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Digital Life Norway

AS IS Report

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This is the first 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. This report discusses DLN and its context in the Norwegian research and innovation system. It is partly descriptive (so that we have a basis for comparison with other examples of research-intensive innovation) and partly diagnostic in order to understand strengths and weaknesses of the project. The next stage involves looking at and learning from good examples internationally and comparing them to DLN in order to identify potential lessons. The third part charts the way forward – partly for the benefit of DLN and partly to draw more general lessons for similar future efforts in Norway.

Research and innovation in the digital life sciences

Developments in digital life sciences provide both scientific and innovation opportunities. The aim of DLN is to help Norway capture both, while building necessary research capacity. Digital life science research combines inputs and expertise from both data and computer sciences on the one hand and the life sciences on the other, and includes research that: enhances knowledge and understanding of biological systems; the creation or improvement of approaches, devices or solutions underpinned by life sciences and digital technology; and the development of digital devices or approaches to inform decisions. The rise of digital life science is underpinned by advances and technological improvements in data collection, data sharing and integration, and data analysis. Advances in data capture and computational methods have enabled the creation of new research fields, notably systems biology, synthetic biology, theranostics, digital health and radically improved mobile or wearable medical devices. The life sciences overall depend to a growing extent on larger-scale and more advanced data use.

The research literature relating to the life sciences indicates that the roles of the academic community are often to generate underpinning knowledge and tools, to – from a commercialisation perspective – 'de-risk' innovation by doing research at early TRLs, to address needs of limited interest to the private sector, provide expert advice and training. Life sciences based sectors have in the last three decades become increasingly open to using extra-mural sources of knowledge and R&D, exploiting skills and equipment they may not themselves possess, working as well with individual small firms as in public-private R&D partnerships. Of course, R&D only becomes relevant where companies experience knowledge gaps; if not, R&D is not generally needed. Where it is, the need may be for translational research. Innovation often involves interactive learning or co-production of innovation. External research labs have become increasingly important sources of knowledge for innovation. The old linear idea of transferring knowledge to one company that then exploits it on its own is increasingly unrepresentative. While researchers must understand the demand side, there is equally a need for companies to do some of their own R&D in order to have the capacity to connect knowledge with the market. Companies that do R&D innovate more than companies that do none. Increased understanding of the importance of the demand side in innovation has triggered the development of more user-centric innovation management through techniques such as user-centric innovation, design thinking and lean start-up, which need to be understood at the stage of innovation and whose underlying idea about the importance of connecting needs and users to knowledge generation is relevant at the stage of deciding what research to do. Particularly in the context of life sciences and the uses of data, it is also important to observe the principles of responsible research and innovation (RRI).

The DLN research and innovation system

Both the literature on innovation in life sciences and more general research on research and innovation literature emphasise that this supply-demand coupling in innovation takes place in a systemic context. The extent to which an organisation like DLN can succeed depends partly on its own efforts and resources and partly on its context, since innovations are largely co-produced in networks rather than being the products of individual 'champions'. A key part of that context is the 'ecosystem' in which communication, technology transfer and co-production among knowledge producers and users take place and where start-up firms are able to develop and grow. If DLN's knowledge production is to be of economic benefit it needs to be valorised across the start-up ecosystem as well as with established organisations.

The academic part of the Norwegian innovation system is rather healthy and well-tuned to DLN's agenda. Norwegian research in the life sciences – especially but not only medicine – and IT is a big part of the university system and its productivity and quality are generally good – though naturally, as a small country, Norway does not figure very much in the most highly rated literature.

However, the business sector does not have the same pattern of research specialisation as the university sector. This matters because R&D-performing companies are best able to make use of external knowledge inputs such as those from DLN, and they are better than others at turning such knowledge into innovations.

While Norway's heavy investment in medical research is relevant to the state healthcare system, the pharmaceuticals industry in Norway is dominated by foreign multinationals, which inhabit innovation ecosystems abroad and do little or no R&D in Norway, so the overall level of R&D in the industry in Norway is low. We do not have good data on the medtech sector, but the pattern there appears to be similar. The fishing and aquaculture industries each spend about three times as much on intramural R&D as the pharmaceuticals industry. However, the proportion of PhDs among R&D workers is much higher in pharmaceuticals than in the other two industries, while extramural R&D expenditure is highest in pharmaceuticals. This suggests that while the small pharmaceuticals industry may be receptive to science-based knowledge inputs to innovation, the other two are less so. We understand that R&D-based innovation relevant to the fishing, aquaculture and food industries takes place to a considerable extent upstream in their supply chains. We lack R&D data for industrial biotechnology because this does not form a distinct industrial sector. Overall, however, we can conclude that, while DLN focuses on many areas of research that are – in technical terms – potentially useful to business, the established, R&D-capable 'demand side' for many of DLN's research outputs is limited. This means that some of the commercial valorisation would have to take place through start-up and technology transfer. We are in the process of trying to understand better what the innovation ecosystems in Norway are that could help with this process of valorisation. There are clearly numbers of start-up companies active in DLN- relevant areas but the difficulty of making a significant economic impact on the basis of start-up in a small country are non-trivial.

These issues with DLN to a considerable extent reflect those of the national biotechnology strategy overall, which has built and builds upon a strong research system but experiences difficulties in connecting with the demand side in order to enable wealth-creating innovation on a large scale.

Overall, Norway benefits from a highly-funded and rather complete set of research and innovation support schemes. A recent spending review focusing on the innovation support infrastructure generated a number of detailed proposals for reform but found little substantively wrong with the system as a whole. The system includes programmes that link the research community with industrial consortia, support to industrial clusters in business development and innovation, a new 'catapult' scheme that aims to accelerate commercialisation as well as a long-established but recently expanded scheme for commercialising ideas from the research and higher education sector. Ten clusters currently or recently supported by Innovation Norway's Norwegian Innovation Clusters group a large number of companies relevant to DLN and provide a way to access the innovation demand side to address both new and established companies. There are also incubator and finance organisations available to support start-ups in DLN-relevant fields. However, university strategies and our interviews suggest that they are poorly linked to these innovation ecosystems.

The Norwegian system of knowledge exchange between academia and society has been studied intensively in recent years. The university technology transfer office (TTO) system was established in the mid-noughties, largely following the pattern established in the USA following the Bayh-Dole Act of focusing on discovery, patenting and exploiting intellectual property through licensing and start-up. These TTOs are organisationally separate from their host universities and operate as profit centres, so they focus on generating income in the short-medium term. This form of local optimisation means they find it hard to make bigger trade-offs on behalf of their university – for example between taking patents and maintaining long-term collaborative R&D relationships with industry or providing patient support and investment in order to secure longer-term returns. It is broadly agreed that the TTO function needs to be reintegrated into the universities to enable them to take a broader, longer and more strategic view of knowledge exchange. This perception is reflected in very recent university innovation strategies, together with the perception that university culture needs to be changed to become more innovation-friendly through training faculty and students alike.

The supply of capital for start-ups in Norway shares problems with many other countries. 'Seed-corn' funding has become harder to obtain, despite the state's efforts, as attention in finance has shifted towards later-stage, less risky investments. While Norway produces similar numbers of new companies per head of population to its neighbours, these tend to grow less well and to be less scalable, which may mean that they have poorer links to markets and user needs than, say, Swedish start-ups.

Digital Life Norway

DLN is the offspring of the bigger national biotechnology strategy that RCN has been working to implement over the last decade and responds to the need to increase the rate of innovation generated by Norwegian biotechnology research, exploit opportunities in the fast-growing bio-economy and address societal challenges. It depends on the idea not only that Norway has research strength in relevant areas but also strong demand for, and ability to use, new knowledge on the demand side in addition to well-functioning systems for connecting demand and supply. Research projects under DLN are selected by RCN based on bottom-up proposals from researchers and RCN's normal quality and relevance criteria. They do not appear to be connected to an analysis of systemic needs and opportunities. Researchers indicate that they apply for DLN funding or become involved with its large graduate school in order to pursue their career objectives and are not necessarily motivated by DLN's aims of innovation and societal impact. DLN works to increase supply-demand linkage by affiliating 'partner projects' and through the work of the DLN office on generating such links.

Success factors in life sciences innovation

The literature in this area is very uneven; there is a lot of focus on biotechnology and health and little on other areas of interest to DLN. The available literature is nonetheless suggestive of issues likely to be felt across the whole DLN scope. In particular, over-focus on supply at the expense of demand and the wider innovation system is a recurring theme.

Studies in biotechnology have identified the importance of test-beds and demonstrators to allow scaling-up, the need for cross-sector collaboration to enable to use of biotechnology in new sectors and the importance of establishing demand-supply linkages to ensure research addresses topics that have innovation potential.

Studies in the bioeconomy point to the importance of establishing new value chains so that there is a context in which innovations can be made. Policies tend to support the supply of research and innovation and neglect demand; so, for example, innovation procurement is little-used as a way to help strengthen innovation ecosystems.

Translational research suffers both from a lack of innovation culture (or interest in innovation) on the research side and weak links to demand as well as poor understanding of the need to address the wider innovation system in areas such as establishing supply chains or connecting to regulation.

Where these problems are being overcome, it appears that research culture is changing to become more friendly to innovation, both in the sense that researchers understand the innovation process and that they are increasingly interested in setting research objectives that not only advance science but do so in areas likely to enable innovation. A key element is that the academia/industry interface is becoming more porous – not only because of increased academic interest but also because the R&D and absorptive capacity on the industry side is increasing. These changes are driving up the volume of 'translatable' research while at the same time sources of public funding are becoming available that support translation at a stage where it poses too big an investment risk to be of interest to private-sector investors with access to lower-risk opportunities. At the same time, at least some of the leading universities are developing knowledge exchange capacities, processes and cultures that support commercialisation and demand-side linkage better than in the past. Experiments by industry in promoting open innovation may also start to play a role. Changes that support innovation involve a combination of at least: skills and education; improved infrastructure and institutional support; and changes to the academic incentive system that reward – or, at the very least do not conflict with – innovation.

Challenges for Digital Life Norway

DLN is in a position to capitalise on important strengths in the Norwegian national research and innovation system but also faces important challenges.

As we have shown, DLN is in a position 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 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.

However, DLN also 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

These challenges are not unique to Norway. Exploring the way they work out in other contexts will be an important part of our work in the next stage of the project.

Next steps

Having painted an AS IS picture of the situation of DLN, the next task is to study successful environments internationally in order to understand the reasons for their success and the way in which they have dealt with the challenges identified above. Our next steps towards building a view of what is TO BE are therefore to

- Validate the findings of this report with the anchoring group and DLN
- Develop a long-list of potential international comparators and refine this into a short list together with DLN and the anchoring group based on information from secondary sources
- Conduct 'site visits' to understand the comparators better and to explore success-factors and challenges with key actors and stakeholders. While we would prefer to make physical visits, we will have to adjust our approach as dictated by the still quickly-changing circumstances of the current pandemic
- Use the information gather internationally to construct a small number of scenarios for DLN and discuss these with DLN and the anchoring group. An important sub-objective here is to produce a result that is at least to some degree generalisable across other fields in Norway
- Finalise the TO BE report, in preparation for producing a road map in the last stage of our work

Insights and lessons

- Both the literature and DLN's specific survey in Norway confirm that a large range of technological innovation opportunities arise from the convergence of data and computer science with the life sciences. Drivers include continued rapid declines in the cost and increases in the power of data collection, storage and processing that enable more intensively data-focused R&D to be done in the life sciences as well as the use of more complex and powerful data-driven decision-making, management and control processes in life-sciences-based production. Examples of DLN-relevant science-based innovation opportunities include

  - Health: using omics data and analytics to understand determinants of health and disease mechanisms and their links to individual genetics, lifestyle and the environment
  - Food and agriculture: capture and analyse data of soil moisture and plant chlorophyll status to inform farming decisions
  - Fish and aquaculture: using mathematical models to understand fish metabolism patterns to help deliver effective feed products
  - Biotechnology industry: using synthetic biology and bioengineering principles to design biological entities or molecular sensors to measure relevant parameters and deliver products more efficiently and in a sustainable way
- Research on the relationship between research and innovation – across national research and innovation systems in general and in relation to the life sciences in particular – shows that doing fundamental research does not automatically lead to innovation. Rather, research-based innovation occurs through the coupling of scientific and technological opportunities on the one hand with needs and opportunities on the other that are pursued by actors with an economic or social interest in generating innovations. This implies that programmes that aim to force the pace of research-based innovation need to forge linkages from needs to research agendas and not rely solely on the serendipitous appearance of innovation-relevant research results
- Academia can provide important functions that support innovation, such as generating underpinning knowledge and tools, de-risking low-TRL research, contributing socially-needed knowledge that may not be demanded (or delivered) by the private sector, providing expert advice and training people to do research and innovation – but can only effectively support innovation as components in wider innovation systems. This means that DLN is not only critically dependent upon its own strategy and actions for success but also relies on other actors and framework conditions in the innovation system
- Innovation is not an individual but a social act – innovations are co-produced by 'innovators' and the 'innovation system' of organisations, institutions and ecosystems that they inhabit. How well these systems work – in terms both of the quality of what they do and the effectiveness of the network linkages among them – is an important determinant of success and helps explain why some (geographical) places are more successful at innovation than others. This means that where there are weaknesses in the Norwegian life sciences-related innovation system DLN needs to mitigate them or find someone else to address them
- There are various organisational units and principles relevant for a well-functioning innovation system, from physical clusters where the various actors can co-locate and effectively interact to networks and virtual hub-and-spoke organisations to scale up local innovations and create a national ecosystem.
- Industry sectors and firms are more likely to innovate, and more likely to collaborate with academic institutions, where these employ themselves R&D employees with higher-degree education (including PhDs). In terms of the DLN-relevant industry sectors, while fishing/aquaculture and food industries have large R&D spend in Norway, the fishing industry employs relatively low number of R&D personnel. The pharmaceutical industry employs R&D personnel with a large proportion of higher degree education, but their overall number in Norway is very low. DLN-relevant industry sectors each performed about 80 R&D man years by personnel with a PhD in 2018.

Strengths of DLN

- Convergence between IT and life sciences is a significant global trend. This is positive for DLN both in the sense that there is a growing amount of science with which to interact but also because there will be new and growing markets driven by innovation, so there should be opportunities to use the knowledge DLN makes. An important implication of international activity, however, is that DLN needs to be well engaged with science and innovation abroad as well as in Norway
- DLN is fortunate to inhabit an innovation system in Norway that in important respects performs well
  - The university system has a large life-sciences (especially medical) component whose research is generally strong and productive, and is also very competent in IT and digitalisation
- The state agencies that support research and innovation are well organised and funded, and have a fairly complete set of funding instruments at their disposal
- There are incubators and clusters active in Norway in which life-sciences and ICT-based innovation is taking place, though many of these have been funded in the context of regional development and business – rather than technological innovation, and they naturally reflect the structure of industry discussed below

Weaknesses of DLN

- The life sciences research focus of the universities is not reflected in the structure of industry or its research, so industrial demand for research-based knowledge in the life sciences is weak and industry is not investing in, absorbing it and scaling up innovations based on it. This limits the amount and quality of signalling from the demand side about its needs. It also limits opportunities to connect knowledge needs on the demand side to production on the knowledge supply side, hampering innovation. This leaves an opportunity to commercialise discoveries through start-ups, but they in turn also suffer from the problem of weak innovation demand
  - A possible response is for DLN or others more proactively to explore potential needs and opportunities on the demand side and to connect them to research agendas
- While the universities are in a position to link IT and the life sciences in research, on the basis of the information available to us so far, this integration in research is not happening as quickly as it could and relevant life-sciences based industry is (with exceptions) neither especially invested in R&D in these areas nor well positioned to combine them
  - This would imply a need for intermediation, either by applied research organisations such as research institutes or by suppliers in industry of capital equipment and other knowledge-intensive inputs
- A problem Norway shares with other countries is the drying-up of seed-corn and other early-stage capital investment. This places the burden of funding such activities onto others, especially the universities, which are poorly equipped to carry this load. This is a weakness that DLN cannot address
- Norwegian TTOs are generally profit centres, separate from their host universities and unable to make either longer-term investments (e.g. to create spin-outs) or to trade off potential income against other aspects of university-industry knowledge transfer such as collaborative research. While this TTO model traditionally works well in pharmaceuticals (where companies regularly license/acquire potential scientific assets), it is less well

adapted to innovation in less R&D-intensive industries or where there is a need to move fundamental knowledge towards the market (including the public sector) through proof-of-concept or translational research. DLN is therefore poorly supported by this part of the innovation system

- The links between the universities that do DLN research and the innovation ecosystems appear to be weak, limiting opportunities for the exploitation of DLN results
- The documentation on TTOs and university innovation strategies both point to a lack of innovation culture in the universities, in the sense that there is not enough education of faculty or students about how innovation works and the mechanics of establishing ownership of intellectual property, so that the take-up of innovation opportunities arising from DLN research tends to be hampered. While the university strategies tend to emphasise measures to make the culture more innovation-friendly, this type of cultural change normally takes time

DLN's governance means that it has little influence on the research undertaken with funding from the programme and there appears to be no mechanism that would make it possible systematically to explore needs on the demand side and connect them to the research portfolio. While DLN recruits 'partner projects' that have clearer demand-side focus and while the DLN secretariat works hard to establish research-innovation links more widely, the lack of systemic link from needs to the research agenda makes it difficult for DLN as a whole to perform its innovation mission

1 Introduction

This is the first report from Technopolis Group in a project called "A roadmap for academic research-intensive innovation", commissioned by the University of Oslo (UiO). The project originates in the activities of the Centre for Digital Life Norway (DLN), but the scope goes beyond DLN. The project aims at, first, understanding the conditions related to translation of research findings into products or services of societal and economic value, including to identify what works well and what does not, and then, to develop vision and an action plan for how to support increased translation. The project will study all levels of the innovation support system, from the individual researcher to the institutional and systemic level, but from the perspective of the digital life sector in Norway.

This first report gives a description of translational research conditions, the innovation system and the various instruments available for DLN's researchers in Norway, and the stakeholder organisations that exist. The perspective shifts between the local DLN level, the national level and the international level. The report has the ambition to give a picture of the situation and the system in place, *as it is*. This part of the project has therefore been labelled 'AS IS'.

The report contains an extensive review of research and innovation in the biotechnological sciences and the digital life sciences – the digital life sector – primarily in Norway, but as indicated, also beyond.

This part of the project was carried out during February and May 2020 and besides the literature review, it included visits and interviews in Oslo, Bergen and Trondheim, plus a number of interviews via telephone or other telecom channels. Interviews were made with researchers linked to DLN, university management representatives, technology transfer office managers, and other stakeholders, for example representatives at the Research Council of Norway (RCN). 37 interviews were conducted; some were made with two or more people together, so in total 42 people were interviewed. Three workshops with DLN researchers were organised, in Oslo, Bergen and Trondheim, where research projects were presented.

Both the review and the interviews will be used in and have an impact also on later stages of the project.

The team at Technopolis Group wishes to thank the interviewees for generously sharing their views and thoughts, and the secretariat function at DLN for its invaluable assistance and support.

2 Research and Innovation in the Digital Life Sciences

The following sections provide an overview of concepts relevant for research and innovation for digital life sciences. Since the converging technology area between digital technologies and life sciences is defined in a variety of ways by different actors in the R&D and business spaces, we provide first a brief science-based framework and a conceptual map that shows how it may deliver value to stakeholders. The following section explores the driving forces behind digital life sciences with relevant examples for data collection, data integration and analysis, to the use of life sciences data. Subsequently we review the role academia plays in innovation for life sciences and the various ways academia, industry and public organisations may interact in an innovation system. Finally, we conclude with explaining the models for pathway to innovation, user-centric innovation management approaches and concept of responsible research and innovation.

2.1 Scientific framework

In the context of DLN, this study defines digital life science research as *research which combines inputs and expertise from data and computer sciences and the life sciences, with the aim of catalysing innovation.* This covers a broad range of research activities, with different (but often overlapping) research aims, including:

1. Research that targets an **enhanced knowledge and understanding of biological systems**, enabled by the increase in 'what can be measured' and scale of data available. The resulting new insights can underpin decisions on the next research steps. This type of research tends to have a strong focus on the life sciences, in collaboration with the data sciences.

   Examples: Use of -omics technologies to uncover changes in response to disease or environmental change (as well as difference between individuals); discovery and prioritisation of drug targets and biomarkers

2. Research that centres on the **creation or improvement of an approach, device or solution** underpinned by digital technology, which can either be:

   - The use of a biological component or system to identify or manufacture a useful product, eg for use in industrial biotechnology processes
   - The development of man-made devices to replace a biological function or system, such as implants and prosthetics

   It is enabled by knowledge gained in category 1 research, and often an outcome thereof, but has an 'applied' focus, targeting the development of specific processes and products rather than new knowledge and enhanced understanding.

   Examples: Synthetic biology / 'designer microbes', bio- and geo-prospecting; artificial organs and nerve systems

3. Research that focusses on the **development of digital devices or approaches to inform decisions** or improve products and processes in the life science sector. These outputs also provide the tools to underpin research leading to the outputs in categories 1 and 2. This type of research tends to centre on the engineering sciences, working in collaboration with the data and life sciences.

