation of research results can build relations with individual larger firms, to explore innovation needs and opportunities and to scout for ideas. A key value of the close contact some innovation ecosystems provide with needs is that the information obtained can be used not only to trigger individual innovation projects but can also be assembled into more strategic pictures of needs. These activities can also take account of needs generated by regulation and compliance, in addition to those generated by customers and markets. Centres can then adjust their research strategies in directions likely to produce results that can be used in innovation. Once trust has been built, organisations can arrange specialised user groups to develop a focused understanding of actual and potential needs and demands.

All our case study organisations focus on understanding the demand side. The Scottish innovation centres IBioIC and SAIC are outstanding examples of organisations set up and run to build and grow specific sectors, in this case industrial biotechnology and aquaculture. The centres are aligned with the national policy targets for their respective sectors and are required to make measurable contributions to Scotland's growth ambitions. They work as natural links between academia and industry, as discussed in Domain 3. SAIC, for example, arranges focused workshops and conferences with groups of companies to get a detailed understanding of needs, used to define research projects. Both centres also have funding for collaboration projects between industry and academia that are expected to address a defined market need/commercial opportunity. Actors from academia and industry are also represented in the centre's governing bodies, networks as well as in the R&I project.

SynbiCITE, one of our UK case study organisations, was established as a synthetic biology industrial translation centre in 2013. To address this task, SynbiCITE has grown a network with 98 partners – 26 academic, 46 industrial and 26 supporting members. The industrial partners range from SMEs to MNCs and come from many different sectors. SynbiCITE uses its network to help companies identify partners who can solve problems using synthetic biology and help identify innovative solutions that are unique to the field. The centre is also intended to reduce the barrier to entry into synthetic biology by offering resources and facilities to explore new technologies through the London BioFoundry. Another pivotal part in establishing a new area in industry such as synthetic biology, is to establish standards and metrology unique to the area. SynbiCITE engages with its industry partners to understand such challenges, which of them will be encountered at the scale-up stage, and which must be understood and considered already in the early phases of research. SynbiCITE has also facilitated and led industry-supported 'sandpits' around specific problems to uncover innovative solutions. Sandpits and problem-solution meetings provide opportunities directly to influence the direction of synthetic biology research and regulation and to connect supply and demand for knowledge.

While long-lasting research-industry links are important for research-performing organisations with long-term commitment to specific fields of research and innovation, they can be less so for organisations that focus solely on start-up support and incubation. These organisations rather need to repeatedly initiate links between new firms and new demands, depending on the ideas and innovations they develop. But even these latter organisations need to understand the demands and future needs relevant to their fields of specialisation and can therefore benefit from continuing user-side links. The two incubators UBI and BII, both have robust evaluation processes, involving the demand side, when selecting projects and start-ups for their programmes to make sure they only accept ideas which propose solutions to an existing problem or need that someone is willing to pay for to be solved. UBI is evaluating the market need by talking to real potential customers and asking critical questions about how they foresee using the proposed product or service and use that knowledge for decision making.

BII has a comprehensive due diligence process, collecting data about the proposed ideas with help of external experts, both individual Key Opinion Leaders and market/IP/regulatory advice providers. The data are then analysed and evaluated by an advisory group of international VC fund representatives and technical experts as a basis for decision. Failing to do such detailed and robust data collection and analysis risks the loss of many years and large amounts of money developing technology that is not wanted by the market. It is therefore important to do such analysis at a very early stage. CDRD, the predecessor of our Canadian case study organisation adMare, was primarily reactive to what researchers were working on, and was less focused on potential commercial/investor demand. This was not very successful and therefore, when adMare was created, a foresight process was also adopted, using a team of scientific and business experts to analyse and evaluate areas of potential commercial opportunity. That enabled adMare to identify which areas would have the most strategic value to the organisation and which could form a basis for a multi-asset financeable company of scale in Canada, based on research outcomes.

5.6.2 *Understanding the demand side as an advisor*

Understanding the demand side can be imperative for an organisation even if the purpose is not to innovate. Government labs like IMR provide good examples on that. Thorough understanding of the marine sector in which they operate is key to the organisation because of the role IMR has as an advisor to the sector. Creating an environment which supports and promotes industry collaboration is therefore important is these organisations. IMR has a large network of business actors and organisations and great activity in dissemination and innovation by using new methods and new ways of working for increased quality and efficiency.

5.6.3 *Industry collaboration as an important source of funding*

Industry collaboration is in many countries a valuable source of funding for research performing organisations and early innovation development. LRD, the TTO of KU Leuven used as case organisation in this study, was created in the 1970s because the amount of government research funding available was very small at that time. There was therefore a need to make KU Leuven more research based and to attract more money for research from industry. PhD students were sent abroad to learn from UC Berkeley, Stanford University and MIT, and when they returned, they helped LRD create the instruments needed to support industry-academia collaborations. Companies in Flanders were incentivised via funding from a new innovation agency (IWT) to approach the university with projects and problems Since then, LRD has become the bridge between the university, industry, and society. Its operational budget is fully covered by taking half the 17% overhead paid by projects involving industry collaboration. Similarly, the Norwegian institute sector, represented by Nofima and IMR in this study, also shows examples of how industry can be an important source of funding, both directly through contract research and indirectly, as partners in applications for large collaborative funding projects.

5.6.4 *Two-way benefits of producer-user relations for both research and industry*

Long-standing producer-user relations are especially useful when information can flow both ways, so that the research side learns about needs and gets feedback about the usefulness of various innovations as discussed above, while the industry side is offered a greater flow of ideas and technological opportunities than would otherwise be the case. VIB, the Flemish Institute for Biotechnology focusing on technology transfer in partnership with 5 Flemish universities, shows that industry-academia collaboration can also give opportunities for researchers to get access to new technology with potential to advance their research. Through its Tech Watch programme, VIB analyses the markets for emerging technologies and start-ups with the potential to boost the research output at VIB. The process targets both novel technologies that are fresh on the market as well as technologies still in prototype stages, looking for opportunities to get early access to the technologies.

Trust is a key ingredient in relationships, reducing the 'transaction costs' involved in exchanging information across organisational boundaries. In some cases, such relationships can survive for long periods, while remaining informal. In others, more formal strategic partnerships can be established, setting out longer-term programmes of activity and defining the scale of the relationship. In Sweden, Karolinska Institutet (KI) has a tradition of maintaining strategic partnerships with major pharma companies, and Umeå University used to have close collaborations both with Astra and Pharmacia back in the days when those companies were located in the region. When the companies left, many of the relationships, on which the collaboration was built, were lost. Having relevant industry actors nearby usually lowers the barriers for collaboration. Astra has since then set up an innovation hub in their premises in Gothenburg, offering life sciences start-ups the opportunity to co-locate with their own facilities. Another example of how geographical proximity can be of advantage can be seen in the Dutch Food Valley.

Research-performing multinationals tend to be acutely aware of where the best research partners are to be found in the global research system, so when they partner to reach research goals, they are very fussy. However, other strategic partnerships with a significant R&D content can also have other objectives, such as securing a regional supply of qualified people, skilled in areas relevant to the firm. Strategic partnerships with regional universities sometimes have this purpose.

University-based research and innovation centres typically also build longer-term industrial linkages. Funding schemes like RCN's SFI programme require industrial partners to be engaged with the centre from the start and to stay engaged for many years. Others require varying degrees of industrial commitment. In general, centres with medium-term funding (say, 5-10 years) nonetheless build up their number of relationships over time, and these are often carried over into subsequent centre arrangements. Nofima and IMR frequently use the SFI programme to build long-term strategic research projects together with industry, based on real industrial and societal needs. SFIs often combine applied and basic research to generate new basic knowledge, evaluate prototype solutions and develop innovations. The institute's role in the projects can both be as a research partner and as a user of technology or solutions that the industry partner is developing for them.