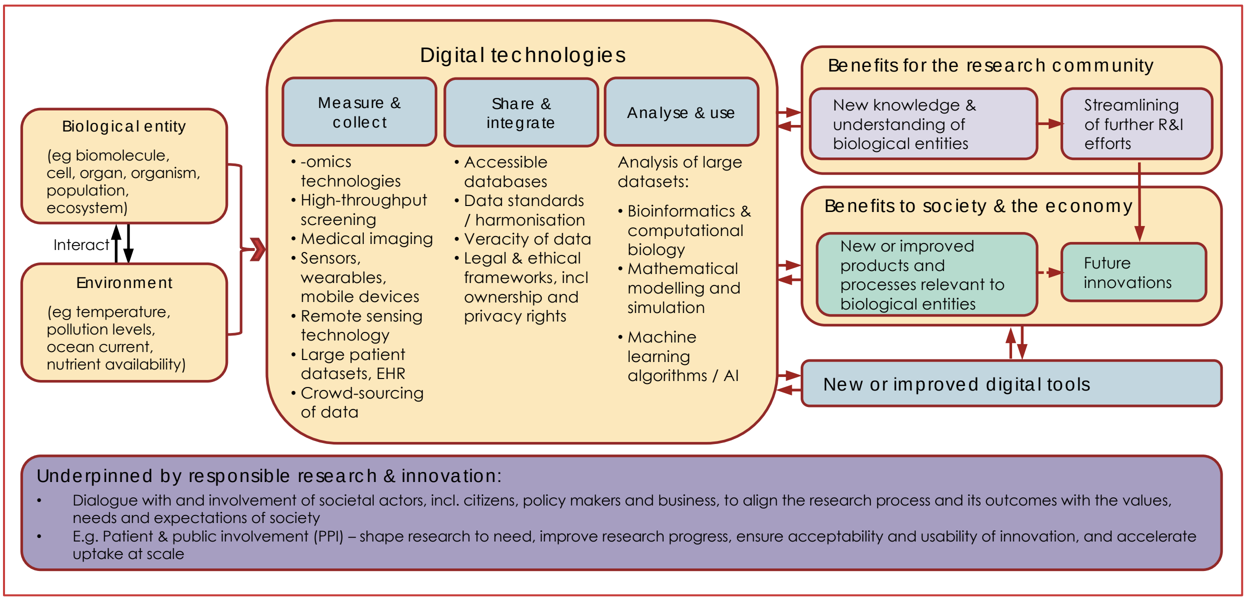
   Examples: Wearables, predictive modelling eg of bioreactors, farming systems

Figure 1 provides an illustration of how digital life sciences research leads to various benefits. The unit of research is a biological entity, ranging in scale from a single biomolecule to cells, organs, organisms, populations, and ecosystems, and the environment it interacts with. Digital technologies allow the data to be measured and collected, shared and integrated, and analysed and used. The findings of data analysis may provide new knowledge and understanding, and thus inform further research approaches ('Benefits for the research community')), which in turn may lead to innovations that become available for societal use. Data may also directly lead or contribute to products and innovations for use by society and for commercial purposes ('Benefits to society & the economy'). These could be entirely new approaches, or they could be improvements of existing approaches, including the development of new (digital) tools to inform and hone performance and use of current research and real-world practice (eg augmentation of cell culture / patient monitoring through sensor networks / wearable devices) ('New or improved digital tools'). Provided the research and its outputs align with the needs and expectations of society affected by it, the innovation delivers the intended benefits once it enters the 'real-world'. This alignment is guided by the application of responsible research and innovation (RRI) principles and activities (see section 2.7).

Rather than a simple linear progression from data capture to research progress and innovation, each step in the process can inform 'earlier' efforts, eg by providing new hypotheses and new approaches/tools for data capture, sharing and analysis.

Figure 1 Digital life sciences – from research to benefits
Source: Technopolis Group

2.2 Developments underpinning the rise of digital life sciences



New data collection approaches and technologies yield large quantities of highly structured – as well as unstructured – data, whose capture and analysis can only be achieved with the help of high-performance computing and computational analysis approaches. The data available and the new experimental technologies developed in the last decades make it easier and cheaper to perform or simulate experiments that until recently would have taken years to undertake. In addition, these trends have accelerated as the costs of data collection, storage, and computing power have decreased. For example, the cost of storing 1 gigabyte of data in the UK fell from USD 1 in 2003 to USD 0.03 in 2012 (Hagel et al., 2013). And while the cost of sequencing a human was estimated at USD 20–25 million in 2006,[1] next generation DNA sequencing technologies enabled for this figure to drop to between USD 1,906 and USD 24,810 by 2018 (Schwarze et al., 2018).

2.2.1 Data collection

A range of technologies have become available to collect data from biological entities at various scales – from single molecules to ecosystems – and their environment. Examples of these technologies include:

- The development of high-throughput multi-platform '-omics technologies', which has enabled the collection of 'summaries' of biological samples. For example, an individual patient's cancer cells can be analysed to determine the nature of a vast array of molecular and functional changes, including changes in gene expression (in the entire tumour or across individual cells) and protein expression, responses to therapy (pharmacogenomics),

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[1] https://www.genome.gov/about-genomics/fact-sheets/Sequencing-Human-Genome-cost

changes in metabolic pathways, mutation load, copy number and structural variation changes, and histological changes at the cell and tumour levels (Gendoo, 2020). Fuelled by decreasing costs and new technologies becoming available, these -omics technologies have led to a 'data explosion'; eg submissions to the European Bioinformatics Institute (EMBL-EBI) data resources continue to increase exponentially (Cook et al., 2019).

- Automation of experiments, such as high-throughput screening (HTS) platforms which allow researchers to quickly test large compound libraries with the help of robotics and assays/detectors. This process can rapidly identify chemical compounds, antibodies, or genes that interact with or modulate a particular biomolecular pathway (Hughes et al., 2011; Lee et al., 2012). The results of these experiments provide insights into starting points for further research, such as drug design, the role of particular genes, or (plant) candidates for biomass production (Decker et al., 2018).
- New sensor technologies – tools that detect specific biological, chemical, or physical processes and then transmit or report this data. Sensors can monitor living organisms (eg vital signs of the human body to trigger health alerts; bioreactor cell cultures to optimise growing conditions (Oliveira, 2019)), components in systems that process biological samples (eg in HTS systems, see above), environmental signals of importance to the life sciences (eg personal air quality sensors (Larkin & Hystad, 2017), eg to assist in identifying trigger conditions for an individual's asthma attack)[2], or a combination of biological and environmental parameters (eg remote sensing of weather patterns, soil moisture and plant chlorophyll status to inform farming decisions (Weiss et al., 2020)). Many of these sensors are integrated into wearable devices (eg fitness trackers) and smart phones/watches (bringing with it the challenges of informed consent and data ownership).
- Crowdsourcing approaches, based on (non-research) volunteers – usually members of the public – to contribute data (as well as to assist in processing and interpretation) ((Lichten et al., 2018), and references within). Crowdsourcing enables the collection of large volumes of data covering many geographical locations or moments in time. Examples include projects such as the Great Backyard Bird Count,[3] which has tracked bird populations across the US for nearly 25 years, and efforts to support epidemic surveillance, such as Flu Near You[4] – and most recently, COVID Symptom Tracker.[5]

  Crowd-sourcing can help to improve scientific understanding and literacy, and enhance the public's trust in science, and improve researchers' understanding of user needs to shape research priorities and project design. For example, communities of stakeholders (e.g. members of the public or patients) can steer the research agenda by identifying areas of importance they feel should be addressed. Examples include PatientsLikeMe's Amyotrophic Lateral Sclerosis (ALS) study.[6]

2.2.2 *Data sharing and integration*

The data collected has typical characteristics, often described as "the 3 V's of Big Data": Volume, Variety and Velocity (Laney, 2001), whereby:

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[2] https://www.propellerhealth.com/how-it-works/

[3] https://gbbc.birdcount.org

[4] https://flunearyou.org/#!/

[5] https://covid.joinzoe.com

[6] https://www.patientslikeme.com/join/als

- *Volume* refers to the amounts of data becoming available through new technologies supporting large-scale generation or collection of data and efficient means of storage
- *Variety* refers to the heterogeneity of data available, a result of the growing number of data collection technologies (see above) and data sources from across a range disciplines, which may all be relevant to the system under research. Because individual disciplines tend to have a background of working in silos and using their own tailored data formats and vocabularies, linking and integration of data from different domains faces multiple technical and semantic challenges.
- *Velocity* refers to the pace at which new data is becoming available, e.g. through real-time data streams

A fourth 'V', veracity, also comes into play:[7] As researchers no longer exclusively generate their 'own' (trusted) data, but draw on and integrate data from other and/or a variety of sources (and fields), they have to rely on large datasets collected by 'unknown' individuals or entities. The integrity and accuracy of data and data sources is highly associated with trust and with having confidence that the quality of data is sufficient to serve as a base, for research and critical decision making (Lokers et al., 2016).

The need for expanded (and ever-expanding) secure data storage capacity, combined with the need for maximising discoverability and access to data collected through publicly-funded research, has led to the establishment of numerous open databases. For example, the Nucleic Acids Research journal has compiled a list of more than 1700 operating molecular biology databases, including information about nonvertebrate genomics (280 databases), protein sequences (214), human genes and diseases (176), molecule and protein structure (172), and metabolic and signalling pathways (168) (Rigden & Fernández, 2018). These databases are relevant across different areas of life science research, for example, a recent publication summarises 71 bioinformatics resources for marine products research (Ambrosino et al., 2019). The availability of dedicated databases also serves to increase trust in the datasets (veracity), as their establishment involves the development of frameworks and working procedures which ensure data integrity. Additionally, sources of extensive medical data exist in the form of electronic health records (EHRs) and data collected as part of clinical trials.

The availability of data in such volumes and of such variety makes it necessary to use automated tools to integrate data from different sources and analyse the relevant information in order to generate new knowledge (which can then be used to develop and tune new processes, compounds, products, and services). Data integration is a process that consists of retrieving, cleaning, and organising data, usually obtained from a number of different sources (Oliveira, 2019). Reliable meta-data, eg data descriptions accompanying individual datasets, are indispensable for the re-use of data. In addition, harmonisation and data standards are required to enable integration of data from distinct sources. However, common standards for biological data are rare, and where many different standards co-exist, harmonisation of data is difficult and time-consuming. Initiatives such as ELIXIR[8] and CDISC[9] are working to address this

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[7] https://www.ibmbigdatahub.com/infographic/four-vs-big-data

[8] ELIXIR is pan-European organisation that coordinates life science resources - including databases, software tools, training materials, cloud storage and supercomputers - so that they form a single infrastructure. https://elixir-europe.org/about-us

[9] CDISC develops data standards for clinical research to enable accessibility, interoperability, and reusability of data. https://www.cdisc.org; The Critical Path Institute (C-Path), public-private partnership with the US Food and Drug Administration (FDA), has developed and maintains databases pooling research datasets for a variety of diseases, including Alzheimer's and Parkinson's, tuberculosis, kidney safety biomarkers and multiple sclerosis. https://c-path.org/core-competencies/

situation, but this area remains a significant challenge – in addition to the increasing costs of data management which are straining research budgets (OECD, 2020).

2.2.3 Data analysis

Today's biologists have to employ computational methods to analyse and make use of the large amounts of data that have become available, identifying clusters and correlation between datasets as well as developing predictive models. This in turn requires massive computational resources – high performance computing (HPC) platforms as well as efficient and scalable algorithms that can take advantage of these platforms (Zekun et al., 2017).

In its broadest sense, *bioinformatics* is concerned with the interpretation and analysis of biological data using computational techniques. With origins in the 1960s, when computational methods were starting to be applied to protein sequence analysis, the term started to be mainly associated with the analysis of genomic data in the 1980, such as sequence alignment, genome assembly, single nucleotide polymorphism (SNP) detection, and genome-wide association studies (GWAS) (Gauthier et al., 2018; Hagen, 2000). Further -omics technologies were added over the next decades, such as proteomics, transcriptomics and metabolomics.

Machine learning is a method of data analysis that enables 'machines' to infer the behaviour of a system by computing and exploiting correlations between observed variables within it[10] – in other words, it lets computers learn without being explicitly programmed (Chunming & Jackson, 2019). In contrast to classic statistical methods which rely on assumptions about the data-generating systems, machine-learning algorithms make predictions based on patterns in very large amounts of data.

Box 1 provides a recent example of advanced technology enabled by machine learning.

Box 1 Example of advanced technology based on machine learning

Mind-controlled prosthetic limbs

Prosthetic devices in use today offer limited functionality or can be too cumbersome for amputees to use effectively. While advanced robotic hands exist, amputees are not able to intuitively control them leading some even to abandon their prostheses because they find life easier without them. A prosthetic limb that amputees could control with their mind would restore their ability to carry out daily tasks, and dramatically improve their standard of living.

A new approach developed by researchers at the University of Michigan centres on the Regenerative Peripheral Nerve Interface (RPNI) – a small graft of muscle tissue surgically attached to the end of a severed nerve in an amputee's arm (Vu et al., 2020).[11] The RPNI uses machine learning in the amplification of neural signals sent from the brain into large, recordable muscle signals. These signals enable intuitive, real-time mind control of advanced robotic prosthetic hands. In the study, RPNI implants allowed four upper limb amputees to control finger movements using hand prosthesis for almost a year without the need for adjustments. It gave them fine control of their prosthetic hands and let them pick up miniature play bricks, grasp items like soda cans, and play Rock, Paper, Scissors.

Advances in data capture and computational methods have led to the definition of new research fields. The following section provides a number of examples.

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[10] https://www.technologyreview.com/s/612437/what-is-machine-learning-we-drew-you-another-flowchart/

[11] https://spotlight.engin.umich.edu/mind-control-prosthesis/

- The availability of data on multiple key cellular pathways simultaneously led to the emergence of the field of ***systems biology***. Systems biology aims to computationally model whole living organisms (or components) and their environments, taking into account all molecular categories simultaneously (Mol & Singh, 2015). In this way, it studies the dynamic and complex networks of biological components, including in response to external and internal stimuli, which would be difficult to interpret and predict from the properties of individual constituents of the biological system. While a whole-cell computational model of the life cycle of one of the simplest known organisms (*Mycoplasma genitalium*), including all of its molecular components and their interactions was reported in 2012 (Karr et al., 2012), this feat has not yet been achieved for more complex systems such as human cells (Spolaor et al., 2019).
- ***Synthetic biology*** also uses mathematical models to simulate cellular networks. But rather than modelling 'natural behaviour', synthetic biology aims to engineer cellular regulatory circuits that do not exist in nature to produce 'biologically-inspired devices' which perform a desired function (Mol & Singh, 2015). It thus combines the investigative nature of biology with the constructive nature of engineering, and can be thought of as a biology-based "toolkit", using abstraction, standardisation, and automated construction to change biological systems, impart new functions to living cells, and expand the range of products (Evans & Ratcliffe, 2017). Originally focussed on microbial cells, synthetic biology is now also being applied to "redesign" mammalian cells. It thus addresses a major stumbling block in bioprocessing, the efficiency of the production strain or biocatalyst, by enabling more precise control of construction of DNA parts, genes, and production strains (OECD, 2020).
- In health research, analysis across multiple types of data, including EHRs, clinical and laboratory tests, imaging data, and genetic information, can provide "intelligence" that cannot be derived from any single data source and is invisible to routine observation (Hulsen et al., 2019; Ristevski & Chen, 2018). For example, the emerging field of ***theranostics*** combines imaging tools with therapeutic agents to optimise selection of treatments and allow tailored therapeutic interventions (The European Institute for Biomedical Imaging Research (EIBIR), 2019). The availability of vast amounts of data, from a variety of sources, provides the opportunity to develop approaches to healthcare that are personalised, predictive, participatory and preventive. The term ***Digital health*** refers to applications, such as software, that support the management of primary and secondary healthcare systems including EHRs, health analytics software to assist healthcare professionals in clinical care, and wearables/mobile medical devices (UK Office for the Life Sciences, 2017).

  Given that multiple sources of data need to be brought together, a large number of collaborative initiatives and/or data portals have emerged (NEJM Catalyst, 2018; Pastorino et al., 2019). For example, the Alzheimer's Disease Neuroimaging Initiative (ADNI) collects, validates and utilises data, including MRI and PET images, genetics, cognitive tests, and biomarkers to track the progression of the disease and to assess the brain's structure and function over the course of the disease.[12] The ClinicalStudyDataRequest portal[13] provides researchers with the opportunity to access individual patient-level data from more than 3000 clinical trials.
- ***Mobile medical devices (or wearables)*** are emerging as opportunities to augment data available for clinical research (eg as part of data collected in clinical trials (Izmailova et al., 2018)) and in clinical decision making (eg by monitoring patients' vital signs at home (Dinh-

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[12] http://adni.loni.usc.edu

[13] https://www.clinicalstudydatarequest.com/Default.aspx

Le et al., 2019; Iman K Al-Azwani, 2016)), often bringing together partners from across sectors. For example, a research team from Stanford University and Apple Inc conducted a clinical trial (the Apple Heart Study) to determine whether the Apple Watch's heart sensor can be used to detect atrial fibrillation (Perez et al., 2019). With use cases only starting to be employed, and many challenges remaining (Izmailova et al., 2018), further robust clinical evaluation such as the Apple Heart Study is required.

2.2.4 Data use

Over the last ten years, research developments in the life sciences have enabled the generation of large amounts of data, and the application of data science to make sense of it – the 'convergence' of life and data sciences. Combined with Information and Communication Technology (ICT) enabling sharing of data across research groups (or virtual research teams), this has brought with it a move from single observational data to using large datasets from multiple sources, e.g. combining '-omics technologies', imaging, and patient reported data. Today, linking and integration of data from multiple sources is seen as a key future research area, driving a shift from reductionist to more holistic approaches, eg to patient care (Ipsos MORI and Technopolis Group, 2019), agro-environmental systems (Lokers et al., 2016) and bioprocesses biotechnology (Oliveira, 2019).

In the health sciences, the ability to quickly gather large amounts of data from individuals has led to a move towards therapies tailored to specific patient groups or the individual patient, rather than to entire populations (stratified medicine / personalised medicine). This 'coming of age' of genetics, precision medicine and companion diagnostics has underpinned a re-focussing by large pharma companies on specialty medicines and biologics, targeted at areas of high unmet need, e.g. addressing rare diseases (de Vrueh & Crommelin, 2017; Gautam & Pan, 2016; Khanna, 2012). For example, biopharma companies including AstraZeneca, Roche, Novartis and Sanofi, are progressing as much as 60–80% of their clinical portfolios with companion diagnostics (IMS Health data, cited in (Gautam & Pan, 2016)).

Advances in data availability and science can also lead to increased R&D productivity by streamlining the research process (EY, 2017). For example, genetic information can be used to identify the most promising candidates in the early translational research phase. A retrospective analysis of approved and experimental drugs for different diseases found that drugs developed against targets that were linked to a disease by human genetic evidence were twice as likely to succeed as those without such supporting evidence (Nelson et al., 2015). Artificial Intelligence technologies are also employed to support and accelerate the drug discovery process (EY, 2017), eg advances in genome sequencing, diagnostics and biomarker identification are used to reduce failure rates in the drug development process and improve timelines. Genomics can take account of variation between patients and define clinical trial populations on a more granular level, e.g. by identifying patients most likely to respond to a particular drug (Eichler & Sweeney, 2018). This allows trials to be smaller and more focussed (with a lower burden on patients), and hence potentially able to reach significance faster. Data suggests that drugs developed with predictive biomarkers, which help select likely responders, are three times more likely to achieve approval than those without (EY, 2017). However, while there have been some successes, notably in the field of oncology, precision medicine products are not currently in use for most diseases.

At the same time, additional costs and skills needs arise as researchers need to collect patient data and implement databases for storage. In some health systems, such as the UK's NHS, the required 'data capability' may move precision out of reach for some time, with many hospitals struggling to implement electronic health records (The Royal Society, 2018). New roles are being created to address these needs. For example, the role of the Chief Research Informatics

Officer (CRIO) has emerged in academic health centres in the USA, and recently in the UK (Sanchez-Pinto et al., 2017; Sridharan et al., 2018). CRIOs are involved in activities including the implementation of informatics tools to facilitate clinical research, the design of data warehouses and workflows to improve the secondary use of EHR data, and the development of infrastructures for advanced data analytics, bioinformatics and precision medicine research. They are also responsible for balancing the need for data security and privacy. A survey of 16 CRIOs at US centres found that all respondents held at least one doctoral degree (either MD, PhD, or both), that half were medical doctors, and that most had advanced training and extensive experience in biomedical informatics. As one author put it: "CRIOs should ideally be established academics with experience in biomedical informatics, biomedical research, electronic health records, clinical data warehousing, clinical medicine, scholarly publication and presentation, research governance and attracting research funding and academic teaching" (Sridharan et al., 2018). Individuals with this demanding combination of capabilities will be difficult to come by.

2.3 The role of academia in innovation for the Life Sciences

Historically, research was largely classified as either 'basic' or 'applied', with basic research perceived as purely curiosity-driven to develop general knowledge by academic researchers without any particular use or application in view, while 'applied' research is carried out with a specific practical aim or objective by industry. In a welcome step this distinction has been blurred in the past decade and its elimination is expected to improve both the culture and the effectiveness of the scientific process, and its potential benefits to society (Flier & Loscalzo, 2017). A more complete view of how research 'happens' underscores that discovery and invention are often two sides of the same coin that move innovation forward. In current thinking, academic research contributes a number of important components to innovation ecosystems:

- **Underpinning knowledge and tools**

  Traditionally, academic research in the life sciences has underpinned innovation by enhancing our understanding of underlying biological processes. This includes insights into how to apply large-scale data to innovation, eg how to link patient symptoms and treatments to their genetic and -omic profiles (Freedman & Mullane, 2017).

  The importance of academic research for biomedical innovation is illustrated in an analysis of the contribution of public-sector funding to the emergence of new drugs (Galkina Cleary et al., 2018).[14] The authors identified more than 2 million publications related to the 210 new molecular entities (NMEs) approved by the FDA from 2010–2016, or their 151 known biological targets. Of these publications, more than 600,000 (29%) were associated with NIH-funded projects in the NIH's online reporting tool, RePORTER (accounting for project costs of more than USD 100 billion over the 2010–2016 period, approx. 20% of the NIH budget over this period). NIH funding contributed to all of the 210 NMEs approved and was *focussed primarily on the drug targets rather than on the NMEs themselves*. Funding related to targets preceded funding related to the NMEs. This is consistent with the expectation that basic research provides validated targets for targeted screening.

- **De-risking through research at early TRL**

  Academic research also plays a role in providing evidence needed for 'de-risking' technologies, moving innovations to a 'technology readiness level' (TRL) where an existing

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[14] The analysis encompasses all biomedical research grants, ie it is not limited to digital life science research.

company will license the technology for further development or a new company can be formed (Fuentes et al., 2016; Schwartz & Macomber, 2017). While industry-led discovery is guided largely by Return on Investment driven business decisions, academic research remains unencumbered by these decisions, and is hence in a position to fill the gap (Roy, 2018). However, academia can rarely 'go it alone' along the entire TRL scale, with few institutions able to access the financial, commercial and operational resources required for market entry. Generally, the private sector will take on the intellectual property and bring the innovation to market (Driscoll et al., 2017).

Publicly-funded research can also help to address high-risk areas, e.g. those with a poor track record of translational success, such as central nervous system (CNS) disorders or many cardiovascular indications (which require large clinical trials) (Freedman & Mullane, 2017). Areas of unmet medical need are well-suited for academic-industry collaborations as they do not compete with large internal industry R&D programmes. Illustrating this trend, the second largest number of partnerships, collaborations and licensing deals in 2017 was the CNS field, behind oncology.[15]

- **Addressing needs and innovation of limited interest to the private sector**

  As described above, industry-led R&D is guided largely by Return on Investment driven business decisions, and hence companies are not incentivised to engage in endeavours without a clear pathway to economic benefit for their shareholders. However, many societal challenges require interventions that do not involve the purchase of a product or service from a commercial entity, or that cannot be monetised. In the healthcare space, these include behavioural and physical therapies and approaches for disease prevention, new surgical techniques, and ways to guide treatment decisions and predict patient outcomes, which feed into clinical guidelines and public health policies. In other life science fields, these include management approaches that minimise environmental impact (rather than maximise outputs).

- **Independent expert advice**

  Publicly funded research also provides an independent pool of expertise to verify R&D findings reported by the private sector. A poignant example is the distortion of the scientific process by the tobacco industry for commercial ends during the second half of the 20th century (Brandt, 2012). More recently, a study reported that research funded by industry had compromised the evidence base on the link between sugar-sweetened beverage consumption and weight gain (Bes-Rastrollo et al., 2013). Academic research can mitigate against these risks; for example, Cochrane, a global network of researchers, health professionals, patients, and carers, produces systematic reviews and other synthesised research evidence to inform health decision-making.[16]

- **Training**

  Research at academic institutions is carried out by group leaders and their teams, which can include students at graduate (PhD or Masters) level, postdoctoral researchers, and undergraduate students completing a research project. Many of these individuals will continue their careers outside the academic environment, and bring the skills and knowledge acquired to their future roles and responsibilities. In this way, academic research contributes to a skilled workforce.

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[15] http://www.evaluate.com/vantage/articles/data-insights/other-data/oncology-continues-reign-licensing-world-0

[16] https://www.cochrane.org

2.4 Innovation systems in the Life Sciences

Historically, R&D in many industries – including the pharmaceutical sector – was predominantly an in-house activity (Schuhmacher et al., 2018). Starting in the 1990s, some pioneering pharma companies started to complement their internal R&D efforts through working with other organisations in order to fuel their R&D pipelines. This can involve acquisition of external technology vendors or innovative units involved in promising R&D projects, licensing of the required technologies, outsourcing of operations to external organisations such as Contract Research Organisations (CROs), or partnering with companies and/or academic research centres through a variety of models (Buvailo, 2018). In addition, the advent of large data technologies led to a recognition that data sharing across organisations was needed to advance research efficiency, such as the ability to employ population-based approaches to health research.

To facilitate movement of scientific discoveries along the innovation pathway, industry research hubs were consolidated and physically co-located with innovation clusters, such as in Boston, San Francisco, Cambridge and London (Gautam & Pan, 2016; Schuhmacher et al., 2016). In addition, virtual R&D models were implemented to reduce the complexity and increase efficiency of R&D by bringing in specialised external service providers (Buvailo, 2018; Gautam & Pan, 2016). For example, established life science companies may not have the required expertise and in-house infrastructure to make full use of new technologies such as genomics and AI. These research components are frequently outsourced to specialised CROs or academic centres (Buvailo, 2018). The transfer of inventions from academic institutions to private industry in these hubs has been a major driver of economic growth and human welfare, helping to create new technologies and new industries, eg Google, Biogen and Genentech are among the data and life science companies with academic roots.

In addition to bilateral 'one-to-one' interactions between academic and industry researchers, an increasing number of public-private partnerships (PPPs) involving multiple stakeholders has emerged over the past decade (de Vrueh & Crommelin, 2017; Khanna, 2012; Yildirim et al., 2016). These R&D networks facilitate pre-competitive collaborations, focussing on the 'lower TRLs'. In many cases, PPPs include academia and industry stakeholders as well as charities, patient organisations, and/or national competent authorities ('regulators'). These collaborations are especially suited to basic research on biological mechanisms that lead to a better understanding of biological systems, such as disease mechanisms and mechanisms underlying differences in patient response, or develop tools that can be employed across the research community (eg biomarkers). Results, data and resources are shared across scientific collaborators with the understanding that improving the fundamental knowledge base can benefit the entire research community.

2.5 Innovation pathways in the Life Sciences

The OECD's reference guide for collecting and using data on innovation (OECD/Eurostat, 2018) sets out that the term 'innovation' can apply to both an activity (process) and the outcome of the activity (product). Not all innovation requires research and development (R&D); in fact, most innovation is based on reconfiguring existing technologies. To qualify as R&D, activities must be novel, creative, uncertain, systematic and transferable or reproducible (OECD, 2015).

R&D hence only comes into play if there are knowledge gaps which need to be addressed before the innovation can be achieved – generally referred to as 'technological innovation'. Technological innovation receives a lot of attention because, considered over the longer term, it drives economic development and growth. However, it is not limited to the private sector, and can also inform non-commercial activities, such as government policies and public sector processes, healthcare guidelines, and citizens' choices and behaviours.

A number of innovation models have been developed to describe the pathway from new knowledge and understanding, through innovation, to societal impact.

Biomedical research uses the term 'translational research' to describe the principle of turning fundamental discoveries into improvements in human health and economic benefit.[17] A number of models have been used to describe the translational research concept, representing the distinct phases research moves through from 'the bench' to societal impact (Trochim et al. 2011; Rajan et al. 2012; Fort et al. 2017; Surkis et al., 2016). These models set out a linked chain, from basic to clinical to post-clinical (practice-based) research, followed by implementation and use of research, which in turn leads to health impacts. At the same time, all models recognise that it is not a linear process and research findings (included unintended ones) inform basic research. Therefore the translational process is a "continuous data exchange within and between various research and non-research practices" (van der Laan & Boenink, 2015). Another model acknowledges explicit multi-directional effects by presenting the phases as interconnected components set in a circle (Glasgow et al., 2012). In addition, this model defines the first phase as the identification of a problem and the 'discovery' of an opportunity or approach to tackle a health issue, linking research and innovation to the concept of RRI. The process is hence iterative; scientific discoveries are integrated into clinical applications and, conversely, clinical observations are used to inform and generate research foci for basic science. Where information flow works well, this is often referred to as a learning health ecosystem.

In farming (agriculture and aquaculture), processes along the science-to-practice chain have been set out as: science/research, technology generation, technology testing, technology adaptation research, technology integration, dissemination, diffusion and adoption (Roling, 1989). While in the past, practitioners (ie farmers) were responsible for most breakthroughs, the role of research labs in producing new innovations has increased drastically over the past decades, and as a result new innovations in agriculture have been primarily thought of as being linked with discoveries of scientists at universities or in the private sector (Sunding and Zilberman, 2001). These breakthroughs are then transferred to end users through extension services[18]. However, as with biomedical innovation (see above), this model of a one-way, linear, sequential flow of technology has been criticised as failing to take account of contributions by, and the potential of farmers as generators of technology (Javier, 1989). Field experience plays an important role in inspiring innovations and ensuring the innovation is aligned with the farmers' incentives and the wider policy and economic landscape they operate in - a pre-requisite for adoption. This 'innovation system approach' emphasises interactive learning between system components (e.g. farmers, traders, researchers, extension, policymakers), in order to enhance the capacity of the system to respond to change (Joffre *et al.*, 2017). It thus frames technological innovation in the wider context and can add institutional and governance aspects during the research design phase. Indeed, there is increasing demand for researchers to have a greater understanding of the farming-systems context of practice change, and the broader innovation system, seen as necessary to improve the

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[17] https://mrc.ukri.org/funding/science-areas/translation/

[18] Agricultural extension is the application of scientific research and new knowledge to agricultural practices through farmer education.

relevance and impact of their research or to prepare agricultural agencies for the process of 'scaling' a new farming practice (Kuehne *et al.*, 2017 and references within).

Similarly, an understanding of context and end-user needs is essential for progress of biotechnology and medical innovations beyond academic research labs, be it through uptake by the private sector for further development, or – in the case of medical innovations - via direct adoption into the health system and by end users (Ipsos MORI and Technopolis Group, 2019). This includes an understanding of industry requirements (both in terms of technical and economic considerations), of the healthcare system and context in which healthcare professionals operate (including constraints such as limited time and resources, and conflicting care pathways), and of the public's motivation to accept or adopt an innovation. One approach to supporting this process has been an increase in the number of public and charitable research funders requiring researchers to involve patients and the public in their research (Bagley *et al.*, 2016). Vice versa, companies need to be in a position to understand research and innovate. A recent study of Norwegian seafood value chains (ie fisheries and aquaculture) showed that firms employing R&D employees were more likely to innovate, and more likely to collaborate, particularly with academic institutions (Bergesen and Tveterås, 2019). The study hypothesised that internal R&D teams increase a firm's capacity to absorb research-based knowledge, as many R&D employees have had research training (primarily PhD), and are thus able to translate research-based knowledge into innovations. However, modelling showed that the positive effect on innovation rates was highly significant for collaboration with other firms in the value chain but mixed for collaboration with academic institutions. The study thus concludes that "the effects on innovation of high public R&D investments in the Norwegian seafood sector are not obvious", but points out that important indirect effects, such as employee training and research employment at universities, may play an important role.

2.6 User-centric innovation management

User-centric innovation, championed by von Hippel in the 1970's, posits that 'users of products and services -both firms and individual consumers- are increasingly able to innovate for themselves'. These models of innovation signal a paradigm shift from more linear manufacturer centric innovation (von Hippel, 2005). Within this ongoing shift, different approaches to user-centric innovation, such as design thinking, agile development and lean start-up, have been developed amongst others.

Design thinking involves immersion in the customer experience even before prototype testing or idea generation. Only after customers' or end-users' needs are deeply understood then ideas, prototypes and solutions can be designed. Crucially, the focus is on learning, experimentation and reframing problem definitions, where a 5-stage process is followed:

1. Empathise – research the needs of the users
2. Define and reframe the problem – state user needs and the problem
3. Ideate – challenge assumptions and create ideas
4. Prototype – create solutions to solve user problems
5. Test – try solutions out

Given the iterative nature of the process, stage 5 may be used to further define problems with flexibility to go back and run through the process again with the additional learnings.

An evaluation of the impact of design thinking highlighted the benefits of the model to an array of industries (Liedtka, 2017). The study concluded from its 22 cross-sector case studies that design thinking improves organisational innovation outcomes due to 5 reasons (see Table 1).

Many of the enablers of design thinking in improving innovation outcomes stem from an increased focused on engaging users to fully understand a problem, reframing iteratively, before solutions are prototyped. This notion is paralleled with the RCN's RRI framework dimension of inclusion, where research and innovation actors are encouraged to get in touch with potential future users and actors.

Table 1 Design thinking and how it enables innovation outcomes

Design thinking improves innovation outcomes by:	**Enablers**
Producing higher quality solutions	◦ Delaying solution generation in favour of defining and re-framing the problem ◦ Developing ideas based on user-driven design criteria ◦ Leveraging diversity of perspectives in the user driven design criteria
Reducing the risk/visibility of failure	◦ better hypothesis generation through an increased initial user engagement ◦ Early emphasis on real-world feedback and testing ◦ Builds trust and ownership among implementers
Improving likelihood of implementation	◦ Promotes change readiness through emphasis on resources and training needed, timelines and measures to paying attention
Improving adaptability	◦ Innovation viewed as a social process, taking many user views into account ◦ Avoidance of top-down solutions and processes in favour of customised ones
Creation of local capability sets	◦ Local voices must be brought into the innovation process, helping to identify and solve their own problems

Source: (Liedtka, 2017), Technopolis 2020

A second user centric innovation model is agile development (also known as agile software development given its focus on software). Progress in this field has been born out of the 2001 Manifesto for Agile Software Development.[19] Agile development typically follows short iterative cycles where users are actively involved to establish and verify requirements, the product is developed incrementally rather than at a single point, teams are self-organised to determine the best way of working, and emergent so that processes and work structures are identified on the project rather than being pre-determined (Boehm & Turner, 2005). Scrum, the most widely used agile process (CollabNet, 2019) provides an empirical framework for effective collaboration on complex products.[20] A survey showed that the key reasons to implement agile practices, according users, are to accelerate software delivery, increased ability to manage changing priorities, increased project visibility and improved business/IT alignment. It leads to customer/user satisfaction and business value delivered. An exploratory study of agile-based software projects in the Norwegian software industry (Siddique & Hussein, 2016) highlighted key differences and benefits of agile methods over more traditional linear methods of software development in assessment, evaluation and involvement of customers.

A third user-centric method for innovation is Lean start-up. The majority of start-ups fail as early on the direct resources towards creating the wrong product in the eyes of the users

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[19] http://agilemanifesto.org/

[20] https://www.scrum.org/

misunderstanding their needs (Nobel, 2011). The key concepts of Lean start-up outline how to avoid this pitfall and are as follows:

- Launch the minimum viable product (MVP) as quickly as possible, allowing for maximum user feedback as the product is refined
- Do not scale until there is product marketing fit (PMF), where the solution matches the problem.

Entrepreneurs test their ideas using the MVP and then decide whether to persevere with it or 'pivot' by changing elements based upon feedback (Eisenmann et al., 2011). Only after iterating and refining the MVP and the PMF is established can scaling begin. Lean start-up has been validated in the ICT industry where MVPs can be launched with minimal barriers. Therefore, Lean start-up may be applicable to projects that are heavily focussing on the digital aspects within biotechnology. However, in other areas of biotechnology such as pharmaceuticals, there may be problems in launching an MVP, in terms of start-up capital required and strict regulations and ethics to adhere to (Nobel, 2011).

Therefore, there are critical lessons from user-centric methods of innovation that DLN can take forward in their innovation support actions and communicate guidelines to researchers.

1. **Encourage projects to iteratively understand user needs/problems at an early stage.** Firstly, with regards to design thinking, it is crucial that projects applying for funding fully outline the processes by which they have come to understand user problems and needs, and how this will be maintained after funding to re-frame the problem. Incorporating user feedback into these iterations is imperative. Whilst potential projects should demonstrate an early stage ability and focus on iteratively understanding user needs and problems, the DLN could also provide sufficient time for this after project funding has been awarded. Facilitating investment of time into reframing problems may reap downstream benefits though increased product quality that is localised and adaptable.
2. **Encourage projects to continually assess and evaluate.** The critical learning from Agile development is the benefit of continual evaluation and assessment. Similarly, to the first recommendation, user feedback should be a key criterion used in continuous evaluation. Projects should be able to demonstrate an ability or plan to do so prior to funding being awarded. This may help to increase knowledge sharing between parties involved in the project as knowledge is produced and also reduce task uncertainty for those working on the project.
3. **Launching a minimally viable product (MVP) may be appropriate for certain projects, but not all.** Where there is little evidence of barriers, regulatory or ethical, to launching an MVP it may be beneficial to do so. This may be of use who want to fully validate the hypothesis of their research. Projects that require expensive infrastructure costs (e.g. laboratory equipment) may not be appropriate for this recommendation.

2.7 Responsible research & innovation

The far-reaching applications of biotechnology by industry and the society at large means that user-centric innovation and thus responsible research is becoming an increasingly important concept to apply within digital life sciences. For example, within the field of synthetic biology there have been concerns about negative consequences such as abuse or misuse of modified lifeforms (Gregorowius & Deplazes-Zemp, 2016). Such concerns are legitimate and pose public threats. Therefore, the RRI concept incorporates societal and ethical consideration along the entire research and innovation process and its expected/potential effects, ensuring these are deemed socially responsible by a range of actors in society. Ultimately it will contribute to generating real benefit to all stakeholders concerned through research and innovation.

Based on RRI guidance developed by the UK's Engineering and Physical Sciences Research Council,[21] the RCN defines the following four dimensions within its own RRI framework[22] for actors in research and innovation, applicable to all large-scale technology programmes, including BIOTEK2021:

- *Anticipation*: map the plausible effects of innovations and develop strategies to prevent undesirable outcomes
- *Reflexivity*: evaluate assumptions when choosing research problems, methodology and innovation design
- *Inclusion*: consult with potential future users and other concerned actors for insights into contexts of application and their opinions on desirable research trajectories
- *Responsiveness*: amend research and innovation trajectories if the feedback from stakeholders or public opinion indicates other societal needs

DLN, funded by the BIOTEK2021 programme, has focussed on putting this framework into practice. It is acknowledged that RRI requires new skills for researchers, institutions need to adjust R&I governance structures, and target both processes and products of innovation.[23] For example, a recent DLN project, Res Publica,[24] was created to provide a platform that will improve RRI activities across DLN and its research projects. The interim Res Publica project report (Åm et al., 2019) found that there was a relatively high awareness of RRI concepts within DLN projects but key challenges remain regarding the substantial RRI writing requirements at the grant proposal stage; lack of clarity about how RRI activities are used in research practices; and ultimately how to mainstream RRI as a cross-cutting issue across the DLN and its infrastructure. Therefore education about RRI theory and practice are best offered to project applicants to ensure RRI is integrated within research projects at the earliest stage.

2.8 Summary

Digital Life Sciences is an emerging concept with a scope to enable the full potential of biotechnology and life sciences and create value for society in a responsible way and provide the basis for future sustainable economic growth. The possibility to capture and analyse large datasets about biological system requires the development of new knowledge and tools and the academic sector has an important role to play to provide the pipeline of ideas, proof of concepts and prototypes that industry can progress to the next level. This requires an ecosystem approach where public and private actors (as well as society) are connected across disciplines, organisational boundaries within and beyond Norway. The existing innovation models provide a baseline of what can work in what context, and what the key stages of a pathway from academic-led research to innovation and deployment are. It was recognised that the reality is more complex than models and feedback loops, iterations and multiple pathways may be required to create a more agile and user-centric approach so that early innovations may mature and succeed.

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[21] https://epsrc.ukri.org/research/framework/

[22] https://www.forskningsradet.no/contentassets/558d5b1a9f53421f81371ecf96cf1692/framework-responsible-innovation.pdf

[23] http://ec.europa.eu/research/swafs/pdf/pub_rri/rri_indicators_final_version.pdf

[24] https://digitallifenorway.org/gb/projects/res-publica

3 The DLN research and innovation system

This chapter provides a short description and analysis of the wider Norwegian research and innovation system within which DLN is situated, based on available secondary sources. Its purpose is to set the scene for a discussion of DLN itself by analysing the structure and performance of relevant parts of the wider system. We begin with a short theoretical justification of our systemic perspective. We then briefly discuss the division of labour in Norwegian research, focusing on the university system and – at an aggregate level – the business sector. Since, except in the special case of SINTEF, DLN does not involve institutes we do not discuss the institute sector. We move on to discuss research and innovation policy, funders and instruments then focus on the 'innovation ecosystem' within which DLN is situated. That is, various kinds of networks that link actors whose cooperation is needed in the process of doing innovation. Finally, we sum up and draw conclusions, providing a context for the description of DLN in the next chapter.

3.1 A systemic perspective

Since DLN aims not only to do research in universities but also to trigger innovations with social and economic impact, a brief look at what we know about this process from the scientific literature on research and innovation provides some key ideas that we take with us into the analysis of DLN.

The 'linear model' of innovation – the idea that basic science ultimately causes applied research, production and wealth creation – was popular in the post-war period but has largely been superseded. Promoted in Vannevar Bush's report to President Eisenhower, "Science, the Endless Frontier" (1945), it was also encouraged by the growth of state-organised 'missions' (defence, health, the moon shot, etc), together leading to the idea that research causes changes in society ('impact'). There are cases – notably in 'science-based' industries such as pharmaceuticals – where the linear model is a good description of the innovation process, but most of the time, reality is more complex. The linear model nonetheless continues to influence policy thinking: because it is simple; because its implication that the state should give them more money to do science and then leave them alone is attractive to the scientific community; and, less obviously, because mainstream economics traditionally treats technology as 'exogenous' to the economy. It investigates how technology affects production and productivity but does not look inside the 'black box' of technological change to understand the role of people, institutions and learning.

The focus of innovation theory on 'science push' and supply side thinking started to crumble in the 1970s as a result of research on the importance of users and the demand side in innovation (Rothwell, et al., 1974) (Shimshoni, 1970) (von Hippel, 1975). Eventually this led to a revolution in thinking, with innovation reconceptualised from 'science push' to interactive 'coupling', spanning push and pull (Mowery & Rosenberg, 1979) and recognition of the importance of the stock of existing knowledge as well as new knowledge in innovation.