The number of long-term industry relationships tends to grow as organisations mature, typically building on supplier-user relations or collaborations in research and technical services. Successful collaborations have a demonstration effect and tend to lead to more collaborations. Thus, Nofima has many 'repeat customers', reflecting its origins as the Norwegian canning industry's research association institute in 1931 as well as subsequently incorporating a range of more recently established institutes in other branches of green and blue food production, generating a range of long-term relations spanning fishing, aquaculture, agriculture and food production. Recently SynbiCITE launched an Industry Club, which is an exclusive community of synthetic biology professionals, both in the UK and internationally. As it evolves it is intended to provide a forum through which innovative SMEs, spinouts and start-ups can connect and form a community. The purpose of the club is to enhance the existing relationships between SynbiCITE and numerous companies in the field, as well as help facilitate relationships with new partners.

University-based innovation centres are normally housed within longer-lasting components of the university. For example, SynbiCITE is housed within the Manchester Institute of Biotechnology, which is strongly industrially orientated but works at a more fundamental level. It is nonetheless industrially well connected, so that SynbiCITE can inherit some of its industry relationships. Other university-based innovation centres similarly build on pre-existing research and relationships, often at lower TRL levels, so that their work involves raising or translating research to intermediate TRLs in addressing company needs. As a grant-funded and therefore inherently temporary network organisation building on capacities at several Scottish universities, it may be more difficult for IBioIC to establish a critical mass of longer-term relationships than for the other university innovation centres.

5.7 D5 Innovation culture and practices in research-performing organisations

We consider a research-performing organisation that regards innovation as one of its central activities together with research and education and uses specific measures to support this attitude to be most likely to possess an internal innovation culture. The AS IS study pointed to an underdeveloped innovation culture in much of the Norwegian university sphere and argued that this needs to be improved in combination with tackling the organisation and mechanisms of commercialisation (such as TTOs and incubators) to increase industry collaboration and innovation. Passible causes of the low level of innovation culture include disdain for economic activities, and personal values that do not support innovation, among some faculty members. In some places, there is a – not wholly unjustified – suspicion of cooperation with pharma companies. The report also pointed to a weak or naïve understanding of innovation processes among academic staff and researchers, in part because of lack of education and staff training in entrepreneurship, innovation and commercialisation and in part because of limited industrial experience or exposure among university researchers. The lack of innovation culture and industrial experience can also be because of the absence of incentives and tradition for partnerships with industry in Norwegian universities. The research agenda is usually not designed with the demand side in mind and innovation is more often considered a "technology push" process than a "pull" process built on a defined need from the demand side.

It was also observed that many research organisations currently lack institutional strategies for translating research into products and processes and, despite governance reforms in recent years, it still seems to be difficult for Norwegian universities to restructure or to make a selective allocation of resources to pursue specialisation strategies, like innovation. Career track incentives in academia do not support innovation, industry collaboration or the third mission more generally and rewards to faculty for inventions are not attractive enough to affect behaviour. Monetary rewards are limited to successful licensing or start-up through the TTO. Because there is little biotech industry in Norway there are also few industrial career opportunities and therefore little incentive for younger researchers to pursue industrial questions.

This domain therefore considers aspects of institutional tradition, organisation and leadership that support innovation culture. In addition, this domain touches (briefly since the topic is also addressed above) the importance of being an active player in ecosystems. Further, the incentive structures – not only financial, but especially career-related – under which the researchers operate will be considered. Finally, we touch on the avoidance of conflicts of interest or privatisation of public knowledge goods, in so far as these are considered by the case study organisations.

5.7.1 Institutional traditions, organisation, and leadership

At the risk of stating the completely obvious, technical universities and other milieux with strong innovation cultures are more likely than others to produce people who know how to innovate and to become an entrepreneur than others. Such organisations are therefore well positioned to be involved in innovation and commercialisation support. Older universities of technology like Imperial College, which hosts Synbycite, tend to have origins as technical training institutes, which have gradually been upgraded to the status of university, bringing their historical tradition of being close to industry and innovation with them[23]. Applied research institutes, like Nofima, have been established specifically to support industrial innovation and depend, to a large extent, on industry collaboration. They therefore tend to have long-lasting links to industry and the culture and attitude towards industry collaboration is mostly positive. Humboldtian universities do not benefit from these path dependencies and tend to place a higher institutional value on curiosity-driven research, pursued without reference to potential application, and so face greater internal barriers to developing innovation culture.

Innovation culture is not easily created, and time is needed to grow a mind-set that eventually becomes tradition. The case organisations we have studied, which do show a strong innovation culture, do so either because they are organisations offering innovation support and thus have innovation as their core mission, or because they are connected to universities or other organisations that already have strong innovation cultures. But there are also support organisations, like UBI and BII, which must train their researchers to become inventors and entrepreneurs because of a lack of innovation culture and education within the academic institutions providing them with inflow of projects.

In Chapter 3, we pointed out that both Innovation culture and the mechanisms of knowledge exchange with industry, are affected by differences between the way knowledge flows between academia and the science-based industries on the one hand and the engineering-based industries on the other. Innovation based on the applied and transfer sciences involves a great deal more cooperation and transfer activity than basic science-based innovation. Technical universities tend to focus on the applied and transfer sciences while the Humboldtian universities are more focused on the natural sciences. DLN is distributed across both types of university.

In Norway, this dichotomy is rather evident in the polarisation in innovation cultures between the Humboldtian University of Oslo and the technical tradition at NTNU, with its close association to SINTEF. This polarisation means that DLN must span two rather different innovation cultures, with its healthcare focus tending towards the Humboldtian culture while the bio-marine, food and agriculture and industrial biotechnology foci fit better with the applied science and engineering culture. The culture also varies among Norwegian universities and not only among the sectors.

Leading technical and technically orientated universities such as Imperial College, where SynbiCITE is located, have increasingly established innovation centres within their areas of scientific strength. Imperial College is a startling example, with its current expansion from South Kensington in London to set up a second campus at White City, more focused on innovation and entrepreneurship and equipped with flexible buildings to co-locate businesses, researchers, academia and the local community with incubation facilities, hackspaces, and other innovation orientated facilities. WUR and KU Leuven have over the years established funding and incubation structures, though not at the dramatic rate that has become possible at Imperial owing to the opening of a second campus.

Umeå University, represented by the case study organisation UBI, the life science incubator in Umeå, is one example of an academic institution where innovation is gradually getting more and more attention, alongside research and education. One success factor behind the

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[23] Well-known examples include KTH, Chalmers, Imperial College and NTNU, which began as a society promoting science, started engineering education at Trondhjems Tekniske Læreanstalt in 1870 and then became the Norwegian Institute of Technology in 1910 and eventually through a series of mergers evolved into NTNU

positive development is the university management. An interested and supportive principal and university board in addition to TTO-like representation in the board, has been imperative[24].

5.7.2 Education and training in innovation and entrepreneurship

Education and training in innovation and entrepreneurship are foci in many of our case studies. While some entrepreneurship training needs are generic, it is also important to offer training that deals with the specific characteristics of knowledge use and innovation in the technologies and industrial branches with which each case study organisation works. Entrepreneurship training is offered at all levels, from undergraduate (sometimes integrated into applied science courses) through masters, PhD levels and researcher/faculty, to training more focused on potential and actual entrepreneurs.

Some of the organisations we have studied has even gone as far as creating their own innovation programmes or academies, to fill a gap in the market. One such example is the Canadian case organisation adMare. AdMare, focuses on systematising the process of commercialising research and building companies around pharma technologies, and early identified a need to train people who can both build and run new companies. The adMare Academy was created to fill the gap. The academy has four different levels of training – Executive Institute, BioInnovation Scientist Program and Fellowship Program, which are further described below, as well as an Undergraduate Institute. The Undergraduate Institute has programmes running over 4-8 months, giving students hands-on skills development. To date, the academy has graduated 225 post-docs, 96% of whom went on to relevant jobs in industry; approximately 85% of them currently work in Canada.

The two Scottish innovation centres, IBioIC and SAIC, are also good examples of organisations that have taken a holistic approach to creating sustainable economic growth in their respective sectors, industrial biotechnology, and aquaculture. One of their main objectives is to *provide an environment that supports the development of the next generation of business innovators, academics and entrepreneurs in Scotland and a culture change towards greater and more effective university/industry collaboration,* and both organisations have developed educational programmes to support this. The purpose of these programmes is either to educate researchers to become entrepreneurs, or to acquire competences and skills needed by the industries and sectors they are supporting.

KU Leuven has also taken initiatives to formalise entrepreneurial learning and courses in the university setting, and a new trend in its educational policy emphasises the entrepreneurial skills that students should acquire regardless of their discipline. Imperial College, where SynbiCITE is located, has an obligatory entrepreneurship course in all undergraduate programmes, exposing the students to innovation and entrepreneurship early on.

5.7.3 Mobility programmes

Understanding the sector and industry within which a research organisation works is fundamental for successful collaboration. According to Nofima, one of the case study organisations representing the Norwegian institute sector, there is still a lot to do within academia on culture and innovative mind-set. Classical research training does not teach PhDs to collaborate with industry. Nofima finds that PhDs who have some business understanding, or industry experience are much better at collaborating with companies, because this requires a

[24] Innovation som drivkraft – från forskning till nytta. SOU 2020:59

different skillset, toolset, and mind-set than pure academic research. Business, market, and end-user understanding along with empathy, communication and visualisation skills were mentioned as key skills.

One way to give researchers industry experience is through mobility programs and internships. Mobility programmes serve both to familiarise students and faculty with life in industry, so that they get a better sense of industrial needs and styles of working, and to broaden their competences and skills. Several case organisations, Nofima being one example, offer such mobility to their employees through a programme that allows researchers to go and stay at a company between one and three months to improve their general industrial understanding and become more industry oriented. The programme is very popular and is offered to both senior and young scientists. SAIC's skills development programmes similarly allow students and researchers to learn to collaborate with industry early in their careers. Its programmes are offered in close collaboration with industry as well as academia under the Aquaculture Academy umbrella.

Another way to train young researchers and at the same time give them industrial experiences and skills is through Industry PhD programmes. Normally, in such programmes candidates are fully employed by a company and do all or most of their research with that company, under combined academic and industrial supervision. Umeå University, one of the owners of our Swedish case study organisation UBI, has set up an industrial PhD programme that is slightly different. The Umeå programme is organised so that the PhD candidate is employed by the university, but the cost and time is shared 50/50 with a company. The programme includes a three-month internship at the company, where the student is supposed to work on tasks not related to the research project. These three months are fully funded by the university. Companies participating in the programme can be Swedish or international.

Umeå University also has a mobility programme for master students. Together with UBI, the university supports master students to do their final thesis in industry. The major challenge they experience with the programme is to attract SMEs, which often have limited capacity for supervising students.

5.7.4 Training the workforce for the industry

In addition to training researchers to become more innovative and to collaborate with industry, some countries see a need to build a workforce with skills needed to build and grow certain strategic sectors of industry. Scotland is one example where initiatives have been taken to strengthen several sectors, among them industrial biotechnology and aquaculture, and our case study organisations IBioIC and SAIC were established to help do this. The mandates of the centres included a clear mission to "*ensure that the [industrial biotechnology] industry has the necessary skilled workforce to innovate in Scotland*", and to "*nurture… innovation by developing aquaculture skills and talent across Scotland through focused skills development initiatives*". Both centres therefore offer training programmes and courses at PhD, MSc and Higher National Diploma (HND) level as well as training for individuals working in the sector. Doing so, they aim to create a sector-wide cohort of people, both from industry and academia, trained in innovation thinking, management and leadership. One of the programmes offered is the Industrial Master provided by IBioIC and the University of Strathclyde, aiming to give students the skills required to work in the biotechnology industry. The programme has been designed in direct response to industry needs and is reviewed annually by the industry to ensure that the content is up-to-date and aligned to the needs of the rapidly growing industrial biotechnology sector. Included in the programme is a 10-week placement where the students participate in industry-led research projects. Most of the students continue to work in industry after graduating. PhD candidates are offered a similar programme consisting of a combination of compulsory and optional structured training, complemented by personal development initiatives and a 3–12-month placement in industry. The PhD programme focuses on three key elements: essential project skills, essential industry skills, and personal growth.

5.7.5 Incentives to stimulate innovation and commercialisation

Invention incentives for researchers are widely discussed. All the case study organisations, are in countries with legislations where the universities hold the right to university generated IP, except the Swedish UBI where they still practice the so called 'professors' privilege'. In all our cases they are keen to support internal inventors, but there is little evidence that financial rewards from patents and licensing are major incentives affecting innovation culture or behaviour. Rather, researchers' entrepreneurial behaviour and desire to do R&D in collaboration with industry seems to stem from organisations' innovation culture and relies on career incentives rather than financial ones. Thus, for example, staff tenure at VIB depends on doing knowledge exchange, not just research.

KU Leuven is one an example of an organisation that has tried to use monetary incentives in innovative ways to strengthen the entrepreneurial interest and industry collaboration among their staff, but who also has learned that money is mostly not what triggers the researchers. Researchers are not allowed to have personal contracts with industry. All the university's industrial research income must come via LRD so that it is transparent, the risk of conflicts of interest can be assessed and to ensure that intellectual property rights on all sides are properly respected. The incentive is capped so that the basic salary plus the supplement may not exceed twice the basic salary. A recent survey indicated that researchers value this possibility (Wang, 2018), but in practice it is little used. KU Leuven had about €300m in industrial research income during 2020, of which about €2m (less than 1%) was paid out in incentives. Such incentive payments are of interest to young researchers typically for one or two years at the stage where they face the costs of getting their own house. Thereafter, they place greater value on the potential of industrial research income to support their research or their research team. Thus, the important incentives relate to careers rather than personal income, even in relation to innovation-relevant research.

Nofima is of the understanding that in Norway, more can be done with respect to incentives to stimulate innovation; there are not enough, or not good enough, incentives for innovation. The experience is that the biggest incentive for a researcher is, usually, to be able to acquire projects and for that purpose, an innovative or translational approach may sometimes be required. However, once the project funding is granted, then there may be less interest in what happens afterwards with regards to achieving societal impact. Nofima offers no salary incentives; it is all up to the individuals. However, since most projects in Nofima are conducted together with industry they are by default applied projects in one or the other way with the aim to solve a problem or achieve value creation and/or innovation.