Economic theory of innovation started to make significant progress when evolutionary economists like Nelson and Winter (1982) started looking at the behaviour of firms and the people in them – understanding technological change and innovation as endogenous to companies, rather than as something that comes from outside. That in turn forced innovation theorists to confront the fact that firms are not the rational robots of traditional economics, but that in fact their rationality is limited or 'bounded'. Learning is therefore important but bounded rationality can also cause lock-ins to sub-optimal technologies, business models and networks. Together, these ideas underpin the national innovation systems heuristic (Freeman, 1987)

(Lundvall, 1992) (Nelson, National Innovation Systems, 1993) that regards innovation as being co-produced in networks of actors and as potentially being stimulated from anywhere in the innovation system. Thus, research and innovation can have impact by satisfying needs, but can also be triggered by the identification of need, especially by organisations that have "absorptive capacity" (Cohen & Levinthal, 1990) or the ability – based on their internal R&D capabilities – to specify scientific and technological problems, seek solutions and apply them to business opportunities.

The idea of innovation ecosystems can be seen as a spin-off from innovation systems thinking that focuses on communities of organisations, often centred on universities, that co-produce knowledge-intensive innovations. Such communities are understood to increase the rate of innovation and growth at a local or regional level. Fostering them is central to the European Commission's Smart Specialisation Strategy (RIS3) approach to regional development.

Definitions and terminology vary. However, Engel and del-Palacio's (2011) definition of a 'cluster of innovation' seems well to capture the phenomenon of interest, and argue that individual clusters can for hubs in global innovation networks. They are local but have a global dimension.

> *We define a Cluster of Innovation as an environment that favours the creation and development of high potential entrepreneurial ventures, and is characterized by heightened mobility of resources, including people, capital and information. It typically includes start-ups; small, medium, and large corporations; universities and research centres; entrepreneurs; investors; and service providers as well as other individuals and organizations that: use entrepreneurial intensive process as a mechanism for innovation and experimentation; have heightened mobility of resources, principally people, technology, and capital; create companies with an early international perspective; and have players who have shared identities and aligned goals.*

Valkokari (2015) decomposes this idea of a cluster into three types of ecosystems.

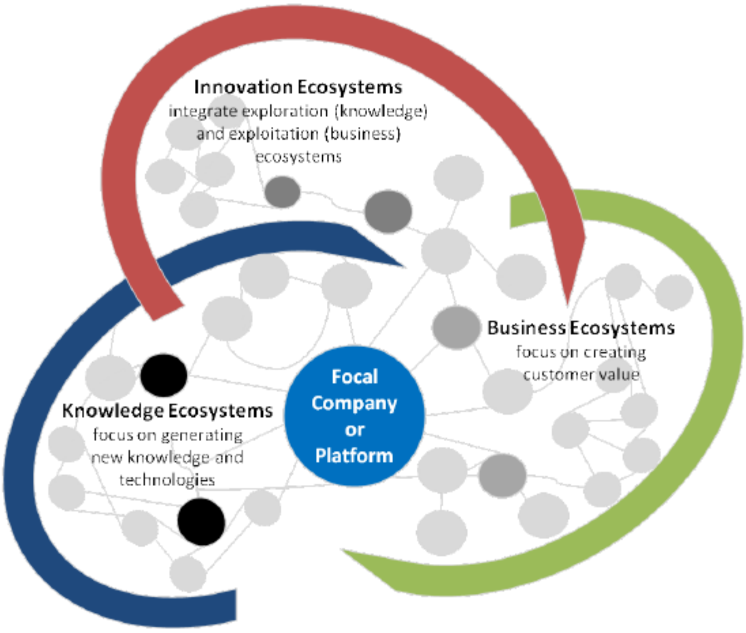
- The business ecosystem – a group of companies and other organisations, which combines its resources to create and capture value, operating around a focal firm or platform. Implicitly, the business ecosystem is not necessarily based on research but may focus on other common issues such as marketing, training, access to resources and so on
- The knowledge ecosystem – a network of organisations that develops and to some degree shares new knowledge
- The innovation ecosystem – a group of organisations that fosters growth, interaction and innovative start-ups around clusters of innovation (in Engel and del-Palacio's sense)

Ecosystems are not self-organised but "They are rather organizational designs that are held together on the condition that their members are in formal or informal agreement about shared purpose and operation modes (logic of action)" (Valkokari, 2015).

These three types of ecosystem can be interlinked Figure 2 but it is not always the case that all of them are present in a particular location. Universities can be important actors but are not necessarily always involved.

The wider literature on regional innovation clusters suggests, first, that individual clusters have individual histories; second, that their formation takes decades rather than years; third, that public policy is not sufficient to creating a successful cluster, but it can help the development of clusters that start spontaneously to form around business, knowledge or innovation opportunities (Saxenian, 1994) (Boekholt, Mckibbin, Charlet, Muscio, & Reid, 1995).

Figure 2 Relationships between overlapping ecosystem types



Source: (Valkokari, 2015)

3.2 The academic innovation system in Norway

Norway's gross expenditure on R&D was equivalent to 2.07% of GDP in 2018. This compared with an EU average of 2.03% and an OECD average of 2.4%. Business spent 1.08% of GDP on R&D, the universities 0.71% and the rest of government 0.21%.[25] So, while Norway does not enjoy the extraordinarily high levels of R&D expenditure seen in Sweden or Finland, the amount of R&D effort is certainly respectable by the standards of Europe and the major developed countries.

Central to the academic innovation system in Norway are the 10 universities and 27 other higher education institutions. Their volume of research has been growing in recent years, while that of the institutes has remained static (Figure 3). With the important exception of NTNU, Norwegian universities have traditionally been associated with fundamental research, as opposed to more applied output, reflecting past policy choices to maintain a strong national applied research institute sector alongside the university system. Particularly over the last decade, however, the universities have been encouraged to engage in more knowledge exchange with wider society and are now measured in part on their income from business.

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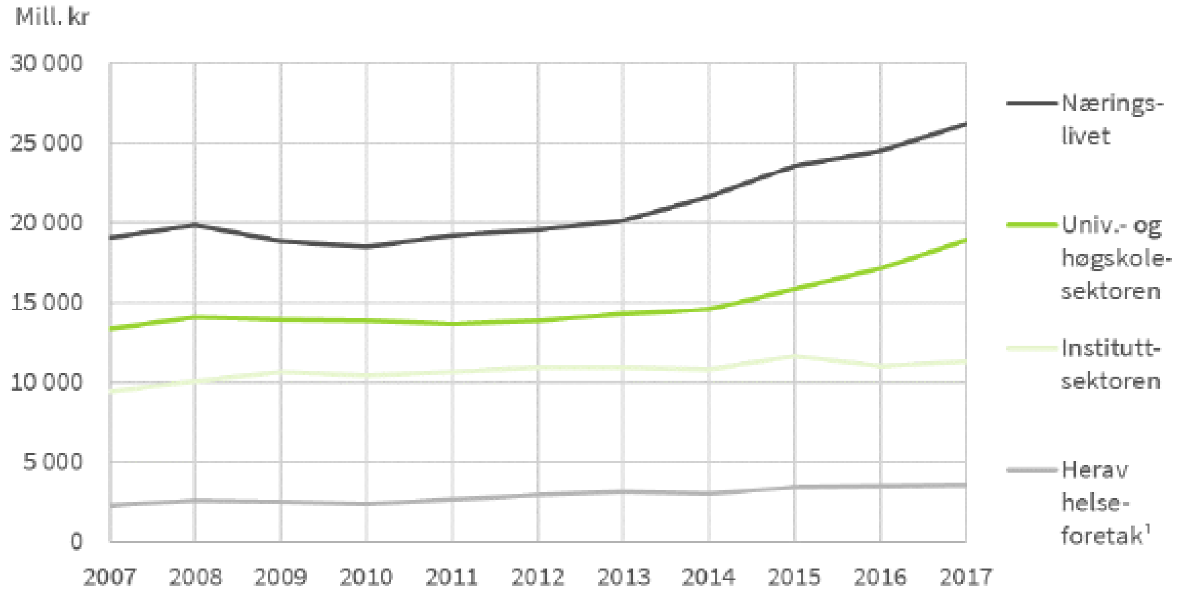
[25] OECD Main Science and Technology Indicators, accessed 21 May 2020

Figure 3 Total expenditure on R&D by sector of performance (constant 2010 prices)



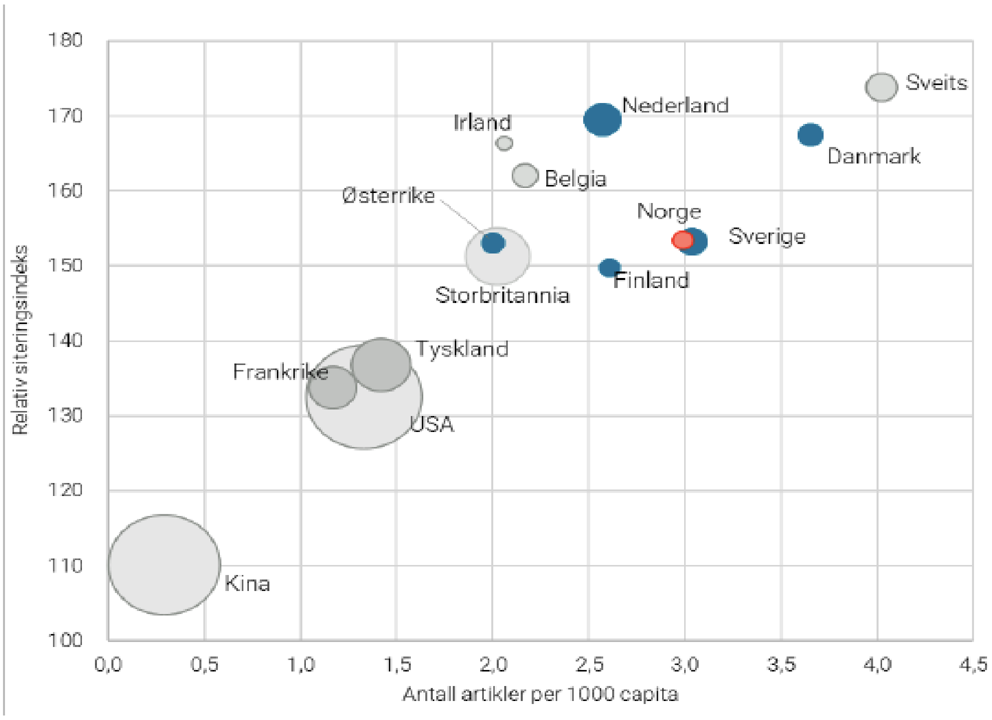
Helseforetakene inngår i hhv. UoH- og instituttsektoren, se faktaboks om sektorinndeling i FoU-statistikken.

Kilde: SSB og NIFU, FoU-statistikk

Source: RCN, Indikatorrapporten 2019

The universities dominate Norway's scientific publications. Figure 4 indicates that their research is productive and highly cited. The small countries shown in the upper right quadrant of the Figure are among the best-performing countries in the world on these indicators, so Norway's comparative position is strong.

Figure 4 Number of scientific articles per 1000 inhabitants (2018) and relative citation indices, selected countries (2016–2017)

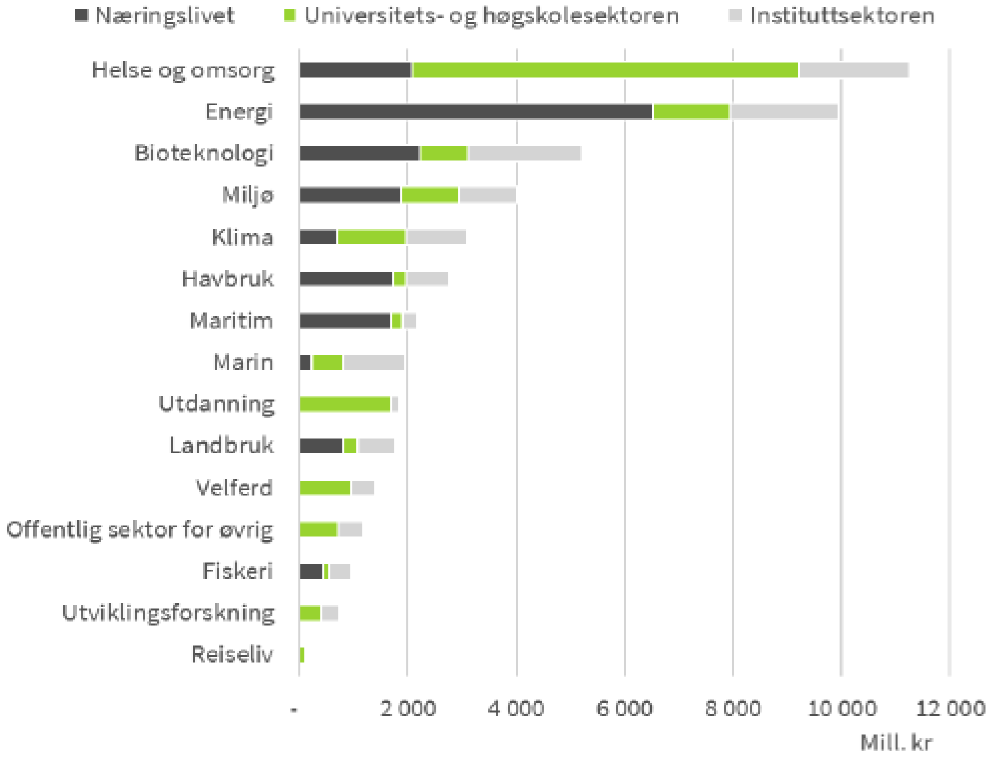


Kilde: NIFU. Data: Web of Science

Source: RCN, Indikatorrapporten 2019

Figure 5 shows that the universities are particularly active in research themes relevant to DLN.

Figure 5 Expenditure on R&D in thematic areas prioritised in the LTP by performing sector (2017)



[1] Tematiske områder kan overlappe hverandre.

[2] I næringslivet inngår foretak med 5 eller flere sysselsatte. For næringslivet inngår ikke spørsmål om velferd, reiseliv, utdanning, utviklingsforskning eller offentlig sektor for øvrig.

Kilde: SSB og NIFU, FoU-statistikk

Source: RCN, Indikatorrapporten 2019

NIFU's analysis of Norwegian scientific publications in the 2019 indicator report shows that those in medicine and health accounted for 27% of national output and – at a more detailed level – that subfields of medicine and health as well as biology are well cited compared with the global average. The report shows the leading 17 fields of Norwegian research, measured by the proportion of national output that is among the 10% most highly cited in its respective field (ranging between 14% and 22%). Fourteen of these fields are medical, the remaining three being Development Studies, Geology and Computer Science.

Two Norwegian universities (UiO and NTNU) featured on the Reuters 2019 list of top 100 most innovative universities in Europe. Despite promising progress, Norwegian universities are yet to feature on the Reuters lists for most innovative universities in the world, suggesting progress is still to be made on a global level. The lists were largely considering IP, factoring in patent volume, patent success, global patents, patent citations, patent citation impact, percent of patents cited, patent to article citation impact, industry article citation impact, percent of industry collaborative articles and total web of science core collection papers.[26]

The need to increase the quality of research has been a persistent theme in Norwegian policy for at least two decades (Arnold, Kuhlmann, & van der Meulen, A Singular Council: Evaluation of the Research Council of Norway, 2001) (Arnold & Mahieu, A Good Council? Evaluation of the Research Council of Norway, 2012). As the Figures above illustrate, there has been considerable progress. University research nonetheless makes a poor showing at the very highest levels, such as in the proportion of scientific output appearing in the Top-1% of most highly cited scientific papers. In 2016, only 0.29% of GDP was devoted to basic research, compared with Austria, Denmark and The Netherlands with about 0.55% (OECD, 2107). Despite a number of recent mergers, research environments often remain fragmented. University governance reforms have been slow to come in recent years, with elected rectors still being common. Despite governance reforms in recent years, it seems still to be difficult for Norwegian universities to restructure or to make a selective allocation of resources in order to pursued specialisation strategies.

Recent developments relating to technology transfer offices (TTOs) and the formation of innovation strategies in the universities, however, give more grounds for optimism. We discuss these below, in the section about innovation ecosystems.

3.3 Business sector R&D and demand for innovation

Our discussion in section 3.1 of the importance of coupling between demand and supply of new knowledge, where that knowledge is being used in innovation suggests that DLN knowledge will most easily be taken up by business in Norway if it addresses areas that are of technological interest to companies.

Overall, traditional bio-based industries employ five percent of the total labour force in Norway and created a turnover of NOK 350 billion in 2015 (Norwegian Ministries, 2016). On the other hand, the IT and software industries do a lot of R&D in Norway and might potentially play roles in relation to DLN's digitalisation focus. However, while publication of national policy documents indicates a recognition that biotechnology can meet societal needs, there is a lack of literature that establishes demand for the particular nexus of digital technologies and life sciences. We explore this issue in more detail at the level of DLN's four industrial foci below. That confirms the sense obtained from the overall numbers that there is an imbalance between academic and business research in a big proportion of the areas where DLN is active. The implication is that new and additional firms and sectors would be needed for many of DLN's activities to be valorised in the economy.

R&D surveys for the business enterprise sector are conducted annually in Norway by Statistics Norway to monitor national activities, following recommendations given in the OECD Frascati manual. We identified three industry sectors relevant for DLN where data are collected: Fishing and aquaculture, Food products and beverages, and Pharmaceuticals (Table 2 Intramural and extramural R&D expenditure for relevant industry sectors (2018)Table 2); Biotechnology however is not defined in the European industry standard classification system (NACE). Relevant data for Computer programming sector are also provided for comparison.

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[26] https://www.reuters.com/innovative-universities-2018/methodology

While the Fishing and aquaculture and Food products and beverage industry had similar intramural R&D expenditure in 2018 (about NOK 1,200 million), the Pharmaceutical industry in Norway spends only a third of that. The IT and software industries conduct a significant intramural R&D in Norway, dwarfing other sectors at almost 20% of total intramural expenditures across all industries in Norway.

When focusing on extramural expenditure, the Pharmaceutical sector appear to purchase services from others (including research institutes and other enterprises) at the highest level of the three sectors, similar level to its internal R&D spend at about NOK 400 million in 2018, not far from the IT and software industries.

Table 2 Intramural and extramural R&D expenditure for relevant industry sectors (2018)

Industry	**Intramural R&D expenditure**[27] **NOK million (% of total intramural R&D expenditure)**	**Extramural R&D expenditure**[28] **NOK million (% of total extramural R&D expenditure)**
All industries[29]	32,748 (100)	7,620 (100)
Fishing and aquaculture	1,196 (3.7)	150 (2.0)
Food products and beverages	1,193 (3.6)	260 (3.4)
Pharmaceuticals	429 (1.3)	384 (5.0)
Computer programming	6,318 (19.3)	426 (5.6)

Source: Statistics Norway (SSB) and Technopolis analysis.

Despite a roughly similar intramural R&D expenditure (including capital expenditure), the number of R&D personnel employed and R&D man-years in the Food products and beverages industry was roughly double that for the Fishing and aquaculture industry (Table 3). The total number of R&D personnel and R&D man-years in the Pharmaceutical industry was however a small fraction of these, echoing the low total intramural R&D expenditure in Norway in this sector.

A closer analysis of the education level of the R&D personnel suggests that in relative terms demand for academic credentials in R&D is highest in the Pharmaceutical industry. While over a quarter of R&D personnel in the Pharmaceutical industry have a PhD, this number is 9% in the Fishing and aquaculture industry and only 5% in the Food products and beverages industry. Looking at the man-years performed by personnel with PhD across the three sectors, a similar trend can be observed, although with a somewhat attenuated relative differences. While the IT and software industries employ a significant number of R&D personnel in Norway, their personnel with PhD are less than 3% of the total within this industry sector.

The proportion of PhDs in the R&D workforce is a key metric for the absorptive capacity of the industry sector for academic-led innovation outputs.

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[27] Intramural R&D expenditure (as defined by SSB) is all expenditures for R&D performed within the statistical unit, includes labour costs, cost of hired personnel, other current costs and capital expenditures on R&D

[28] Extramural R&D expenditure (as defined by SSB) is R&D services purchased from others including research institutes, other enterprises, also including units in the same enterprise group.

[29] All industries (A-N NACE SN2007): Economic statistical units are classified according to Standard Industrial Classification (SIC2007). Includes only businesses with 10+ employees.

Table 3 R&D personnel and R&D man-years for relevant industry sectors (2018)

Industry	**Number of R&D personnel[30] (% of total R&D personnel)**	**R&D personnel with PhD (% of total R&D personnel within given industry)**	**Number of R&D man-years (% of total R&D man years[31])**	**R&D man-years performed by personnel with higher degree education (incl. doctorate) (% of total man-years within given industry)**	**R&D man-years performed by personnel with PhD (% of total man-years within given industry)**
All industries	36,796 (100)	2,209 (100)	20,979 (100)	14,598 (100)	1,692 (100)
Fishing and aquaculture	1,067 (2.9)	96 (9.0)	414 (2)	216 (52.2)	80 (19.3)
Food products and beverages	1,952 (5.3)	105 (5.4)	812 (3.9)	380 (46.8)	74 (9.1)
Pharmaceuticals	346 (0.9)	92 (26.6)	282 (1.3)	243 (86.2)	81 (28.7)
Computer programming	6,769 (18.4)	187 (2.8)	4,479 (21.4)	3,505(78.3)	126 (2.8)

Source: Statistics Norway (SSB) and Technopolis analysis

Importantly, the greater demand for personnel with higher degree education within the Pharmaceutical industry also correlates with the industry achieving the highest level of innovation activities (86%, see Table 4) compared to other industries relevant to the DLN. The Pharmaceutical industry (as well as the Beverages sector) also scored highly for product innovation for goods compared with the overall industry scores. The data also reveal a relatively poor product innovation performance of the Fishing and aquaculture industry.