IMR is of much the same opinion as Nofima; researchers are very cynical in their publication behaviour, and publishing in high-impact scientific journals is what counts. To reward collaboration in itself is therefore not very useful. For collaboration to be attractive to researchers it must generate something of value to them. One way IMR is trying to stimulate collaboration is by actively using Researcher 2 positions and PhD students. In fact, the marine sector is in great need for innovation and renewal and therefore instruments to accelerate idea generation are needed. Competitions and awards can sometimes be useful, if appropriately organised. Every year, various prizes and awards are given to the players in the

Norwegian marine sector to stimulate innovation. One example is the innovation award established in 2003 by the Nor-Fishing Foundation to stimulate equipment suppliers and others to innovate and improve. Over the years, the Innovation Award has helped the winners to launch their finished products and services. Another award is the Norwegian Directorate of Fisheries' Environmental Prize, given to a producer who has launched environmentally friendly products or processes. The award has a long tradition and enjoys great prestige among suppliers. UBI, our Swedish case study organisation, also mentions innovation awards as instruments the organisation is keen to implement. The experience of UBI is that innovation grows in permissive environments. In order to create systemic impact and inspiration, and not just individual impact, through such an award, a larger group of people should benefit from it. The award should therefore ideally be given at the department level at the university, and not to an individual, and be used for activities such as competence building or study visits.

5.8 D6 University innovation support and commercialisation systems

The AS IS study pointed out that the Norwegian universities' innovation support and commercialisation systems appears not to be realising enough of their potential for generating research-based innovation in digital life. Several possible causes were identified, which together point to a gap in the system. One example is that in Norwegian universities, innovation support is outsourced to TTOs, which are run as competing commercial companies and therefore become risk averse and focus on innovation opportunities mature enough for them to realise themselves. Some of the TTOs seem reluctant to support the early phases of idea development because the risks are too high. Since faculty members have not been trained to handle early-stage innovation processes themselves (see Domain 5), and since there is little or no in-house innovation support within the Norwegian universities, this risk aversion of the TTOs may result in innovation opportunities not being identified, developed, or valorised. The situation varies among the universities, but even where there are improvements progress is slow. The AS IS study also noted that the Norwegian TTOs tend to have complex ownership structures and sometimes also find it difficult to abandon low-potential projects.

The AS IS study concluded that the Norwegian system is particularly weak in supporting projects through the difficult phases going from verification to proof of principle, pilot testing and demonstration (TRL 3-7). This might be because of insufficient cooperation and knowledge exchange between the universities and industry (see Domain 4), lack of infrastructure required to do optimisation and scale-up of industrial processes, lack of commercial partners, funding, or regulatory expertise. The latter is of especial importance for health-related projects. In addition a question was raised whether separating the TTOs from the universities' makes it more difficult to explore other knowledge exchange activities through, for example, collaborative research directly with industry. This may result in a smaller amount of knowledge exchange reducing potential innovators' access to equipment and projects tackling scale-up problems.

We have devoted limited effort to collecting evidence about the Norwegian TTO function in this study because for the time being the TTOs are subject to an evaluation by several others, including the Ministry of Education and Research. What we have focused on is tech transfer as a process and how that process is designed and operationalised in other countries and innovation systems, aiming to find good examples that may differ from the Norwegian model. This domain therefore considers case-study organisations' wider knowledge exchange activities and how TTOs fit into them. We focus particularly on understanding how incubation is done.

5.8.1 Technology transfer and industrial liaison

As we indicated in the AS IS report, Norwegian TTOs were generally set up based on US practice in the post-Bayh-Dole period, a model that focused on extracting revenue from inventions, often through profit centres detached from the other activities of the university. The US Association of Technology Managers (AUTM) has been key in codifying, celebrating, and disseminating this model, which appears to be highly relevant to science-based industry – especially pharmaceuticals – but less so to the much more interactive transfer style of the applied sciences and engineering, where transfer tends to take place at higher TRLs and universities are forced to make choices between taking intellectual property and doing collaborative research with industry in the early phases of the innovation process. Norwegian practice has been similar - to establish TTOs as limited companies, whose incentives cause them to optimise (or sub-optimise) locally, to generate profit, often quickly and mostly from patents and licensing, and sometimes, but not very frequently, taking equity in start-up firms, rather than optimising across Knowledge Exchange (the third mission) as a whole.

Before the explosion in the number of TTOs that followed the Bayh-Dole Act, many technically orientated universities already had 'industrial liaison' functions that handled various kinds of interactions with industry. The kinds of activities involved could include: identifying university cooperation partners or advisors in response to company inquiries; managing consultancy work or service provision by the university or individual members of faculty; arranging placements of students in industry for parts of their degrees or for doing in-company final-year projects; and managing strategic partnerships with individual companies.

A good current example is the Research and Development arm of our case study organisation LRD at KU Leuven, the only case organisation which includes a role as a Tech Transfer Office. The organisation began life with the intention of learning from technology transfer practices at Stanford, Berkeley, and MIT, but has since then expanded its role from acting as a first-generation TTO to manage the whole spectrum of knowledge exchange from patents, licensing and start-up through contract and collaborative research, industrial liaison, the use of R&I subsidy instruments, incubation, and internal measures to support innovation culture. It does so in a university that is embedded in the Flemish inter-university research institutes and their associated ecosystems. Some 900 out of 2500 professors at KU Leuven work via LRD. The TTO function is therefore internalised at Leuven, in a way that allows LRD to trade off the costs and benefits of alternative knowledge exchange mechanisms on a case-by-case basis rather than having to prioritise the classical TTO approach. This trade-off can flow down to the level of the individual researcher, who can be in the position of choosing among money, collaboration, and other kinds of benefits from knowledge exchange (see also Domain 5).

Conventionally, TTOs handle a number of steps in the tech transfer process from identifying and scouting innovative ideas, evaluating and validating their potential and securing IP, to developing them and, at the end, selling or licensing the technology or setting up a company. These steps are further explained in the next sections with examples of how our case study organisations have solved them.

5.8.2 Idea scouting and evaluation

Practices for identifying and deciding whether to support ideas to be developed vary among the case organisations. Some 'scout' actively for inventions, whereas others wait more passively for researchers to approach them. Among the organisations having a proactive approach are VIB, and adMare, both focusing on drug discovery with the aim of bridging the gap between early research results and obtaining investments. VIB has its own Discovery Science team screening VIB research projects, looking for promising pharmaceutical discoveries or inventions with commercial potential. Targets identified as realistic candidates are then incubated to the stage where investors would be willing to consider the project for funding. AdMare has a similar approach, and carries out a proactive, focused search throughout academia for researchers that might have novel therapeutics that meet the needs of commercial end-users. Since adMare is a not-for-profit organisation with no direct link to academic institutions and with ambitions to build companies around technologies instead of licensing, the organisation has been forced to spend a lot of time and resources in building relationships with the universities and TTO's in Canada to interest them in collaboration and give adMare insight into the research going on.

The Swedish incubator UBI and the Centre for Drug Design and Discovery (CD3) at KU Leuven are also only interested in ideas with commercial potential but take the opposite perspective to VIB and adMare, saying that there is no point in dealing with inventors who themselves are not motivated enough to contact them for support. Neither of these organisations therefore scouts for projects or investment opportunities. An important element of innovation culture (Domain 5) involves making sure that researchers are sensitive to the potential commercial value of their inventions and take appropriate action. At Umeå, the university Innovation Office plays an important role, together with UBI, in informing researchers about innovation and how to create value from academic research and directs many of the more promising ideas to UBI.

SAIC, IBioIC, adMare and BII place particular emphasis on working with the demand side to identify needs and trends that then guide their research or start-up support behaviour. VIB has an active technology watch group that scans the horizon for interesting developments in research that have innovation potential and helps the university develop capabilities in these areas. WUR also does technology watch, partly to inform its own research and partly to obtain information to disseminate within its ecosystem. This practice of looking outside – as at SAIC and IBioIC, for example – as well as inside for opportunities should, in principle, increase the effectiveness of the case study organisations in identifying opportunities, and corresponds to the outward-looking 'face' of R&D that is recognised as being important in creating absorptive capacity (Cohen & Levinthal, 1989).

VIB, adMare, UBI, CD3 and BII are only interested in ideas with commercial potential. They have therefore developed well-defined assessment and evaluation processes for selecting ideas, projects, and start-ups to support. AdMare, for example, bases its decisions on evaluation criteria including differentiation and competitive advantage of technology, quality of the team, the impact of seed money (can the funding get the project to a value inflection point?), scope and strength of IP coverage, type of co-investors and potential investment returns. A willing and engaged PI is the most important criterion for adMare. The PI must understand that the investment is not just monetary but is in fact a partnership where adMare brings relevant expertise to the table to help the technology/company to grow. Further, the innovation process team is an important building block since it forms the bridge between the academic and industry.

BII, also has a well-defined and developed evaluation process for recruiting projects/companies for its innovation programmes, Venture Lab and Creation House (see Domain 6), which is the entry point to get access to their convertible loans. The process has four steps. First, the material submitted by the applicants – a pitch slide deck and a written proposal for the work to be performed with BII funding – is evaluated and ranked in a pre-screen by BII business development staff. Selected applicants then go through a due diligence process where data relevant for an investor, such as the market size, IP-strategy, regulatory strategy, B2B attractiveness etc. are compiled with the help of external experts and presented to an advisory board for comment. These experts may be individual Key Opinion Leaders or market/IP/regulatory advice providers. BII generally spends DKK 100.000 per project on due diligence in the form of external consultancy fees and in-house work. After the due diligence process, the applicants must pitch to a programme advisory group and the BII business development staff, which score them independently. BII then synthesises the input from the due diligence and programme advisory group discussion to rank applicants and recommend which should be funded. Finally, the BII Board of Directors approves funding decisions. Normally, BII selects approximately twice as many projects to pitch based on due diligence as will eventually funded. UBI and CD3 have similar processes, going through several steps of data assessment and pre-incubation before a project can be approved to enter their full incubator programmes. What they all have in common is their emphasis on involving business experts in the process and that the projects must show both scientific excellence and commercial potential to be of interest.

5.8.3 Incubation support and services

Because our case study organisations are very different in terms of organisational structure, ownership structure, role, and mandate, they also have different ways of supporting innovation and entrepreneurship. In most cases, the innovation activities are fully or partly integrated into research-performing organisations, which means their services are mostly aimed at the organisation's own researchers, who have direct access to them. The exception is BII, which is a free-standing incubator that collects start-up opportunities both from across the Danish research system and internationally. AdMare, which has a similar role in Canada, also contains two previously existing research institutes, giving it a strong foothold in the sciences with which it works.

Because of their different roles and structures, there are also differences among the case study organisations about which phases in the innovation process they support – some organisations, like the incubators BII and UBI, offer support even at the earliest phases, when there is only an idea and some scientific data. Others, like the Scottish centres IBioIC and SAIC, focus on more developed ideas further downstream in the innovation process. Some organisations, like BII and LRD, only support start-up development, whereas others, like VIB, also consider licensing and industrial uptake. The Norwegian institutes support applied research in collaboration with industry which mostly implements the results without the institutes being involved. Examples are given below.

Innovation support for start-up creation

LRD at KU Leuven promotes entrepreneurship by reducing the burdens related to the business side of research commercialisation, which in practice means that they are assisting researchers in setting up spin-off companies and helping them develop business plans, validate the market, find investors and infrastructures, and manage intellectual property. LRD also offers legal support and helps the researchers assemble a competent team able to manage further growth of their spin-offs. Researchers supported by LRD work 25–30% in LRD's research division, and early-stage development and validation projects can be financed from the resources the division has acquired from research exploitation. Projects and activities that are carried out by the researchers are set up and monitored as virtual companies under the umbrella system of LRD, meaning that professors are supported to be entrepreneurial without having to take any financial or administrative risks. The role of KU Leuven and LRD funding in launching spin-offs should not be underestimated (Domain 2). The aim is that all the type of early-stage funding and support needed for researchers to valorise their research should be available through LRD, though LRD is happy also to make use of external funding. In addition, LRD manages the Leuven Bio-Incubator, which can provide support services to start-ups and entrepreneurs which goes beyond the scope of LRD. The scale and number of projects makes it possible for LRD to be self-sustaining.

Innovation support for start-up creation and industrial uptake

VIB focuses on doing and translating basic research results into commercial applications both through industrial uptake and start-up creation. There is a dedicated team, VIB Discovery Science, which focuses on identifying promising fundamental research at VIB and facilitates its transition towards commercially viable products. The team was established to bridge a gap identified between the fundamental research conducted by the VIB researchers and the interests of investors. Another team, IP Management, works with IP strategy development and patent applications, and VIB Business Development manages business outreach and collaboration. VIB New Ventures fosters the development of start-ups and acts as an incubator for promising research conducted at VIB. Ideas are typically considered when there are enough research data available to start evaluating IP potential. If this assessment is positive, the IP Management team will do a freedom to operate analysis and develop an IP strategy. Once this process starts, the researchers have up to one year to move the research to a stage where New Ventures can engage in PoC support. Sometimes the team can make an exception and support projects already from the idea stage, if they can be convinced that the ideas have commercial potential. Research can also be classed as strategic projects. In those cases, New Ventures funds the researchers while also looking for grant opportunities. Such projects have a longer time perspective, over several years. Income from all the different tech transfer and contract research activities conducted exceeds 15% of the annual VIB budget and all profits are immediately ploughed back into research.

Design thinking as a tool to generate innovative ideas

Nofima, the Norwegian research institute for food and aquaculture, is working consciously to find applications for the research it performs, mainly through industrial collaboration and uptake; hence start-up creation is not the primary goal. The food section of Nofima works particularly close to market, for example with questions to with consumer product development and the has over the last five years started actively to incorporate design thinking methods in its research projects to improve idea generation, both for new research projects and applications. Nofima has a dedicated team of five-six people, facilitating these activities and working as innovation catalysts, or translational developers, helping to translate information into something useful or new concepts. They all have a scientific background, for instance within food chemistry, in addition to industry experience. The team also hires external designers and use them in the projects as full project members. The design-thinking methods are usually applied during the projects, involving all the different stakeholders, but they could potentially be used in a pre-application process to come up with new ideas for new projects. The way design-thinking offers an iterative and reflective process differs from what is normally done in research, and Nofima finds that when applied to research projects, it improves collaboration and increases trust between industry and research partners. Therefore, projects applying these methods seems to have a slightly higher success rate in terms of implementation of the project in the market or the partner organisation.

5.8.4 Intellectual property

Provision and maintenance of a system for researchers to report ('disclose') their inventions is traditionally one of the responsibilities of a TTO. The system allows the TTOs to make judgements about whether the ideas are innovative, have commercial potential and, if so, whether the intellectual property they represent should be patented or otherwise protected. Assessing the technical and commercial potential of inventions and deciding whether to invest in IP protection, especially via patents, is a very expensive process. Keeping patents in force involves annual costs, so such decisions must be taken with care. Therefore, in Norway as in most other countries, university/hospital researchers need to go through the TTOs whenever they have an idea they believe has commercial potential. However, many researchers are shown to, for various reasons being hesitant to contact, or even deliberately bypass, the TTO. In Sweden, which still retains 'professor's privilege', giving Swedish researchers full ownership of their findings, the Swedish innovation offices do not have automatic ownership rights to researchers' ideas. Researchers are therefore not obliged to consult the university about IP but can normally obtain TTO-like support from an internal group – such as the Innovation Office at Umeå, which cooperates with UBI.