On the other hand, the product innovation for services is generally low for all DLN industry areas which may be expected for traditionally products/goods focussed industries. Nevertheless, the future for these industries, and for the pharma industry in particular, lies in integrating their products with services and in that transition, digitalisation and personalised data-driven decision making will be crucial.

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[30] R&D personnel (as defined by SSB) encompass all personnel directly involved in research and development, including administrative personnel, persons in supporting functions, both inside and outside the R&D department.

[31] R&D man-year (as defined by SSB) is the R&D work one person has performed during the year

Table 4 Innovation activity for relevant industry sectors (percent of all enterprises engaging in type of innovation, 2016-2018)

Industry	Innovation activity[32]	Product innovation[33]	Product innovation (goods)	Product innovation (services)	Process innovation[34]	Business process innovation
All industries	61	39	29	26	39	48
Fishing and aquaculture	64	30	25	15	44	48
Food products	63	43	42	11	39	46
Beverages	72	65	65	22	55	57
Pharmaceuticals	86	57	57	14	53	57
Computer programming	85	67	41	58	60	70

Source: Statistics Norway (SSB) and The Innovation Survey; Technopolis analysis

A survey conducted by DLN in 2017 identified where bio-based industries are in terms of implementation and need for digital biotechnology (Evjen et al., 2017). The industries examined were medicine and health, marine, agriculture and industrial biotechnology. Stakeholders included in the survey were companies, research institutions, network clusters amongst others. Eighty-one percent of respondents said that digital biotechnology was 'relevant' to them, mostly in relation to R&D though digitalisation was beginning to affect subsequent stages in product and service design and marketing. Knowledge, access to capital, and commercialisation were seen as the three main challenges in making better use of the convergence between digitalisation and life sciences. Small and medium sized enterprises (SMEs) tended to find it more difficult to keep up with developments in digitalisation; larger, IT-based companies were better placed and also had better access to capital. The report pointed to a large number of areas of potential application for digital biotechnology.

The structure in Norway of the four sectors addressed in the DLN report suggests that inducing innovation will be a substantial task. The healthcare industries in Norway are dominated by foreign multinationals, which normally turn to their own headquarters in order to get knowledge for innovation and to do product development. There is a small, Norwegian-owned pharmaceutical sector, however which should provide some opportunities. Biomarine is dominated by national companies, but this is a sector that does little intramural R&D, getting knowledge inputs from public research and suppliers. Agriculture is similar, dominated by Norwegian-owned companies (some of them holding monopolies) and traditionally dependent on the public sector for new knowledge. In industrial biotechnology, a few large

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[32] An enterprise with Innovation activity (as defined by SSB) is an enterprise with either innovative or had innovation projects that were either abandoned or had not yet led to an innovation by the end of the observation period.

[33] A product innovation, (as defined by SSB) is the introduction of goods or a service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics. Oslo Manual 3.

[34] A process innovation (as defined by SSB) is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.

firms may provide opportunities, but the structure of the process sector in Norway is traditionally more tied to chemicals and metals than to businesses where biotechnology is immediately relevant.

3.3.1 Healthcare

The healthcare market may be divided into two sub-sectors: medical technology and pharmaceuticals. The Norwegian medical technology market has an estimated turnover of NOK 10 billion.[35] The Norwegian Association for Health and Welfare Technology, known as Medtek Norge, includes 90 percent of the industry, equating to 115 companies and 2,500 employees. All but a handful of the members are headquartered outside Norway. The Association of the Pharmaceutical Industry in Norway (LMI) has 62 member companies with 4,000 employees collectively, pointing to the larger average size of companies in this sub-sector. The Norwegian pharmaceutical and diagnostics market is also larger than the medical technology market with an annual turnover of NOK 36 billion (LMI, 2019).

In terms of wealth creation in Norway, pharmaceuticals accounted for 35 percent, diagnostics 34 percent, medtech 13 percent and health IT 9 percent. LMI noted that despite increasing private R&D investment from the top companies (NOK 123.5 million in 2018) there had been a significant decrease in the number of clinical trials carried out in Norway in the previous decade: 177 in total in 2008 compared to 121 in 2018(LMI, 2019).

Table 5 provides detail on the main pharmaceutical companies in Norway and their cluster affiliation (see Section 3.6.2 for more detail about the Norwegian Innovation Clusters). None of the top 15 pharmaceutical companies (by sales) is Norwegian-owned. In 2009, Norwegian companies held some 10 percent of the market.[36]

Table 5 The top five pharmaceutical companies in the Norwegian market

Position 2018	**Position 2017**	**Company**	**2018 Turnover based on pharmacy purchase price (mNOK)**	**Share of total market in 2018**	**Cluster affiliation**
1	3	Pfizer AS	1 457.8	6.2 %	The Life Science Cluster Oslo Cancer Cluster
2	1	MSD (Norge) AS	1 409.1	6.0 %	Oslo Cancer Cluster
3	2	Novartis Norge AS	1 387.8	5.9 %	The Life Science Cluster Oslo Cancer Cluster
4	15	Gilead Sciences	1 102.8	4.7 %	None specified
5	7	Biogen Norway AS	851.7	3.6 %	None specified

Source: Accenture Consulting, 2019, Technopolis Group, 2020

The DLN 2017 survey identified that within the medicine and health industry, digital technology can fulfil a need regarding:

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[35] https://medteknorge.no/english/

[36] https://www.farmatid.no/artikler/fag/farmasoytisk-industri-norge-en-historisk-oversikt

- Development, production and marketing of medicines
- Prediction of treatment response and personalised treatment
- Diagnostic computer tools
- User-friendly apps and medical technology
- Quality assurance and risk management of patient care
- Use of health and registry data for knowledge generation around illness, and for drug development

Supporting interviews to the survey showed that there is demand for computational models in R&D of novel drugs. There is also extensive data available in disease and product-specific registries, which can be utilised by pharmaceutical companies to speed up demonstration of safety and efficacy. Post-authorisation safety studies in particular could benefit from analysis of large datasets where digital data capture and innovative analysis approaches would be valuable.

Large companies, such as pharmaceutical multinationals, possess enough resources to invest in the latest digital technology. However, SMEs may often lack resources continually to invest in the latest technology. That is not to suggest that such enterprises cannot benefit from digitalisation, nor that there is no demand. However, their demand for digital technology may be best met through the knowledge exchange and spill-over that occurs in innovation ecosystems, e.g. science parks.

Patient-reported outcome measures (PROMs) also offer demand for digitalisation. PROMs are critical in value-based healthcare systems and are often reported in the form of national registries. The collection of such data may often be in paper format, such as that for the Norwegian Arthroplasty Register.[37] A pilot launched by the Prostate Cancer Registry in Norway is piloting the best way to collect PROMs data, which may point to a use case for digital solutions (Evjen et al., 2017).

A consumer survey has shown that demand for digital health care products is increasing in Norway in clinical and non-clinical settings (Accenture Consulting, 2017). Based on the survey, in 2016, one quarter of Norwegian consumers accessed their electronic health records (EHRs). This represented a 12 percent increase from only two years prior. The same survey showed a similar trend in increasing consumer appetite for wearable health technology. Those who already used wearable health technology, such as smart watches, increased from 15 percent in 2014 to 19 percent in 2016.

A more recent survey conducted in 2019 further explored consumer demand for digital health in Norway (Accenture Consulting, 2019). Over 75 percent of respondents indicated that their choice of health provider would be influenced on a provider’s ability to offer digital capabilities. The proportion who would choose a provider with a specific digital capability has consistently increased from 2016 to 2019. This suggests that as a consequence of consumer demand, there will be increasing demand from clinical professionals to utilise digital technology.

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[37] http://nrlweb.ihelse.net/eng/Skjema/Hofteskjema.pdf

3.3.2 *Biomarine industry*

Norway is in a position of strength in the biomarine sector due to its long coastline, coastal waters and climate. The biomarine sector is used here to refer to aquaculture, fisheries and fish processing, the supplier industry, emerging biomarine areas and relevant research institutes and public bodies, similar to the 'Value created from productive oceans in 2050' report. With an estimated value of NOK 90 billion in 2010 the industry is forecasted to be worth NOK 550 billion by 2050 (Olafsen et al., 2012).

After oil and gas, seafood is Norway's largest export industry and supplies farmed and wild fish to more than 150 countries. The Norwegian Seafood Federation represents 680 member companies and 14,300 employees that cover the entire value chain of fisheries, aquaculture, feed production, supplier industry and others.[38] Global demand accounts for 90 percent of the Norwegian seafood market (Olafsen et al., 2012). The top 100 companies in the Norwegian Fishing and aquaculture industry had a combined NOK 115 billion turnover in 2018.[39] The top five fishing and aquaculture companies in terms of turnover were Austevoll Seafood ASA, Lerøy Seafood Group ASA, Cermaq Group AS, Grieg Seafood ASA and Lerøy Midt AS (see Table 6). Unlike the healthcare sector in Norway, the biomarine industry is dominated by Norwegian companies.

Table 6 The top five fishing and aquaculture firms on the Norwegian market

Position 2018	**Company**	**2018 Turnover (million NOK)**	**Cluster affiliation**
1	Austevoll Seafood ASA	22,837	None specified
2	Lerøy Seafood Group ASA	19,879	NCE Seafood
3	Cermaq Group AS	9,891	None Specified
4	Grieg Seafood ASA	7,808	NCE Seafood
5	Lerøy Midt AS	3,929	None specified

Source: Largest Companies 2020

Traditional demand within the Norwegian biomarine industry has been for aquaculture (salmon and trout), fisheries and the supplier industry (Figure 6). However, new areas are emerging where demand is forecasted to emerge over the coming decades. Norwegian aquaculture has the potential to meet the increasing demand for food through increased farming of cod and halibut. Larger markets also exist for mussels, scallops and oysters although high production costs have historically hindered entry to this market (Olafsen et al., 2012).

In 2009 marine related R&D funding amounted to NOK 2.8 billion (Sarpebakken, 2011), 63 percent of which was public, 25 percent from private industry and the rest from overseas and other sources (Olafsen et al., 2012). Knowledge production is thus dominated by the public research sector. Most innovations are produced in the supply chains by capital equipment manufacturers and feed suppliers.

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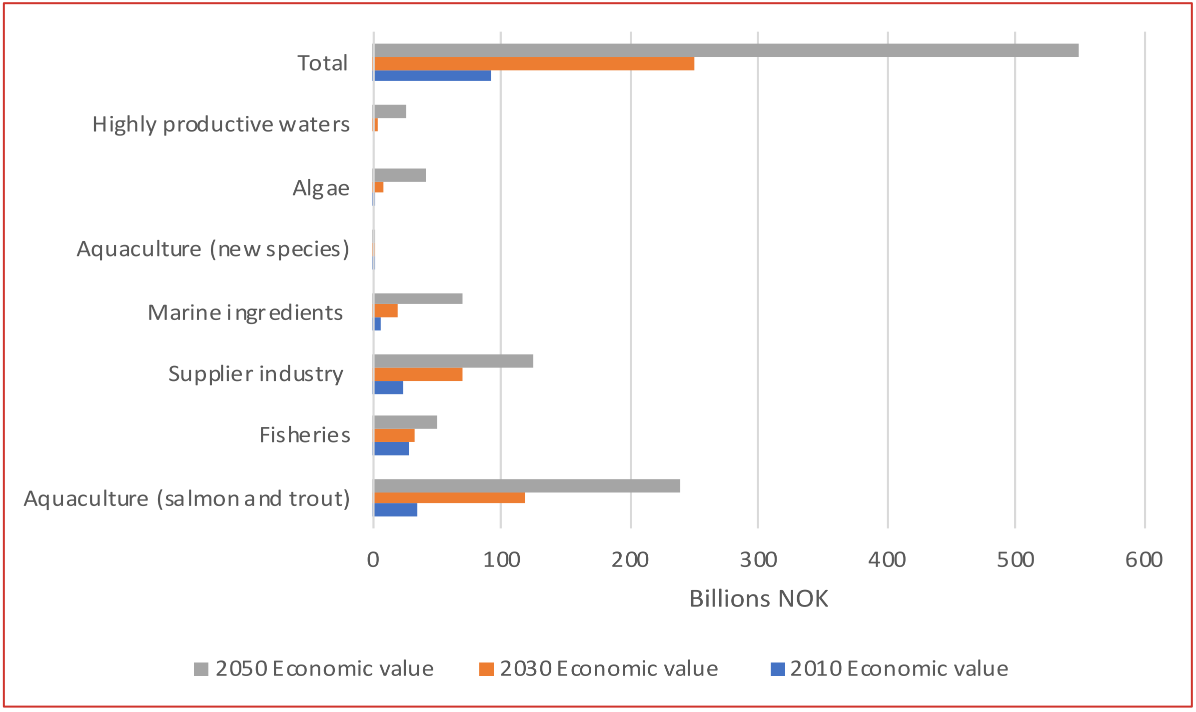
[38] https://sjomatnorge.no/dette-er-sjomatnorge/

[39] http://www.largestcompanies.com/toplists/norway/largest-companies-by-turnover/industry/fishing-and-aquaculture

Figure 6 Forecasted value of the Norwegian biomarine industry by total and breakdown of sub-categories



Source: Olafsen et al., 2012

3.3.3 *Food and agriculture*

Agricultural value chains are more relevant in rural regions, compared to the health and pharmaceutical industry which is more concentrated around Oslo. However, with only three percent of Norwegian land being arable, a significant proportion of agricultural products are imported. Put into context, in 2015 imports totalled NOK 59.1 billion whereas exports currently total NOK 9 billion (Norwegian Ministries, 2016). In terms of investment into the sector, in 2018 the Ministry of Agriculture and Food made NOK 900 million available for the Norwegian agriculture sector. Innovation Norway spent over 2/3 of this on development of traditional agriculture, including new technology.

The Government's Bioeconomy Strategy notes that technological developments in agriculture have led to more substantial and sustainable growth in terms of volume and productivity (Norwegian Ministries, 2016). Digital biotechnology was recognised as an enabling technology that can further aid agricultural productivity. It is anticipated that there will be future demand for robotics, artificial intelligence and automation on both national and international agricultural markets. The industry is characterised by the largest companies having monopolies within certain areas. These companies are internationally oriented with respect to where they operate and invest in technology (Evjen et al., 2017). However, the monopolisation of submarkets in this industry works as a barrier to SMEs that want to enter the market. The National Centre of Expertise Heidner cluster has been engaged with the food and agricultural industry by increasing international co-operation and networks.

The top 100 companies in crop and animal production, hunting and related service activities turned over NOK 8.7 billion in 2018,[40] more than a factor of 10 less than the equivalent turnover for the fishing and aquaculture industry. The top five crop and animal production companies according to 2018 turnover are listed in Table 7, with only Geno SA is listed as being a partner of the NCE Heidner Biocluster.

Table 7 The top five crop and animal production firms on the Norwegian market

Position 2018	**Company**	**2018 Turnover (million NOK)**	**Cluster affiliation**
1	Gartnerhallen SA	2,430	None specified
2	Steen & Lund AS	630	None specified
3	Hugaasgruppen AS	397	None specified
4	Geno SA	376	NCE Heidner Biocluster
5	Norsk Folkemuseum	281	None specified

Source: Largest Companies 2020

3.3.4 *Industrial biotechnology*

The industrial biotechnology industry is involved with refining natural and raw materials, of which Norway has an abundance. Although this industry is a strength in the Norwegian economy, it has demonstrated little demand for or awareness of digital biotechnology. The DLN 2017 survey (Evjen et al., 2017) suggested that actors in the chemistry and process industry were the least convinced that digital biotechnology was of relevance to them. However, owing to the generation of large datasets in industry, there may be future demand for digital technology.

An interview conducted by the DLN with the Industrial Biotech Network of Norway suggested that use of digital biotechnology was more prevalent in R&D and academia. The industrial biotechnology market is characterised by few large companies, of which Borregaard[41] is the leading player. SMEs that lack the time and resources to generate their own knowledge of digital biotechnology can benefit from interaction with R&D and academia (Evjen et al., 2017).

3.4 National biotechnology policy in Norway

At the highest level, the Government's Long-term Plan for Higher Education 2019–2028 (Ministry of Education and Research, 2018) is the most recent strategy that includes biotechnology, superseding the National strategy of biotechnology 2011–2020. The Long-term Plan for Research and Higher Education 2019–2028 indicates that the Government now recognises biotechnology as a an 'Enabling *and industrial* technology', as opposed to just an 'Enabling technology' in the previous strategy. The change in terminology reflects that biotechnology (amongst the other previous priority areas of ICT and nanotechnology), also cover advanced industrial production. The priority areas are aligned with the 'Leading and Industrial Technologies' set out under the EU Framework Programme for Research and Innovation, Horizon 2020.

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[40] http://www.largestcompanies.com/toplists/norway/largest-companies-by-turnover/industry/crop-and-animal-production-hunting-and-related-service-activities

[41] https://www.borregaard.com/

DLN forms part of a central pillar in Norway's research and innovation policy. Six ministries were involved in the development of the National strategy of biotechnology 2011–2020 (Norwegian Ministry of Education and Research, 2011): Ministries of Education and Research, Health and Care Services, Agriculture and Food, Trade, Industry and Fisheries, and Climate and Environment. The strategy deemed biotechnology as an 'Enabling technology and also highlighted that Norwegian biotechnological research and development work has a higher share of public funding than many other research areas (Kunnskapsdepartementet, 2011). Consequently, the Government recognised that biotechnology should represent a greater proportion of the business sector in the long term to reflect investment.

The strategy identified four thematic areas where biotechnology can help meet societal challenges. The four areas were:

- Aquaculture, seafood and the marine environment
- Agricultural-based food and biomass production
- Environmentally friendly industrial processes and products
- Health, healthcare and health-related industries

RCN devised its BIOTEK2021 strategy at about the same time as the national strategy, in effect contributing to the implementation of the national strategy. It was a continuation of the Functional Genomics (FUGE) programme and was initially intended to run for 10 years, but BIOTEK2021 is now a continually on-going programme without set end date.

The overall goal of BIOTEK2021 is to support the development and use of biotechnology that contributes to innovation in connection with addressing societal challenges in a responsible way.[42] The programme's results are expected to have a long-term impact on the development and use of biotechnological research in Norway by prioritising research that builds a bridge between fundamental research and innovation. BIOTEK2021 treats biotechnology as an enabling technology; other programmes connect the use of biotechnology to more specific applications areas. DLN is one of the pillars of the BIOTEK2021 strategy.

An evaluation (Angelis et al, 2017) reported that with its industry-orientated profile BIOTEK2021 can bridge a gap between basic research and industry, whilst aiding translation. A survey raised concern that researchers did not see value creation through the development of products, processes and services as a motive for participating in the programme. Motives of these researchers lie more with the pursuit of scientific advance, rather than innovative and commercial progression.

In 2018 a total of NOK 261.8 million was allocated to BIOTEK2021, which represented over 25 percent of RCN's total allocation to biotechnology. Proportionally, funding has increased given that BIOTEK2021 received 15 percent of RCN's biotechnology funding in 2017 (Angelis et al, 2017). The primary objective of BIOTEK2021 is to "promote the use and development of biotechnology that contributes to innovation needed to solve societal challenges in a responsible manner".

The 2018 BIOTEK2021 work programme outlined four priorities for a structured research effort:

1. A strategic initiative "Digital Life – Convergence for Innovation"

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[42] Forskningsrådet, Programplan BIOTEK2021 Gjelder fra 2018, Olso: Norges Forskningsråd, 2018

  - The Digital Life initiative was started in 2016 and designed to create societal value through a transdisciplinary approach and technological convergence. It builds on similar initiatives in place in Norwegian universities such as University of Oslo, NTNU and the University of Bergen. The Centre for Digital Life Norway leads on this priority area
2. Measures to foster greater innovation in the private and public sectors
   - Enhanced cooperation between academia and the private sector/health trusts
   - Mobility programmes between academia and the private sector
   - Mentor programmes where researchers are given access to senior private sector expertise
3. Responsible Research and Innovation (RRI)
   - RRI is an approach that that increases focus on the incorporation of societal responsibility in the development of technology. RRI acknowledges that new technology can address societal problems but may also hinder or create additional challenges, this balance must be considered at the outset in technological development
4. International cooperation
   - European programmes such as the EU's Framework Programme Horizon2020 and European Research Area Networks (ERA-NETs) are the most important areas for collaboration at an internstional level

3.5 National research and innovation support

Norway has a rather comprehensive portfolio of support measures for research and innovation. Table 8 shows the division of labour among the funding organisations at the time of the 2019 spending review. RCN is the main funder for R&D, while Innovation Norway leads on general business development and therefore tackles non-R&D-based innovation. SkatteFUNN is an R&D tax incentive scheme, primarily focusing on increasing the rate of R&D among smaller firms; hence, there is a cap on the amount of tax credit an individual company can get. Unusually (in international terms), SkatteFUNN not only offers corporation tax reductions to incentivise R&D performance but also has a concept of 'negative corporation tax'. This means that where companies get tax credits worth more than the tax they are due to pay, the finance ministry pays the difference to the firm in cash. Thus, even firms that are not in profit can benefit from the credits. Skattefunn has a particularly strong effect on increasing R&D efforts among companies in the early stages of doing R&D (Arnold, et al., 2019) and can therefore be exploited by technology-based start-up firms.

Table 8 De facto division of labour among major state actors in Norwegian R&I Policy

Organisation	Basic research	R&D, proof of concept	Pilot and large-scale demo	R&D capacity building	Routine product/ process development	Start-up funding	Business skills	Investments and loans
RCN	√	√	√	√				
Innovation Norway					√	√	√	√
Norwegian Space Centre	√	√						
SkatteFUNN		√			(√)			
FHF		√						
Enova			√					
RFF		√		√	√			
Pilot-E		**√**	**√**					**√**
EU programmes	√	√		√	(√)			
	Relevant to technological innovation				*Relevant to all kinds of innovation*			

Note: Innovation Norway funds some technological innovation as well, e.g. though Miljøteknologiordningen and Trebasert innovasjonsprogram.

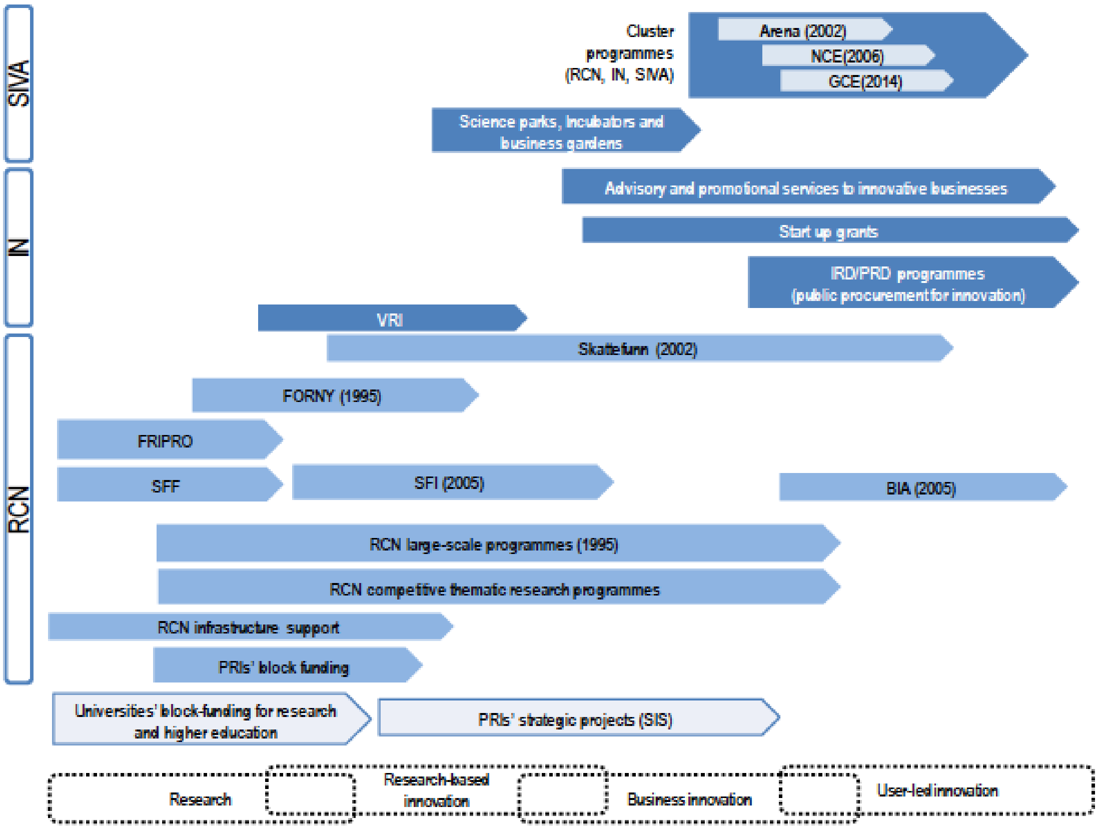
Source: (Arnold, et al., 2019)

The portfolio of research and innovation support instruments available is extensive. The only significant change in content since Figure 7 was originally drawn is the addition of the Norwegian Catapult Centres (discussed below). The recent spending review of policy instruments to support innovation (Deloitte, 2019) has yet to result in any substantive changes in practice that we have been able to identify. It made a number of relatively minor proposals about division of labour as well as suggesting ownership and organisational changes for Innovation Norway which do not affect this report. It preserved the principle that RCN handles research and R&D-based innovation while Innovation Norway looks after business support and non-R&D-based innovation.

RCN has in the meantime been merging its 60 or so research and innovation programmes into 15 larger 'portfolios' and intends in future to plan at the level of these portfolios rather than individual programmes. For the time being, this involves rearranging rather than changing the existing programmes. Substantive changes may occur once the new portfolio plans have been written, but at the time of writing these are still being drafted. RCN has also simplified its funding instruments (*søknadstyper*). 'Commercialisation' funding for translational research and proofs of concept continues to be available through the FORNY2020 programme. RCN has introduced a new commercialisation funding instrument, in effect making it possible to offer FORNY-style funding within other programmes or portfolios.

RCN, Innovation Norway and SIVA have for many years cooperated closely to try to ensure that needs do not 'fall into the cracks' between them and there has been a tradition of referring potential beneficiaries to each other where it is felt that would help the beneficiary. As a result, many companies find themselves supported by two or even three of these organisations for different purposes. These three funders also tend to refer companies to SkatteFUNN, where relevant. It is difficult to see the needs of innovating companies as under-supported by the state in Norway.

Figure 7 Research and innovation support portfolio of RCN, Innovation Norway and SIVA



Source: (OECD, 2107)

RCN is a combined research council and innovation agency. The main task is to provide funding for research and innovation. It also provides strategic advice to the government on national priorities for research, works to enhance international relations and promotes collaboration and dissemination of research. In 2018 RCN allocated NOK 1 billion to research and innovation projects in the thematic area of Biotechnology, approximately 10 percent of its total allocation of NOK 9.8 billion across all thematic areas. Out of 20 thematic areas, nine received more funding than Biotechnology (Energy, Seas and oceans, Food, ICT, Health, The environment, Environmental technology, Industry-oriented research and Scientific quality). However, specific projects may be classified under multiple thematic areas.

Innovation Norway is a business support agency that allocated NOK 7.2 billion in funding to innovation projects, loans and services in 2018. The agency offers services in funding, advice, expertise, networking and promotion. Digitalisation and automation of the bioeconomy are among the agency's strategic priorities (Martin et al., 2018), e.g. by providing support for development and internationalisation of Norwegian Agritech companies. Innovation Norway is distinguished from RCN in that it is more focussed towards start-up companies and SMEs and does not normally fund R&D. The recent Deloitte report (Deloitte, 2019) suggested that the division of labour between RCN and Innovation Norway could be further clarified and has proposed minor changes to the division of labour, which are not consequential for this study.

The Industrial Development Corporation of Norway, known as **SIVA**, focuses on the provision of physical infrastructure and support. It "aims to develop strong regional and local industrial clusters through ownership in infrastructure, investment and knowledge networks as well as innovation centres".[43] SIVA invests in industry and science and technology parks to offer co-localisation environments. Aside from providing physical infrastructure SIVA also mobilises private actors, investors and knowledge networks. It has been argued that Siva start to move away from 'single-purpose' investments, which may be inefficient in terms of both costs and innovation (Deloitte, 2019). Rather, investment should be continued or increased in pilot and test facilities, and science parks where knowledge spillovers occur.

The key platforms where biotechnology can be developed are the Centres for Research-based Innovation scheme (**SFI**), the Norwegian Innovation Clusters programme (**NIC**) and the **Norwegian catapult scheme**, complemented by other smaller programmes.

3.6 National funding schemes supporting innovation

Three major funding schemes are of particular interest in connection with commercialisation of research and the creation and support of innovation ecosystems.

- The SFI scheme, which is an RCN-funded 'competence centre' scheme, funding academic-industry research consortia at least part of whose research portfolio is in areas that involve more fundamental research and longer timescales than normal for academy-industry collaboration programmes
- The Norwegian Innovation Clusters schemes, which supports regional business and innovation networks at different levels of R&D-intensity
- The (new) Norwegian Catapult scheme, run by SIVA to accelerate commercialisation of new research-based knowledge by SMEs

3.6.1 The SFI Scheme

RCN runs the **SFIs**. The scheme fosters innovation and value creation through long-term collaboration between research groups and research performing companies. There is a particular focus on partnering high quality research units with end users so that knowledge, innovation and value creation are achieved. The SFI scheme aims to:

- Facilitate active, long-term cooperation between innovation-oriented, R&D performing companies and prominent research groups
- Promote the development of outstanding industry-oriented research clusters that are an integral part of dynamic international networks and that enhance the internationalisation of the Norwegian business sector
- Encourage and enhance researcher training and the transfer of knowledge and technology in areas with major potential for future value creation[44]

With the first call for funding in 2005, there have been three generations of centres being granted SFI status (SFI I, SFI II and SFI III). Centres are jointly financed by enterprises, the host institutions and RCN. In 2018 RCN allocated NOK 273 million to the SFI scheme. Universities or university colleges have increasingly dominated as SFI host institutions. In the third round of SFIs, 59 percent of the host institution types were universities or university colleges (the remainder

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[43] https://www.regjeringen.no/en/dep/kmd/organisation/etater-og-virksomheter-under-kommunal--og-moderniseringsdepartementet/Subordinate-institutions/The-Industrial-Development-Corporation-o/id85811/

[44] https://www.forskningsradet.no/contentassets/0cf6015a8bb2411b80850b1fd82cfe1c/sfi-requirements-and-guidelines---january-2019.pdf

were hospital trusts/regional health authorities, companies or research institutes). In the previous two SFI generations, universities or university colleges accounted for 33 percent in SFI I and 38 percent in SFI II (DAMVAD, 2018).

Central to the scheme is the coupling of end users to centres to accelerate knowledge transfer and foster innovation. A mid-term evaluation (RCN, 2019) of 17 SFI centres in SFI III found that the centres were places of scientific excellence and also had good processes for monitoring and stimulating knowledge transfer to partners to accelerate innovation. However, the centres shared issues with regards to innovation in terms of:

- recruitment and mobility
- verification of simulation results
- proof of principle research
- pilot testing and the use of demonstrator projects
- patenting and intellectual assets in projects

The mid-term evaluation also found that the scheme had provided strong organisational structures and management to the centres. Within the centres, many PhD candidates and postdocs demonstrate strong research skills. However, it was observed that direct collaboration between industry and PhD candidates and postdocs is lacking. Industry contacts are not properly engaged and with respect to PhD candidates, often due to the pressure of having to submit a thesis within 3–4 years of starting doctoral training.

One example of an SFI where biotechnology and digital tecnology have been used together is the Centre for Research-based Innovation in Sustainable fish capture and Processing technology (CRISP). CRISP, hosted by The Institute of Marine Research, started research activities in 2011 and concluded in 2019. The centre brought together industry and research partners to develop 'smart technologies'. One part of the centres research was to accurately assess fish biomass using digital fishery sonars. The CRISP Final Report (CRISP, 2019) suggested progress had been made in using algorithms to estimate the volume of fish schools. Technologies for acoustic fish sizing have also been developed that have the potential to be marketed. Future collaborative projects are being planned as a result of the centre.

3.6.2 The Norwegian Innovation Clusters programme

The **NIC** programme is operated jointly by RCN, SIVA and Innovation Norway. Project support is provided at three different levels that differ by i) target group and ii) duration of support. These levels are known as Arena (for early-stage clusters), Norwegian Centres of Expertise (NCE – for established national clusters) and Global Centres of Expertise (GCEs for clusters in the process of internationalising). The NCE programme was incorporated by the NIC in 2014 but has since stopped running, however clusters can still use NCE as a brand name. Current clusters relevant to digital biotechnology include Norway Health Tech and The Life Science Cluster, NCE Seafood Cluster, NCE Heidner Biocluster and the Oslo Cancer Cluster. Over 80 percent of those involved in Norwegian biotechnology are connected to one or more clusters or networks (Evjen et al., 2017), which underlines the importance of the programme.

Norway Health Tech is an NCE and the largest health cluster in Norway with over 270 members, ten of which fall under the category of Biotechnology. The office is located in Oslo Science Park and offers co-working space with more than 60 companies already situated there. The cluster offers several programmes to support members, such as **Aleap**, a non-profit incubator whose mission is to facilitate innovation and value creation for health entrepreneurs. Norway

Health Tech also runs a programme that promotes innvation in the Norwegian healthcare sector by establishing collaboration through Horizon2020. An additional focus of Norway Health Tech is sharing of knowledge amongst its members. This is achieved through educational forums that plan 3–5 annual meetings, workshops or courses.

Past clusters relevant to biotechnology included **Arena Biotech North,** which ran from 2012–2016 in Tromsø. An evaluation of the NIC that included Arena Biotech North as a case study found that the cluster had a high degree of national ripple effects when compared with other clusters in different industries (Samfunnsøkonomisk analyse AS, 2017). This was due to a relatively high member share of food product manufacturing; these members have a high intensity of intermediate output. The evaluation found clear evidence that cluster participation increased collaborative relationships by 11 on average across all industries surveyed. As also indicated by an NTNU literature review (Kaloudis et al., 2019), the evalutation did not provide direct metrics, such as patent volume or patent success, to suggest how cluster participation improved innovation activities. Rather, it indicated improved innovation in terms of active SkatteFUNN (an R&D tex credit scheme) projects within clusters. Overall, participation in the cluster programme appears to benefit participants in terms of increased collaborative partnership.

Another former NCE is the **Oslo Cancer Cluster**, This currently has 114 members, including university hospitals, research centres, patient organisations, start-ups and biotech companies, global pharma and technology companies, investors, financial institutions as well as service providers in the cancer field. It coordinates research projects and clinical trials and runs the Olso Cancer Cluster Incubator and the Oslo Cancer Cluster Innovation Park, both set up in 2015.

We further explored clusters under the NIC programme and analysed more closely those which appeared relevant to DLN's goals. Within each cluster, we assessed members and companies whether they could be considered part of a digital life sciences ecosystem and a potential source of demand for academic-led innovations in Norway.

Overall, the ten clusters list a total of 988 member organisations and 58% of those (or 573) have relevance to DLN (Table 9). The Life Science and Oslo Cancer Cluster scored high in terms of relevance, suggesting that demand or at the least interest for DLN innovation activity maybe the greatest in health and life sciences. Many of the members are large multinational (pharma) companies often without intramural R&D expenditure in Norway. However, Biotech North (blue biotech industry) and the Seafood Innovation Cluster also scored high in terms of relevance, broadening the demand for biotechnology innovation in the marine aquaculture area. Norwegian Smart Care Cluster and Norway Health Tech are more relevant for digital healthcare and medical devices, however, owing to their large size, these would contribute many DLN-relevant companies to the ecosystem. We identified the lowest number of companies with this approach that are relevant for food innovation (see Heidner Biocluster), suggesting there may currently be less demand for DLN activity in this area.

Table 9 Norwegian clusters and number of members that are relevant to DLN

Programme	**Cluster**	**Area**	**City**	**Number of current organisations**	**Number of DLN relevant[45] organisations**	**Percentage relevant to DLN**
Arena	The Life Science Cluster	Life sciences	Oslo, Oslo	79	62	78%
Arena	Stiim Aqua Cluster (Blue Planet)	Aquaculture	Stavanger, Rogaland	88	54	61%
Arena	Biotech North (former Arena cluster)	Blue biotech industry	Tromsø, Troms	26	20	77%
Arena-plus programme	Norwegian Smart Care Cluster	Digital healthcare solutions	Stavanger, Rogaland	170	53	31%
NCE	Seafood Innovation Cluster	Innovation in seafood	Bergen, Vestland	62	48	77%
NCE	Aquatech Cluster	Aquaculture	Trondheim, Trøndelag	100	62	62%
NCE	Norway Health Tech	Health innovation	Oslo, Oslo	270	163	60%
NCE	Blue Legasea	Fishing	Ålesund, Romsdal	48	22	46%
NCE	Heidner Biocluster (food)	Food production	Hamar, Innlandet	50	18	36%
NCE	Oslo Cancer Cluster (former NCE)	Oncology	Oslo, Oslo	95	71	75%
			Total	**988**	**573**	**58%**

Source: Technopolis analysis, cluster and organisation websites. Note: some organisations are listed multiple times in different cluster programmes

3.6.3 *Norwegian Catapult scheme*

The **Norwegian Catapult** programme is administered by SIVA, in partnership with RCN and Innovation Norway. The scheme supports the development of catapult centres, which support SMEs to accelerate the transition from product concepts to market launch.[46] The programme has the ambition to create 7–9 catapult centres that are highly specialised in a given field. At present there are five centres, none of which target biotechnology explicitly. However, owing to the field's interdisciplinary nature these centres may encompass biotechnology to some extent. The current catapult centres are:

- Manufacturing technology
- Future materials

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[45] DLN relevant defined as combining activity in any of health, marine, land or biotech industry with a digital aspect

[46] https://norskkatapult.no/information-in-english/

- Ocean innovation
- Sustainable energy
- Digicat

It appears that there is room for more engagement of biotechnology with the Catapult programme, either in the development of new catapult centres, or utilising the existing centres. Digicat, headquartered in Ålesund, offers potential for collaboration in the digitalisation of biotechnology. In particular Digicat offers digital twin technology whereby products or processes are modelled digitally so that ideas and concepts can be tested with less risk than if done in a physical sense.

3.7 Norwegian universities in the innovation ecosystem

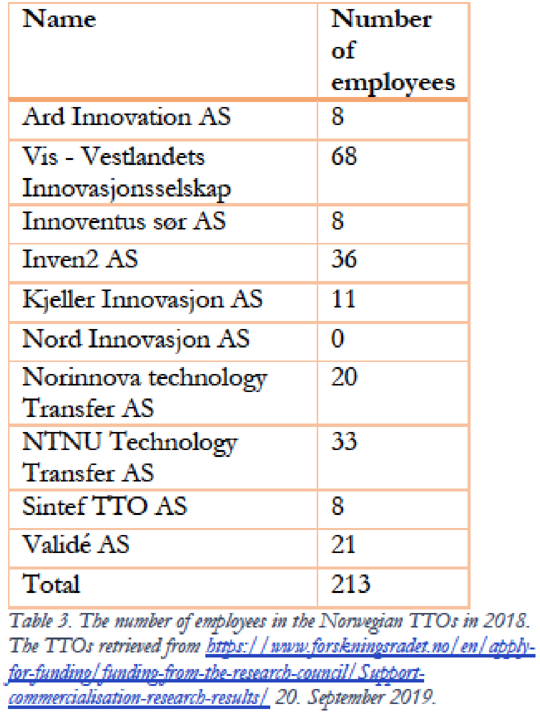
3.7.1 University technology transfer and knowledge exchange

The US Bayh-Dole act of 1980 transferred intellectual property rights to inventions by people working as employed or funded using government money, to their employers, ending the so-called teachers' exception (professor's privilege) in the USA. It is generally thought to be the cause of a dramatic increase in the numbers of patents taken out by US universities in subsequent years. In fact, university patenting was already rising when the Act was passed because of rapid growth in biomedical research, judicial rulings that "engineered molecules" were patentable and a hardening US attitude to protecting US IPR. Bayh-Dole nonetheless triggered a revolution in how universities worldwide thought about commercialising the knowledge they produced, a revolution that was further encouraged by policies from the 1990s onwards that encouraged universities to pursue a 'third mission' of sharing knowledge with society.

Both inside and outside the USA, universities' responses to Bayh-Dole focused on patenting, and they set up (TTOs). In some cases (KTH in Stockholm is a good example) this was done alongside a pre-existing industrial liaison function that linked researchers, students and faculty with industry for collaborative research, helping with company problem-solving and finding industrial partners for engineers' final-year projects. This first generation of TTOs tended to be treated as profit centres (though few of them in practice made profits). They focused on scouting for inventions within the university, taking patents and then exploiting them through licensing and spin-off (Arnold, et al., 2012).

Norway acted later than many others and made legislative changes to the University and College Act and the Employees' Invention Act only in 2003, which ended the teachers' exception and meant that Norwegian universities were given clearer responsibility for the commercialisation of research. These changes resulted in the reorganisation of commercialisation activities and establishment of new TTOs (Spilling et al., 2015). Table 10 provides a recent tally of the numbers of employees working in the Norwegian TTOs and shows that the amount pf resource (213 people) devoted to the TTO function is very substantial.

Table 10 Number of employees at Norwegian TTOs, 2019



Name	Number of employees
Ard Innovation AS	8
Vis - Vestlandets Innovasjonsselskap	68
Innoventus sør AS	8
Inven2 AS	36
Kjeller Innovasjon AS	11
Nord Innovasjon AS	0
Norinnova technology Transfer AS	20
NTNU Technology Transfer AS	33
Sintef TTO AS	8
Validé AS	21
Total	213

Table 3. The number of employees in the Norwegian TTOs in 2018. The TTOs retrieved from https://www.forskningsradet.no/en/apply-for-funding/funding-from-the-research-council/Support-commercialisation-research-results/ 20. September 2019.

Source: (Lekve, 2019)

Norwegian TTOs are run by universities as external autonomous companies with an economic framework agreement between the two types of actors. Imperial Innovations[47] and Warwick Ventures[48] also follow this model in the UK. Other international TTO models increasingly have them either partially or fully integrated within a university (Good, 2019).

Before the removal of the teachers' exception in Norway, individual inventors had greater rights to income generated from intellectual property. After the amendment, universities and colleges were given the rights to inventions, as long as the employees/inventors were given appropriate remuneration (Teie et al., 2018). Specific details of how rights should be distributed are not given; this should be negotiated within the employee-employer relationship. The Norwegian Industrial Property Office (NIPO) offers free mediation, where costs are covered by the state, in cases of disagreement.[49] A report prepared for the Ministry of Trade and Industry (Teie et al., 2018) investigated licensing revenue and showed that amongst the five universities it was common for researchers and universities to receive 1/3 of licencing income each. There were variations in how the remainder was distributed with common recipients being TTOs, the researchers' institute/department or the relevant research group.