How IP is handled and shared among different stakeholders varies between the organisations we have studied, as well as their strategic approach to making money from IP. BII, for example, only deals with start-up formation and does not license IP to corporates. Therefore, the companies participating in any of the two BII programmes must license any required background IP from the university or company where it originates. Licensing is done on market terms and BII does not engage in negotiations or contracts about licensing; that is the role of the relevant TTO. Licensing models and conditions depend significantly both on the university partner and the type/value of the invention.

At LRD, the TTO of KU Leuven, negotiations on IP are done case by case. LRD has learnt from its long-standing collaboration culture that there are limits to what you can expect and what companies will accept in terms of the division of IP income and allowing the university to take partial ownership in start-ups. The policy is like the norm in Norway - any IP coming from academic research funded by government belongs to the university. If it is used in industry collaborations, the university expects to get a fair return from the company. However, this fair return does not necessarily need to be monetary or in the form of shares in a spin-off. It can just as well be agreements about sponsorship or PhD positions, or long-term contracts with the university. The "fair return" principle aims to ensure that a business agreement is advantageous for both parties, that there is a proper distribution of value from IP, and fair compensation to the university where the IP ownership lies with the company. Experience suggests that such flexibility helps in building strong and sustainable relationships with individual companies, resulting in a retention rate of about 80-90% among the companies with which KU Leuven collaborates.

At VIB, all IP-related activities are exclusively handled by the Institute's Innovation & Business team through a signed framework agreement, giving them full freedom and rights to file, administer and commercialise IP. The commercial benefits from IP are shared equally between VIB and its Innovation & Business team. By managing and marketing the portfolio of VIB patents and patent applications to businesses, the Innovation & Business team has signed around 1500 agreements with local and international companies from the biopharmaceutical industry, and agriculture.

It is important to note that TTOs are often loss-making and may survive only because they are subsidised. Returns to patenting are very skewed, so the economics of a TTO can depend on the success of less than a handful of patents and there are corresponding benefits to scale. TTOs are normally set up at the level of a university. In some cases, as in Bergen, they may span several geographically related organisations. About ten years ago, France clustered universities into small regional groups and shared the TTO function within each group to build scale and share resources. However, as seen from LRD above, there is a countervailing force in the form of a need for TTOs to understand and maintain relationships within the sectors where they hope to commercialise inventions. WUR established a central TTO in 2004 but in 2017 re-embedded TTO functions into individual institutes to enable specialisation and maintain market contact with different communities of firms. The SynbiCITE case is based at Imperial College, London. Part of the context there is a decision by the university, after working with an external TTO (Imperial Innovations) for two decades, to re-internalise the TTO function into the university to make it possible to take a more holistic approach to knowledge exchange.

The Norwegian research institutes have more freedom to decide how to handle IP originating from their research than the universities, and the two institutes we have studied, IMR and Nofima, have chosen slightly different models. IMR is one of the co-owners of VIS, the TTO of the Bergen region, and has for that reason outsourced everything related to innovation and commercialisation to the TTO. IMR and VIS have a close partnership and VIS plays an active role in regularly reminding IMR, who does not have innovation of the top of its agenda, to look for ideas and opportunities that can be developed further. IP ownership is regulated case by case and there are some examples of researchers getting some IP in inventions and selling their rights. Nofima, which has a more prominent focus on innovation than IMR, handles IP and Tech Transfer processes through a mix of in-house competence and resources and collaborates with several of the Norwegian Tech Transfer Offices.

Advising inventors at the university about how to secure and benefit from intellectual property is an important task since exploiting intellectual property can involve maintaining secrecy until an application has been made for protection. This sometimes causes tension between the needs for secrecy and publication, in collaborative projects between academic researchers and industry. KU Leuven handles this though agreements. An industry partner cannot prevent a researcher from publishing but publishing delays of up to six months can be negotiated. In addition, since publication is usually most pressing for PhD students, PhD candidates are normally not involved in industry projects. PhDs' salaries are not taxed, and the government requires PhD projects to be free from commercial interests. PhD work is therefore typically kept separate from the industry collaborations.

5.8.5 Team development

There are three schools of thought about the role of the original inventor or researcher in entrepreneurship-based commercialisation. One is that successful commercialisation depends upon the personal involvement of the inventor, and on their willingness to take risks and to engage in the operation of a start-up company, even though they are unlikely to have the full set of business and managerial skills needed and therefore have to be trained and educated. The opposite view is that the inventor can play a less central role, provided other people can be recruited who will take over the business leadership. A middle way is represented by the understanding that the inventor or researcher is indeed important for the commercial development of the idea, but in the role as scientific or technical expert and should not be forced into an entrepreneurial career. All three perspectives are present among our cases.

Capital investors tend to focus on the importance of entrepreneurs' motivation in establishing companies. The incubators adMare, BII and UBI tend to take the investors' perspective and employ a more forceful and rigorous approach to incubation than the academically orientated ones. Their attitude is that entrepreneurship is a serious business, not to be taken lightly or to be done as a side-activity. They give a stronger sense of being 'in business for money' by developing portfolios of start-ups, while the academic organisations are undertaking several broader and more societally orientated missions. AdMare and BII have especially demanding assessment criteria for accepting start-ups into the incubator and strict timetables for firms to achieve certain milestones. They are both risking their own money by investing in incubation. Like private venture capitalists, these incubators are very proactive in introducing people with needed skills – for example in management, marketing, or accessing investment funds – into the companies they incubate. AdMare brings together the very best partners from throughout academia, industry, patient foundations, the investment community, as well as other key opinion leaders to build an experienced management team for the companies they support. The goal is to generate a complete and highly compelling business case to secure private investments, grow the company, and take technologies to patients.

Some of the case organisations take a softer approach, believing that commercialisation is more likely to happen if the researcher does not completely have to abandon their academic career. Some university systems, like KU Leuven, will hold faculty positions open for a time or will create 'virtual companies' to reduce the risks of entrepreneurship and to make it easier for academic entrepreneurs to return to the university. These systems may be more willing to involve new people with business and commercialisation skills and motivation so that the success of the start-up does not necessarily happen at the cost of losing a member of university faculty. For example, VIB has a practice of introducing entrepreneurs into start-up companies to strengthen their business abilities and escape over-reliance on the narrower skill set of the inventor. UBI puts a lot of effort into the teams of the projects that are accepted for the incubator. The researchers, who had the original idea, are always kept involved, because it is in those brains that the ideas reside, and they are needed to guarantee high quality of data and the experimental design. But to ensure commercial success, other resources and other competences need to be added. The team will also need a 'champion' with the interest and ambition to drive the innovation project. The ideal situation is when there is a PhD candidate or postdoc who has the trust of the PI and the right entrepreneurial mind-set and skills to run the business. If no such person is to be found, UBI can bring in an external person to lead the innovation project. In those cases, there must be trust between the researchers and that person, and if the external person is an experienced entrepreneur, he or she must move very slowly to make sure the researchers, who will be part of the process, are trained and taught along the way. If this goes too fast, trust will be lost, and disagreements will arise. According to UBI, most conflicts arises when the start-up is about to take in external capital or when the product is to be launched in the market. These are critical phases where people are most afraid of failure. UBI therefore sometimes brings in psychologists to manage the situation. Finally, the companies are given carefully selected boards with competence and composition optimised to secure their development. The members are chosen to have slightly overlapping competences as that usually produces better discussions. Any historical success stories of individual board members must not dominate the dialogue and development process. The board should be established before external investors are attracted, and preferably early in the process.

Many of the case study organisations also provide some degree of entrepreneurship mentorship to inventors and start-ups, varying from appointing specific, individual mentors to individual companies through to more general mentorship being provided by organisation staff. SynbiCITE, for example, provides long-term mentorship to existing companies and researchers wanting to spin-out their own company by experts, either from Imperial College or from outside.

5.8.6 Research infrastructure and facilities

Access to specialised instrumentation, facilities and infrastructures is often crucial for research projects in life sciences. These instruments and facilities are generally too expensive for individual research groups or start-ups to have in their labs, or they require specific expertise to operate and maintain, and research projects. Sometimes researchers or start-up companies only need to use a certain piece of equipment once, so large investments are neither justified nor possible. The solution is often to find a collaboration partner for that specific purpose.

Most of our case study organisations have research facilities as part of their total offer to researchers and start-ups they support. The facilities can either be owned and managed by the case organisations themselves or they can act as coordinators, giving their members access to facilities elsewhere. Using VIB as the first example, they have eleven, in-house, core facilities which provide researchers access to novel and specific technologies required for scientific breakthroughs. The core facilities were conceived to solve the issue of maintaining complex and expensive scientific technologies, including technical upkeep, infrastructure investment and the technical knowhow that evidently was beyond the scope of any single scientific group or even university. Another example is the London Biofoundry, which is one of the hubs of our UK case organisation SynbiCITE. This provides state-of-the-art automation of end-to-end design, construction, and validation of large gene constructs. The foundry is specifically designed to support the commercialisation of synthetic biology, allowing SynbiCITE's partners to prototype new biologically based chemicals, drugs, and materials. The management of SynbiCITE had earlier identified the impact of biofoundries in the private sector of synthetic biology and wanted to incorporate this into the public sector. The foundry was the first one in the public sector and was funded by Research Councils UK.

IBioIC, on the other hand, gives its members priority access to two scale-up centres located at two of the network's member universities: the Rapid Bioprocess Prototyping Centre at the University of Strathclyde; and the Flexible Downstream Bioprocessing Centre at Heriot-Watt University. IBioIC members get priority access to a wide range of fermentation technologies and services from small scale culture to pilot-scale production, process optimisation, downstream processing, and data analysis. The centre's team also helps to identify collaborators and support the bid writing process for external funding to realise members' scale-up ambitions. Project costs are partly covered by the centre. IBioIC is also part of BioPilotsUK – a collaboration of four open-access centres to develop and strengthen UK-based value-chains offering further R&D facilities, technical assistance, and collaboration opportunities. WUR is another example, presenting a university-wide Shared Research Facilities scheme to permit shared access by researchers in the university to 559 different pieces of equipment of which 305 pieces were available for external as well as internal use. This has increased equipment utilisation to 60%.

Whereas some instruments and equipment can be of general interest within life sciences, there is also a degree of specialisation within the various sectors. The Norwegian institutes, Nofima and IMR, have set up facilities needed to address their missions. Nofima and IMR offer access to research facilities, both to their own in-house or collaborative research teams and to external researchers and companies. IMR has a world-class infrastructure with extensive biological experimental facilities, advanced equipment for monitoring and observation, laboratories, and IT infrastructure, in addition to several research vessels and a database for genetic bioprospecting. The infrastructure is a prerequisite for IMR to be able to deliver both monitoring services, advanced research, and advice in line with the needs of the government and the marine industry. A specific committee is appointed to work strategically with the development and renewal of the infrastructure. The activity within the institute is high and the most modern facilities are usually fully utilised by the institute staff. Generally, IMR allows external researchers to come on its research cruises, and the research stations and facilities can be accessed by both external researchers and companies when there is unused capacity, usually for a fee and depending on how engaged IMR is in the research. Nofima has several laboratories and pilot plants which are available for use both in their own research and to industry. Among these facilities is BioLab, an accredited contract research laboratory that offers analytical services in chemistry, microbiology, and physical measurements as well as expertise in process and product development based on marine and vegetable raw materials. Another facility is the Tromsø Aquaculture Research Station, a modern research facility for experimental studies of fish, molluscs, crustaceans, and other aquatic organisms. The Aquaculture Station is an important tool for Nofima's industry-oriented research activities and the research going on at the station contributes to building knowledge and competitiveness in the seafood industry.

The Swedish incubator UBI cannot offer research facilities itself and has therefore solved the issue of accessing instruments and technology by setting up a Facebook community for facilities sharing. Through the community, researchers and companies can share, buy, and sell second-hand laboratory equipment and access laboratory services they do not have themselves or cannot afford to acquire. A similar system is used in the Food Valley ecosystem, of which WUR is a part. There, an equipment sharing scheme is set up to provide access for both companies and researchers to about 300 pieces of equipment.

Sharing equipment and instruments and research facilities not only advances research but also has encourages and supports collaboration. Several of the organisations that provide physical incubation facilities emphasise the role of facilities in helping start-ups build social and business networks. By implication, where such facilities are embedded in innovation ecosystems their effectiveness in network-building is increased further. The UBI Facebook community not only allows different stakeholders to support each other but also helps members of the community to solve each other's problems. The Facebook group has increased the networking opportunities between members and made it easier to identify synergies and collaboration opportunities.

5.9 RRI

The AS IS study found that a concern with the principles of RRI was not well embedded into Norwegian research-performing organisations. In our case studies, we focused on trying to understand the role of interdisciplinarity in fostering disciplinary convergence, how public-private partnerships could be accommodated to RRI principles, incentives for interaction between the research and user sides, what could be done to align values and needs of society and research and innovation institutions. This alignment may reduce the privatisation of public knowledge.

Our two RRI-focused cases – Synbiochem and CMSB – were generally very resistant to the idea of RRI being streamlined or instrumentally implemented as a process within the centres. The changes they described were more in terms of building awareness, collaborative working, and gradual change of perspectives, rather than concrete changes to procedures. The CMSB case underscores the role of the 'embedded' social scientist/humanities scholar working with innovation processes without using the term RRI. This also goes for NOFIMA who have embedded reflexive practices related to innovation processes in their toolkit without explicitly labelling this as informed by RRI-principles. These include design thinking and reiterative processes around consumer needs. The Synbiochem case suggest that value could be added in designing IPR policies requiring openness and access for user groups when developing non-disclosure agreements and patent applications in collaboration with industry.

The case study organisations fall into four groups, with respect to RRI.

- Norwegian research institutes, which are influenced by government's interest in RRI but are not compelled to follow RRI principles. In practice, as a government laboratory IMR largely produces public goods, so adherence to RRI is easier than for Nofima, which is an RTO and works primarily for industry
- Incubators, which focus little on RRI, presumably because they have a focus on start-up and entrepreneurial innovation, so that they do not see wider social issues as being very relevant to their remit
- University-based innovation centres in the UK, where those working with synthetic biology had a strong focus on RRI because it has been built into national policy and come under the influence of both the research councils' and the British Standards Institution's frameworks for RRI. Other centres (aquaculture, industrial biotechnology) operate with government funding that encourages RRI but does not enforce it so strongly
- Large, broad-spectrum research performers (VIB, WUR and KU Leuven) that follow the broader European trend of having an interest in RRI but whose practices appear not yet to have been strongly influenced by it

While we explored RRI issues as far as practicable in all the cases, we placed a particular focus on RRI in the cases on Synbiochem and CMSB , to ensure that we covered RRI issues in greater depth in these two places which regard RRI as being central to their mission.