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[47] https://www.imperial.tech/

[48] https://warwick.ac.uk/services/ventures/

[49] https://www.patentstyret.no/en/services/patents/employee-inventions/

The Norwegian TTO system has been much analysed and criticised in the past five years. Spilling et al 2015 recommend strengthening of TTOs. OECD 2017 and the Productivity Commission 2016 both say technology transfer and commercialisation need to be more visible and strengthened. The Menon report (Flateland et al, 2017) proposed

- Increasing the inventors' share of IPR from 33% to 49%
- At least half the universities' income from inventions should go to the departments in which the inventors work
- A flexible IPR model should be adopted for spin-outs
- The TTO should be allowed to own no more than 10% of a spin-out
- Use commercialisation as a performance indicator for the universities BOA
- Establish a national system of leave-of-absence for commercialisation
- Set TTO-income goals for the universities and either integrate the TTOs into the universities or free them so that they can serve more than one university

Most recently, (Lekve, 2019)) found that "for Norwegian universities to succeed with commercialisation, they must repossess substantial parts of the activities associated with the commercialisation process. In particular, the universities must take control of the management of their IP. Consequently, the universities will need to build internal units with the necessary competency and capacity to manage intellectual property. Furthermore, the universities will need to assign dedicated responsibility for innovation, entrepreneurship and commercialisation to persons in top management, and they must continue to have such a responsibility clearly visible and prominent over time." Lekve recommended

- Initiate university strategy processes for knowledge transfer
- Dismantle the TTOs
- Establish knowledge transfer units within the universities
- Create a heterogeneous system for commercialisation of research
- Commercialisation is just one part (of the third mission)

3.7.2 *University commercialisation strategies*

A flurry of commercialisation strategies was produced in Norwegian universities from 2018. For example, the Faculty of Mathematics and Natural Sciences and the Medical Faculty at UiB both produced innovation plans for 2018–2022 that proposed a comprehensive introduction of good practices ranging from increased understanding and awareness of innovation among staff through the creation of incubators, management training, setting up an innovation coordinator and an incubator, mainstreaming entrepreneurship into technical education and so on. NTNU produced an innovation strategy that called for more systematic disclosure of inventions and a process for the TTO to have the first option to evaluate and to commercialise them.

These plans suggest that the traditional rather anti-innovation culture of the Norwegian universities (NIFU, 2013), with a tendency to view applied and commercialisation research as antithetical to excellence, is in decline. The change may have been hastened by the inclusion of commercial revenues as an indicator in the university performance-based funding system. The reports on commercialisation discussed above tend to point out that faculty members lack incentives for commercialisation in two senses. First, the universities offer no monetary rewards for commercialisation work (though, of course, successful commercialisation through a TTO does lead to the inventor being financially rewarded). Second, the primary basis for promotion in the academic career remains research performance, so in career terms, working on commercialisation and the third mission more generally is a waste of time.

UiO's position in commercialisation and technology transfer is in important respects different from that in the other universities. Apart from being bigger than the others, UiO has a particularly strong focus on medical research, with long-standing and close links to its large university hospital. The first-generation TTO model, focusing on patenting and licensing, was developed in the USA as a response to the rapidly-growing opportunities in patents based on medicine and life sciences. While some of the other Norwegian universities also work in medicine, many of the parts of industry that can benefit from their university-generated knowledge are in other branches where, unlike in medicine and the biosciences, transferring knowledge takes much more interaction. To oversimplify somewhat: the medical/pharma technology transfer route is one of the places where reality can resemble the linear model of innovation; in most other fields, technology transfer is a more interactive process where knowledge is sometimes even co-produced. The first-generation TTO model works well in the first case; a more internal industry collaboration and liaison function is needed in the second case.

Notably, most of the Norwegian universities have both; UiO only has the TTO model. The Working Groups on Innovation Meeting held at UiO in 2017 (University of Oslo, 2017) pointed this out and – rather usefully – illustrated the reasons for the difference. According to the working groups, UiO is culturally averse to doing applied work for industry and would need considerably to improve its understanding of industry in order to do so. NTNU, in contrast, focuses on technology and industry, needs to have insight into needs and therefore a large number of adjunct professors and joint work with industry – which was the original purpose of SINTEF. The BDO report on INVEN2 proposed a way to improve commercialisation at UiO that appears sensible, namely to end INVEN2's monopoly of the TTO function, refocus it on life sciences (where its working model is appropriate) and establish an internal industry liaison and technology transfer function to foster innovation culture and look after the other disciplines.

More broadly, the UiO medical faculty's commercialisation strategy was sharply critical of the situation at the university. Not only was there a lack of innovation culture and recruitment from industry so that the university had a poor understanding of industrial needs, there was also a lack of tools and support for the translational research and proof-of-concept support needed to bring discoveries and inventions to the stage where they are interesting to industry. A key claim was that – while Oslo boasts a vibrant start-up and innovation ecosystem – UiO was disconnected from it.

3.7.3 Other organisations in the innovation ecosystem

Digital biotechnology has a potential for more rapid innovation than other areas of life sciences, with faster R&D processes (at lower cost) compared to other biotechnology research areas, e.g. pharmaceutical development. However, in order to fully capture this advantage there is a need for close interaction of different actors in the innovation chain (Evjen et al., 2017). As we indicated above, the NCE programme triggered some relevant clusters. The Norwegian innovation ecosystem includes a number of other institutions providing financial support and physical space of which academic researchers in the field of digital biotechnology can take advantage.

The Life Science Cluster (TLSC) lists 72 member companies and organisations that are key players in Norwegian life sciences. Reflecting the thematic areas raised as priorities in the

National strategy of biotechnology 2011–2020, members encompass health and medicine, the marine sector and agriculture and forestry. The cluster's aims include increasing collaboration beteen industry and research institutes, support to start-ups and early stages of business development, sharing of expertise and facilities and development of talent.[50] **The Life Science Pilot Network** is linked to TLSC. Anyone involved in a life sciences project or business can send a service request to the pilot for public funding, services or other kinds of help. The pilot deals with the service request by finding and mediating contact with the most appropriate members of the network. In terms of funding, the pilot can propose a relevant funding programme and assist with applications. The ultimate goal of the Life Science Pilot is to facilitate industrial product development in Norwegian life sciences.

Oslotech has been one of the main providers of infrastructure for Norwegian life sciences since it was established the Oslo Science Park in 1986. Around 60 percent of all life science research in Norway is carried out at Oslo Science Park.[51] Oslotech is an independent company; the Norwegian government (Ministry of Trade, Industry and Fisheries) is the main shareholder, with 34.2% of the shares. A share buy-back programme is in place with the Norwegian government so that this proportion is maintained. Oslotech is also responsible for helping to create and support life science cluster development networks such as Norway Health Tech (formerly Oslo Medtech), The LifeScience Cluster and BioVerdi.

The innovation system also includes specialist funders. One such is **Radforsk**, an early stage fund dedicated to oncology. Radforsk initally started as a TTO named The Radium Hospital Research Foundation. The TTO was intended to identify oncological research with commercial potential conducted at the Norwegian Radium Hospital. It established its first company, Photocure, in 1997. Currently, Radfork runs three main projects that cover the oncology value chain and help bring research to hospitals: The Oslo Cancer Cluster, set up in 2005, the Oslo Cancer Cluster Incubator and the Oslo Cancer Cluster Innovation Park, both set up in 2015.

Also located in the Oslo Science Park is **ShareLab** and **StartupLab**. ShareLab is a launchpad for entrepreneurs, start-ups and industry in the areas of life sciences and biotechology. It has partnered with Abbvie, The Life Science Cluster, VWR, Oslo kommune, AkerBioMarine and Oslo Science Park to help Norwegian biotechnology start-ups. They offer a fully equipped lab including management services, office space, and a commerical and scientific network. StartupLab, which also has a location in Bergen, is an incubator that as of 2020 is working with over 80 members. The incubator offers advice and a network for start-ups.

SPARK Norway, part of the SPARKLGOBAL, is a is an innovation programme that is designed to increase the success rate of health related innovations in life sciences. It is led by the University of Oslo: Life Science and supported by University of Oslo top management, Inven2 and Oslo Univeristy Hospital (OUS). The programme has a portfolio of 23 teams, with the most recent batch of six teams admitted in January 2020. Projects under digital biotechnology include Fabuli, which aim for better faster and better ultrasound imaging. Projects that are selected for the programme receive mentoring and milestone-based funding for two years (up to NOK 500,000 per year). Applications to the programme are restricted, in that at least one member of each project must be employed by University of Oslo.

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[50] https://tlsc.no/about-us/

[51] https://sharelab.no/#service

SiVA is a governmental enterprise facilitating a national infrastructure for innovation consisting of incubators, business gardens, catapult centres, innovation enterprises, innovation centres and industrial real estate. SIVA part-owns 33 organisations it describes as having an incubator function. Many of these are small and/or regionally anchored, that means in many cases that there is no particular thematic of branch focus; in other cases, especially the West coast, the presence of industries such as aquaculture means they have a de facto specialisation. We explored these incubators to understand better the startup ecosystem in Norway. We first identified eleven incubators with relevance to DLN. Within each incubator, we then assessed members and companies whether they could be considered part of a digital life sciences ecosystem and a key source of absorptive capacity for academic-led innovations in Norway.

Overall, the eleven clusters list a total of 235 member organisations and close to half of those (48%) were deemed relevant to DLN activities. This number is likely to be greater in reality as five of the relevant incubators did not list their current membership on their websites. The greatest proportion of relevant organisations was in incubators covering areas of health (Aleap and Oslo Cancer Cluster Incubator), marine and food biotech industries are less visible.

Table 11 Norwegian Incubators and number of members that are relevant to the DLN,

Incubator	**Areas**	**City and County**	**Number of current organisation members**	**Number of DLN relevant[52] organisations**	**Percentage of members relevant to DLN**
Aggrator Inkubator Ås	Agri Tech and Forest, food tech, environmental, sea farming	Oslo, Oslo	19	10	53%
Aksello	Marine	Florø, Vestland	6	4	67%
Aleap	Health (devices, digital health, diagnostics and drugs)	Oslo, Oslo	45	45	100%
Klosser Innovasjon	Bioeconomy, health, industry, IT and digitalisation	Hamar, Innlandet	67	17	25%
Kystinkubator en	Aquacultue and fisheries	Helgeland, Nordland	not listed	-	-
Norinnova	General innovation in North Norway	Tromsø, Troms	not listed	-	-
Oslo Cancer Cluster Incubator	Oncology	Oslo, Oslo	35	28	80%
StartupLab	General innovation	Oslo, Oslo	63	9	14%
T:Lab	General innovation	Steinkjer, Trøndelag	not listed	-	-
Visinnovation	General innovation (west coast Norway)	Bergen, Vestland	not listed	-	-

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[52] DLN relevant defined as combining activity in any of health, marine, land or industry with a digital aspect

Incubator	Areas	City and County	Number of current organisation members	Number of DLN relevant[52] organisations	Percentage of members relevant to DLN
Åkp	Innovation, regional development, the ocean	Ålesund, Romsdal	not listed	-	-
		Total	235	113	48%

Source: Technopolis analysis, Incubator and organisation websites. Note: some organisations are listed multiple times in different incubator programmes.

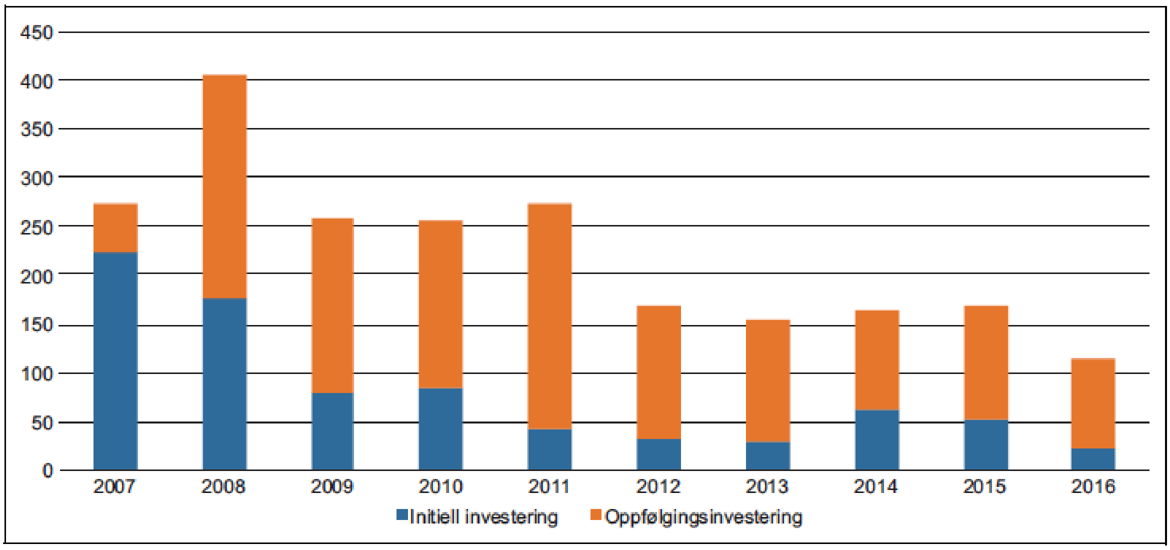
3.7.4 Capital to support innovation

The recent report of kapitaltilgangsutvalget (NOU 2018:5) provides a good overview and is the primary source for this section.

The committee's report points to a general weakness in the Norwegian capital market in that it cannot tackle small investments up to about 20 MNOK. On the one hand these are usually too big for families, friends and angel investors to provide; on the other, they are very small from the perspective of professional investors because the amount of evaluation needed to assess the investment opportunity is very big in relation to the size of the investment.

'Seed corn' investment is particularly important to technology-based start-ups. The Norwegian state-supported seed-corn funds set up between 1997 and 2015, however, have not been successful either in terms of return on investment or in terms of generating sustainable companies. The purpose of these funds was to share the risk of investing in companies whose technology and business models were not yet proven. Figure 8 shows that Norwegian seed-corn investments have declined and moved away from initial investments and towards follow-on investments, where the risks are lower. More generally, the capital market in Norway focuses on buyouts, provides a little venture capital but invents little in seed-corn (Figure 9).

Figure 8 Seed-corn investments by members of the Norwegian Ventura Capital Association, 2007-2016

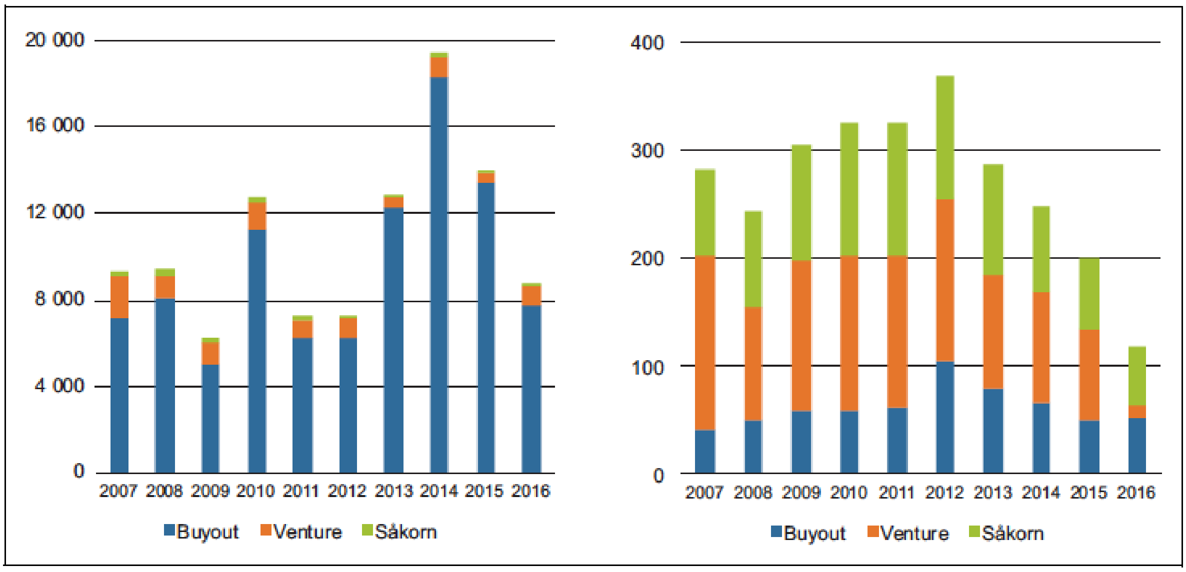


Figur 7.7 Såkornkapital. Nyinvestering og oppfølgingsinvesteringer blant Norsk Venturekapitalforenings medlemmer. Millioner kroner. 2007–2016

Kilde: Norsk Venturekapitalforening

Source: SOU 2018:5

Figure 9 Investments in Norway in MNOK and number of deals, 2007-2016



Figur 7.9 Investeringer i Norge. Beløp i millioner kroner etter kategori (t.v.) og antall etter kategorier (t.h.) 2007–2016.

Kilde: Norsk Venturekapitalforening

Source: SOU 2018:5

In response to the Committee report, Innovation Norway has launched a new seed-corn fund in 2019.

The traditional explanation for the 'Valley of Death' phenomenon, where investors are reluctant to invest at the seed-corn stage in order to develop technology or businness ideas to the stage where they are reasonably well proven, is the (rational) risk-averseness of the market. An interesting and different perspective has suggests that this phenomenon is particularly prevalent where innovations are based on publicly-funded research and need to make the transition to private funding for commercialisation. The argument is that public funding for relatively fundamental research is provided without consideration of market attractiveness; as a result, there is an over-supply of unproven concepts looking for investment (Beard, Ford, Koutsky, & Spiwak, 2009). If nothing else, this perspective underlines the importance of establishing pathways to to market at an early stage if research is to be commercialised.

The Committee report says that while Norway launches a comparable number of small companies to its neighbours, they tend to grow more slowly and generate fewer jobs. While Sweden has produced many digitally-based companies that are scalable, Norway appears to be less successful at launching companies with scalable ideas. Companies that need prolonged investment ahead of starting to make money appear more difficult to fund in Norway than elsewhere in the Nordic countries.

3.8 Conclusions about the DLN innovation system

We began this chapter by referring to literature about innovation, innovation systems and ecosystems. Key messages affecting the way DLN needs to act include the ideas that

- Successful innovations are generally not produced solely as a result of doing good research but of coupling technological opportunities with customer needs
- Innovations are co-produced in networks, so successful innovation also depends upon the performance of different parts of the innovation system or ecosystem. Correspondingly, missing or defective parts are barriers to innovation
- Linking innovation with research and ensuring the adequacy of the innovation system or ecosystem are deliberate acts, requiring organisation and management

The performance of the Norwegian research and innovation system is in many ways strong and supportive of DLN. Norwegian research is dominated by the universities. Overall, scientific quality has been rising and both quality and productivity are better than in most countries, though a little behind the very best. There are few peaks of global excellence in Norwegian research, but the strong performance should provide a solid basis for DLN, especially as Norwegian science is especially good in medicine and life sciences and strong in IT. However, research in the university sector remains somewhat fragmented despite the recent round of institutional mergers, and reform is hampered by governance systems that make it hard for universities to take strategic decisions.

Given the importance of coupling between research and needs in successful innovation, the mismatch in Norway between the thematic foci of university and business research is problematic. While the big Norwegian research effort in medicine and life sciences is doubtless very relevant to the state healthcare system, there is little private-sector R&D in these areas. This is partly due to the dominance of key sectors by foreign multinationals, and partly because of limited interest and absorptive capacity among Norwegian firms in other businesses to which DLN research appears, on the face of it, to be relevant. This leaves DLN with the difficult task of addressing a weak demand side: persuading multinationals to make use of Norwegian knowledge and not just that which they can obtain from corporate headquarters; persuading or educating Norwegian companies in both R&D-intensive and non-R&D-intensive sectors to appreciate the value of DLN research; or trying to be a midwife to 'unborn industry'. Biotechnology is nonetheless a major focus in national research strategy, and this has been reflected both in the BIOTEK2021 programme and in the creation of DLN.

The Norwegian system of research and innovation support organisations and funding instruments is strong and rather comprehensive. RCN, Innovation Norway and SIVA together cover most needs, and the SkatteFUNN tax credit scheme is particularly supportive of small and start-up firms. The key missing ingredient seems to be a dedicated commercialisation or translational research scheme. The SFIs provide a useful set of links between the research system and industrial users of knowledge. Innovation Norway's cluster schemes help develop ecosystems supportive to innovation. At this stage, it is hard to judge the effectiveness of the new Norwegian Catapults.

Outside these national policy-driven arrangements, there are also complementary clusters and ecosystems with potential to promote technology transfer and innovation. These include the Life Science Cluster, Oslotech, Radforsk, Sharelab, Startuplab and SPARK Norway. Much of this activity takes place in Oslo but UiO – which is the major producer of relevant new knowledge in Norway – is said to be poorly connected to this ecosystem, instead focusing its commercialisation efforts on the university TTO. If correct, this would appear to be an important systems failure.

Norway was rather late in abolishing the teachers' exception and setting up university TTOs. It relied on what we might think of as a 'first generation' TTO model, focusing on patents and licensing rather than wider knowledge exchange with society and organised as a profit centre outside the university. This model can be appropriate in biotechnology and pharmaceuticals, but less so in many other fields. It makes it difficult for the TTO to do things that would only pay off in the longer term and removes the possibility for the university to trade off the benefits of TTO-based commercialisation and other forms of knowledge exchange on a case-by-case basis. A flurry of studies in the last five years have proposed TTO reforms, the creation of intra-university industry liaison functions alongside the TTOs and comprehensive education of staff and students in commercialisation accompanied by improved processes for managing it.