RRI and processes within the case study organisations

The case study organisations viewed RRI as something to be instrumentally mainstreamed in their activities. The changes they described were more in terms of building trust, awareness, collaborative working, and gradual change of perspectives, rather than concrete changes to procedures. The influence of RRI on R&D collaboration agreements was individually negotiated and covered by non-disclosure agreements. Researchers emphasised working with company partners to develop approaches that fit their individual needs, rather than using a standard approach. The promotion of RRI by the research funding organisations provided a basis for Synbiochem to develop its own Manchester RRI Framework. Colleagues from the Manchester Institute for Innovation Research are collaborating with Synbiochem, doing social-scientific studies in line with the Institute's wider interest in RRI, for example via the EU Framework Programme Horizon 2020. Both Synbiochem and the UK Centre for Mammalian Synthetic Biology have contributed to research standards on RRI and to the industrial standards developed by the British Standards Institution.

Disciplinary convergence

Interdisciplinarity has been viewed as positive in research and innovation policy for many years, so organisations tend to pursue it independently of the current policy interest in RRI. Problem-orientated organisations like the Norwegian institutes are particularly strongly driven to be interdisciplinary. Synbiochem and CMSB were deliberately placed in interdisciplinary environments, but the same is true of the other university-based innovation centres such as IBioIC, which emphasises not only interdisciplinarity but working across sectors and which makes a lot of effort to engage with its ecosystem through matchmaking, outreach, networking-building and collaborative R&D projects. However, there is little emphasis on building particular knowledge practices around transdisciplinary collaboration in an explicit manner. The terms trans- and interdisciplinarity seem to be used interchangeably. The concept was used sparingly among the respondents in both centres, yet many features of ongoing interaction with stakeholders could be understood as transdisciplinary in nature.

Public-private partnerships, IPR and openness

Synbiochem works in an area where existing patents can block potential research pathways, so it conducts patent analysis to try to find IP-free research directions. Its focus on RRI, however, does cause tensions between industrial partners' desire to stick to their traditional position of secrecy and ownership of IPR and Synbiochem's desire for data openness and open publication. In practice, Synbiochem is gradually persuading companies to be more open, while in key areas signing non-disclosure agreements and agreeing publication delays and conditions. Synbiochem is also under pressure from the UK's REF performance-based research funding scheme and academics' career needs to publish. (All the case-study organisations are subject to this type of pressure.) Our case studies suggest this tension can sometimes be resolved by agreeing short delays to publication.

Partnerships with industry build on trust and rely on arrangements that help protect the interests of both companies (confidentiality) and researchers (ability to publish). Collaboration on joint projects and sharing good practice – e.g., encouraging the use of national RRI guidelines (eg those of the BSI) – is more fruitful than attempts to impose rigid requirements. The case study organisations generally try to work with standard agreements for collaborative research that set rules for IPR and publication.

To a greater degree than the other case study organisations, Nofima and IMR have a role in making data available for research as public goods. IMR uses Creative Commons licences to make data available for non-commercial uses. In contrast to their British counterparts, the Norwegian cases seem to lack a particular approach towards steering partners towards specific IPR practices aiming towards public good.

Incentives for interaction between the research side and demand or end-users

In 2010, the UK BBSRC and the ESRC jointly organised a public dialogue on Synthetic Biology, involving broad consultation with a variety of stakeholders. Among other things, the final report conclusions outlined the 'Leadership and Funding Roles of the Research Councils' as well as capabilities needed by scientists to 'Think through Responsibilities' with respect to emerging synthetic biology technologies.[25] These then fed into a national road map for synthetic biology, the design of the Synthetic Biology Programme and the creation of its centres, including Synbiochem and CMSB. More broadly, the university innovation centres are mandated to interact with the demand side in a range of ways by the terms of their funding, so there is pressure towards interaction from their normal modus operandi, and this is not done solely because of interest in RRI principles.

Membership of ecosystems (Domain 3) is important to maintain contact between research and the demand side. Thus, CMSB provides opportunities for industry to access facilities, in-house training, collaborative projects, consultancy services, and licencing opportunities. Industrial

[25] Synthetic biology dialogue: Findings and recommendations, June 2010: https://bbsrc.ukri.org/engagement/dialogue/activities/synthetic-biology/findings-recommendations/

engagement is evidenced by visits from 14 industry partners[26] and two start-up companies.[27] The use of industry clubs (SAIC), networking meetings (IBioIC) and foresight exercises to understand future demand (adMare) provide examples of ways to create the needed interaction.

Several of the case study organisation emphasised the need to disseminate usable results – for example, IBioIC has communication activities and a dedicated public affairs person who deals with public engagement, SynbiCITE, Synbiochem, SAIC, WUR and others also put a lot of emphasis on outreach.

Ensuring innovation benefits flow to society rather than being privately appropriated

The Synthetic Biology Programme centre grants required the universities to develop RRI as part of the centres and created the conditions for the centres to be "a series of experiments" on ways of implementing RRI in specific disciplinary contexts. The Programme also created mechanisms for networking among the funded centres to reflect on lessons learnt during their operation, and to exchange and develop ideas for improvement. Centres have also been able to participate in international RRI networks, increasing the scope for reflexivity.

Embedding RRI into the way the centres work encouraged them to work with standardisation processes both for RRI (via the research councils and the British Standards Institution – BSI) and to generate standards for synthetic biology processes and interfaces, helping ensure these are generally available and not dominated by proprietary standards.

Like other university innovation centres, CMSB has succeeded in attracting additional funding to move towards commercialisation, including grants from research councils, innovation agencies and charities, as well as industry co-funding. Long-term collaboration and building multidisciplinary research capacity form the basis for attracting further funding. Thus, the centre grant can act as a platform for 'leveraging' funding for further activities, whether training grants, cooperation, and co-funding from industry. However, the boundary between the centre's 'own' research and associated activities should not be observed too strictly and instead be allowed to get blurred and interwoven with other activities. RRI and contributions from social scientists have been incorporated into the centre explicitly because funding has been available for it. Without this, it is not clear that RRI would have been involved.

RRI training and in relation to innovation culture

Synbiochem's RRI team has provided a range of policy briefs and training activities including:

- A workshop for early career researchers in synthetic biology, in which participants were asked to reflect on notions of responsibility and how to apply RRI in their own work[28]
- RRI support for teams in the international student competition iGEM[29]
- Pop-up stalls in public venues to collect data and engage the public on issues related to RRI[30]

[26] https://gtr.ukri.org/projects?ref=BB%2FM018040%2F1#/tabOverview

[27] https://www.ed.ac.uk/biology/mammalian-synbio/for-industry

[28] RRI Group Research Brief 20/03, March 2020

[29] https://synbiochem.co.uk/igem-Manchester/

[30] RRI Group Research Brief 17-01, May 2017

The RRI team also has a wider role as a public resource beyond the immediate constituents of the Centre, engaging with companies and other external organisations.

CMSB has had a dedicated team of social scientists within the centre from the outset and encompasses groups from the field of science and technology studies (STS), as well as innovation studies. Training is not included in the centre grant – it excludes PhD training. However, RRI training has been injected as a compulsory course into the Edinburgh masters in synthetic biology.

SynbiCITE's strategy for incorporating RRI principles is through embedding them in education and the development of new technologies. The centre fosters dialogue among the public, scientists, engineers, and policymakers and is participating together with the various bodies that fund research in the UK in developing a comprehensive RRI framework. In association with social scientists at King's College London methods have been developed by which RRI principles can be translated into governance of synthetic biology. The approach maps onto a framework called AREA, set out by the EPSRC. Since this is tied to a funding organisation, it is likely to be influential in future practice.

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