As in many countries, commercialisation through start-ups is impeded by the way the capital markets operate. Investors in Norway are not very start-up friendly and are reluctant to invest patent money. Despite the state's repeated efforts to ensure an adequate supply of seed-corn capital, rational market actors have increasingly focused their attention further downstream in the company life cycle, where the risks are smaller, and the rewards are bigger. This is consistent with the international trend.

Overall, then, there appears to be a strong research basis for DLN's activities. This is a precondition for DLN to have an impact on innovation and society. The research and innovation funding and support systems also appear strong, though there may be a need for a specific commercialisation or translation research-funding scheme. However, the 'demand side' is weak, in the sense that many firms in DLN-relevant sectors are foreign-owned multinationals while the Norwegian-owned companies tend to work in sectors that are not R&D intensive. For different reasons, each of these segments has low absorptive capacity for digital life knowledge. This means that technology-based start-ups could be an important route to commercialisation, but these are hampered by a risk-averse capital market.

Linking demand and supply is central to successful innovation, and there appear to be networks and ecosystems where this could be achieved. However, the Norwegian university system needs to change its modus operandi from 'technology transfer' to 'knowledge exchange' and to take greater account of innovation opportunities when selecting topics to research.

4 Digital Life Norway

This chapter analyses the role of DLN and considers evidence from our interviews about what its organisation and context mean for its ability to perform as intended. It is not an evaluation of DLN: that would require a great deal more evidence than we can collect within the scope of the current project.

We begin by explaining the origins and intended form of DLN and go on to develop a tentative intervention logic for the programme. In doing so, we have gone beyond what we can find in programme documentation, so we need feedback from DLN about whether our draft intervention logic is consistent with the view of the people running the programme and where it might need to be amended. We then outline the way DLN has been implemented and report evidence from the interviews about how successfully this has been done.

4.1 The origins of DLN

DLN's origins are in the national strategy for biotechnology,[53] produced by six ministries in response to the white paper on research, 2008–2009.[54] That strategy argues that Norwegian effort in biotechnology could make an important contribution to addressing societal challenges but that it needed to be more focused. In particular, it decided on a strategy that focuses on health and healthcare, seafood and aquaculture, environmentally friendly (industrial) processes and agriculture. These priorities are reflected in DLN's work, as discussed in the previous chapter.

The BIOTEK2021 programme, which contributes to implementing the national biotechnology strategy, is RCN's strategic, long-term initiative designed to develop biotechnological research in Norway. The BIOTEK2021 programme has a distinct innovation-oriented profile. The objective is to generate biotechnology that contributes to innovation and subsequent value creation in order to solve societal challenges in a responsible manner. BIOTEK2021 continues and broadens the work of the earlier FUGE programme in functional genomics and, while it represents only a fraction of the research RCN funds in biotechnology and related fields, it is the biggest single programme in the field.

After consultations with stakeholders and BIOTEK2021's international Scientific Advisory Board, The Board launched 'Digital Life – Convergence for Innovation' as its major strategic effort. DLN forms one block in BIOTEK2021's intervention logic (Figure 10).

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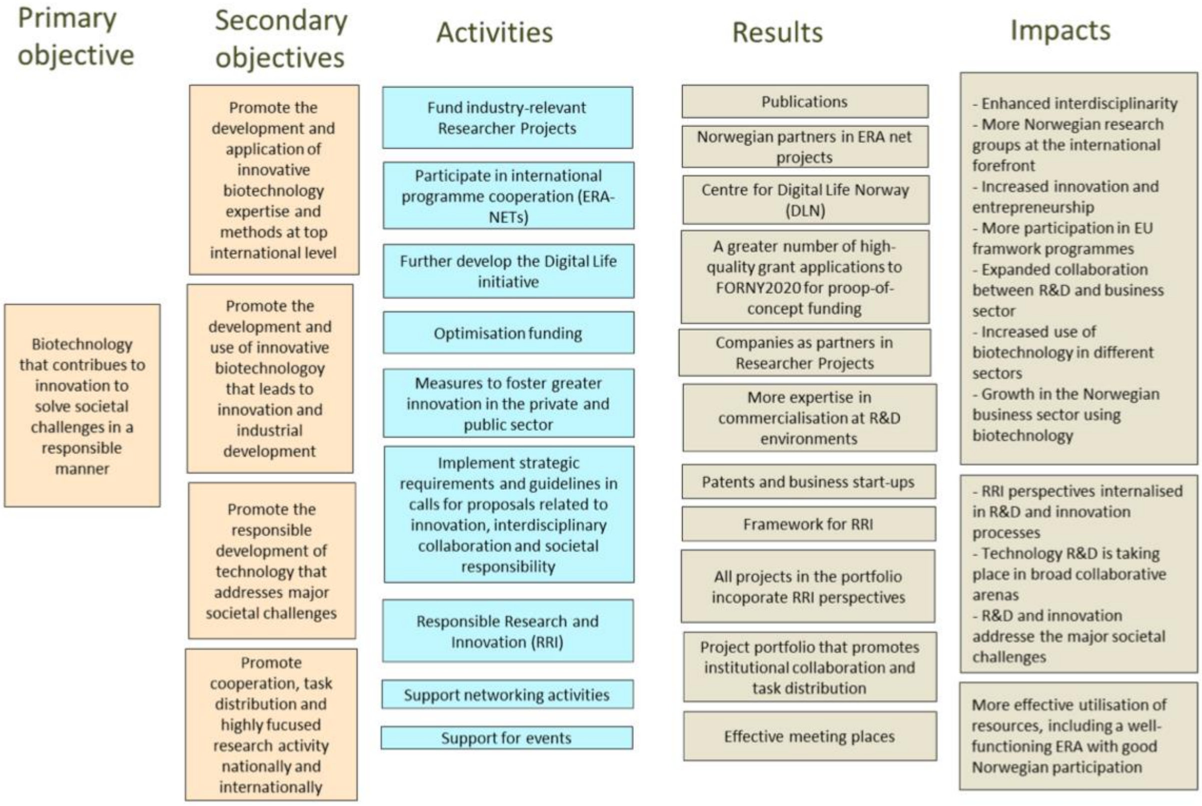
[53] Kunnskapsdepartementet, Nasjonal strategi for bioteknologi for framtida verdiskaping, helsa og miljø 2011–2020, Oslo, 2011

[54] St.meld. nr. 30 (2008–2009) Klima for forskning

Figure 10 BIOTEK2021 intervention logic



Source: BIOTEK2021 Work Programme, 2018

BIOTEK2021's Board decided that DLN should have seven 'strategic elements' (Figure 11).

- **Lighthouse** – building a digital life community in Norway by doing multidisciplinary research that is well connected internationally, to be organised in a hub-and-node network, as illustrated in Figure 12
- **Talent** – recruiting young researchers and running a PhD programme
- **Future** – learning by doing, evaluation and stakeholder consultation
- **Growth** – generating innovations linked to solving societal challenges
- **Brand** – communication and dissemination
- **Responsible Research and Innovation (RRI)** – DLN should follow the principles of RRI
- **International perspective** – promoting knowledge exchange, fostering mobility and facilitating the use of common platforms and infrastructures[55]

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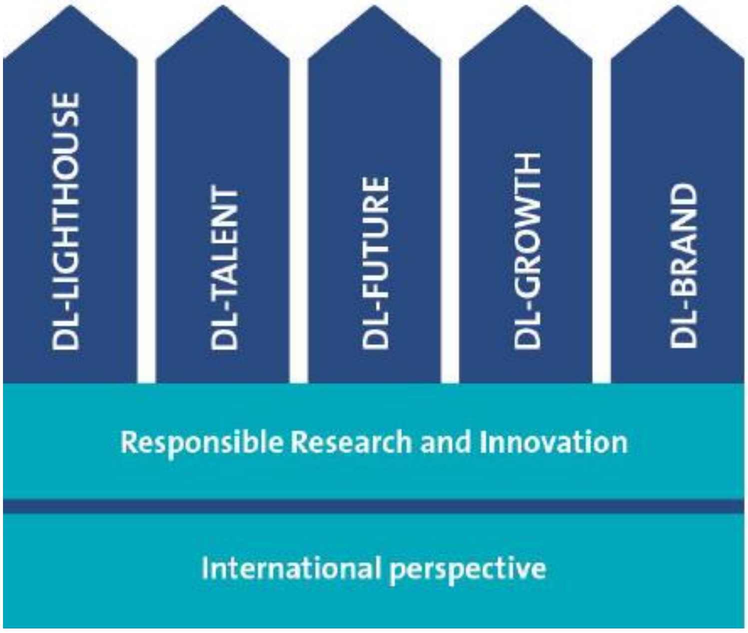
[55] Research Council of Norway, Digital Life – Convergence for Innovation, Oslo, 2014

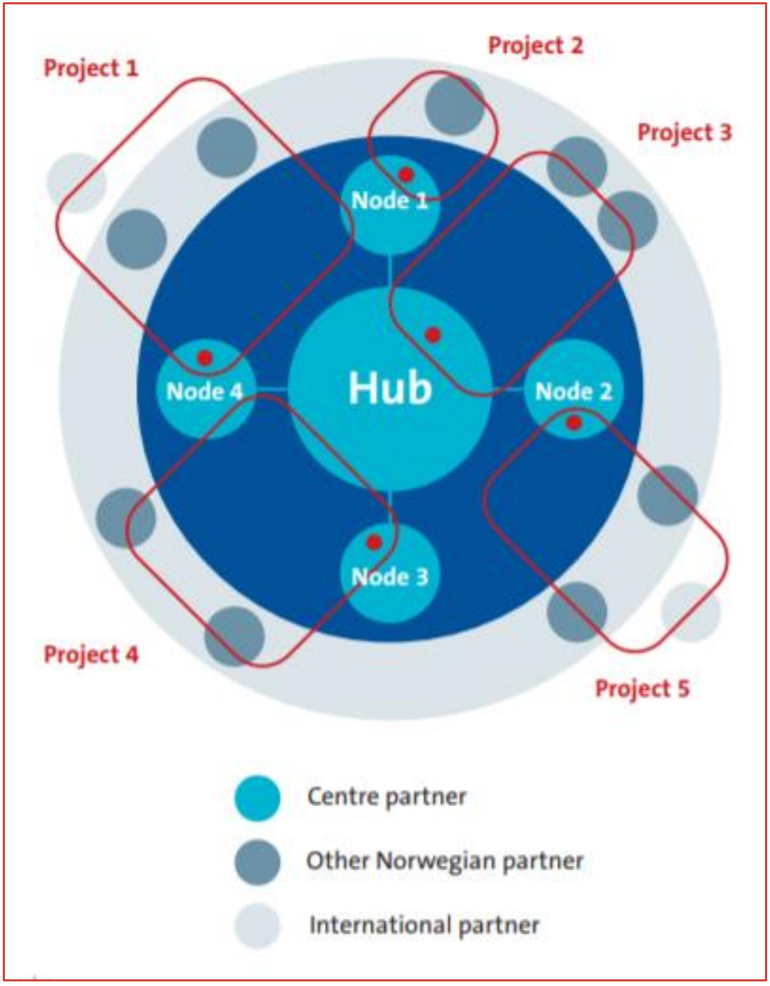
Figure 11 The seven strategic elements of the Digital Life initiative



Source: Research Council of Norway, Digital Life – Convergence for Innovation, Oslo, 2014

It also specified that DLN would have a 'hub and node' structure (Figure 12), functioning as a 'virtual' centre overlaid on the university system.

Figure 12 Hub and node structure of the DLN



Source: Research Council of Norway, Digital Life – Convergence for Innovation, Oslo, 2014

In August 2014, RCN issued a call for Expressions of Interest in running the DLN centre, in which UiB, UiO and NTNU qualified. Eight other organisations expressed interest in functioning as nodes.

According to the full Call for Proposals for setting up the DLN centre and for research projects to be performed in the programme, issued in November 2014:

> *The centre will comprise a coordinated national effort consisting of* ***a portfolio of research projects which together makes up an integrated whole, both technologically and thematically****. The projects should cover areas of strategic importance with significant potential for national value creation and must target important societal challenges. The projects should be designed to develop knowledge and biotechnology of present-day or future relevance to Norwegian trade and industry and/or the societal challenges that Norway is facing.*[56] *[our emphasis]*

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[56] RCN, Establishment of a "National Centre for Digital Life, Call for Proposals, Oslo 2015

The BIOTEK2021 programme plan argued that Norwegian biotechnology faced three challenges.

- The need to increase the rate of innovation generated by Norwegian biotechnology research
- Using biotechnology to exploit the opportunities in the fast-growing bioeconomy
- Using technological development and innovation to address societal challenges

The plan 2018 clarifies some of the ambitions for DLN, describing it as a "development project for Norwegian biotechnology as a whole that aims to create societal value based on technological convergence and transdisciplinary cooperation in research, education and innovation across disciplines, technologies and societal actors…. DLN's mission is to catalyse the development of Norwegian biotechnology and contribute to appropriate national cooperation and division of labour. As a national cooperation platform, DLN will also bring the Norwegian research milieux together and can function as a Norwegian node in international networks with leading centres in other countries." [Our translation]

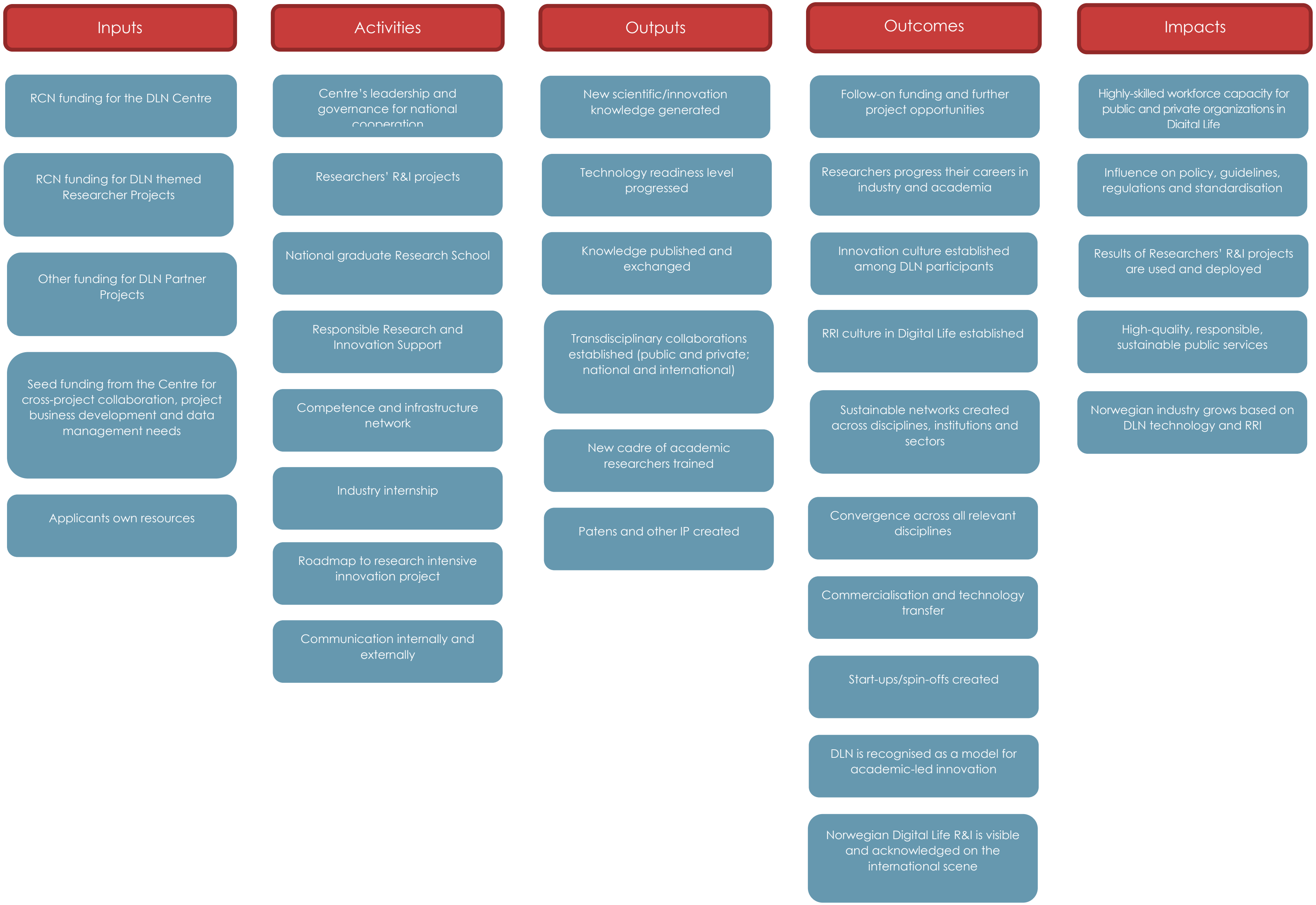
4.2 DLN intervention logic

Based on available documentation and information obtained in our interviews, we have reconstructed a (draft) intervention logic for DLN. Figure 13 shows that logic in the form of a logic chart.

Defining an intervention logic normally means making assumptions, some of which can prove to be critical to programme performance. In our analysis, the following assumptions are worth testing against the information we were given in our interviews, as they may prove to have a significant effect on programme performance.

- There is sufficient, relevant research expertise in the constituent technologies – ICT/computational sciences and biotechnology/life sciences – to support the DLN strategy in Norway
- Academic innovation is incentivised (monetary, reputational, career progression) by the university system, industry and society at large
- DLN accesses relevant strategic intelligence about industrial and societal needs, and uses it to influence its research agenda
- Academic innovation fills a gap (ie, there is a need) on the demand side (public or private), so that knowledge generated is relevant for public services, industry, investors and regulatory authorities
- There are demand-side actors who have the absorptive capacity needed to identify problems and exploit technological opportunities and therefore to engage with DLN and the knowledge it produces
- DLN can access and exploit viable institutions, innovation ecosystems (including networks, TTOs, infrastructures and relevant finance) to support technology transfer
- Societal actors are ready to adopt the principles of RRI

Figure 13 Draft intervention logic for DLN



Inputs

- RCN funding for the DLN Centre
- RCN funding for DLN themed Researcher Projects
- Other funding for DLN Partner Projects
- Seed funding from the Centre for cross-project collaboration, project business development and data management needs
- Applicants own resources

Activities

- Centre's leadership and governance for national cooperation
- Researchers' R&I projects
- National graduate Research School
- Responsible Research and Innovation Support
- Competence and infrastructure network
- Industry internship
- Roadmap to research intensive innovation project
- Communication internally and externally

Outputs

- New scientific/innovation knowledge generated
- Technology readiness level progressed
- Knowledge published and exchanged
- Transdisciplinary collaborations established (public and private; national and international)
- New cadre of academic researchers trained
- Patens and other IP created

Outcomes

- Follow-on funding and further project opportunities
- Researchers progress their careers in industry and academia
- Innovation culture established among DLN participants
- RRI culture in Digital Life established
- Sustainable networks created across disciplines, institutions and sectors
- Convergence across all relevant disciplines
- Commercialisation and technology transfer
- Start-ups/spin-offs created
- DLN is recognised as a model for academic-led innovation
- Norwegian Digital Life R&I is visible and acknowledged on the international scene

Impacts

- Highly-skilled workforce capacity for public and private organizations in Digital Life
- Influence on policy, guidelines, regulations and standardisation
- Results of Researchers' R&I projects are used and deployed
- High-quality, responsible, sustainable public services
- Norwegian industry grows based on DLN technology and RRI

4.3 Implementing DLN

The three universities pre-qualified to run DLN originally submitted competing proposals. However, after negotiation between them and RCN, they joined forces and submitted a joint proposal, in effect making a 'take it or leave it' offer to RCN.

The first DLN call was in two parts: A Centre Networking component worth up to NOK 50m over five years, and a number of research projects up to a total value of NOK 200m. Only UiB, UiO and NTNU could apply for the Centre Networking activity; only they and the other organisations which had expressed interest in being nodes, could apply for the research projects. There were further calls for research projects in 2017 (NOK 100m) and 2018 (NOK 80m). In each case, it was possible for companies to participate in the research projects and to receive part of the grant to fund R&D.

DLN currently has three components, funded by grants spread across NTNU, UiO and UiB, which provide a 'competence unit', which is led by six of their professors.

- A network project, which consists of five work groups
  - Governance & responsible research and innovation
  - Innovation and industry involvement
  - Training and recruitment (including the management of the DLN graduate school)[57]
  - Competence and infrastructure network
  - Communication
- The Digital Life research school
- Since 2019, "A road-map for academic research-intensive innovation from the Centre for Digital Life Norway" (ie the present project)

The research projects are initiated and managed decentrally by the project performers, who apply to RCN for grants using the 'Researcher Project' funding instrument, whose main purpose is to fund investigator-initiated research. RCN drafts the Calls for Proposals and funding decisions are made by the BIOTEK2021 Board, based on external peer review. Thus, DLN itself has little influence on the composition of the portfolio of projects funded.

DLN currently[58] has 36 research projects, 16 of which are funded from RCN's budget for DLN, and 20 are associated partner projects from other sources – though funding for all projects is ultimately distributed by the RCN. The research projects are led by people from the seven 'owner organisations': NTNU, UiO, UiB, UiT, NMBU, SINTEF and the Oslo University Hospital. Most projects are oriented towards health at present as illustrated by Figure 14. The figure does not include the Res Publica project which aims to improve RRI across all DLN research projects.

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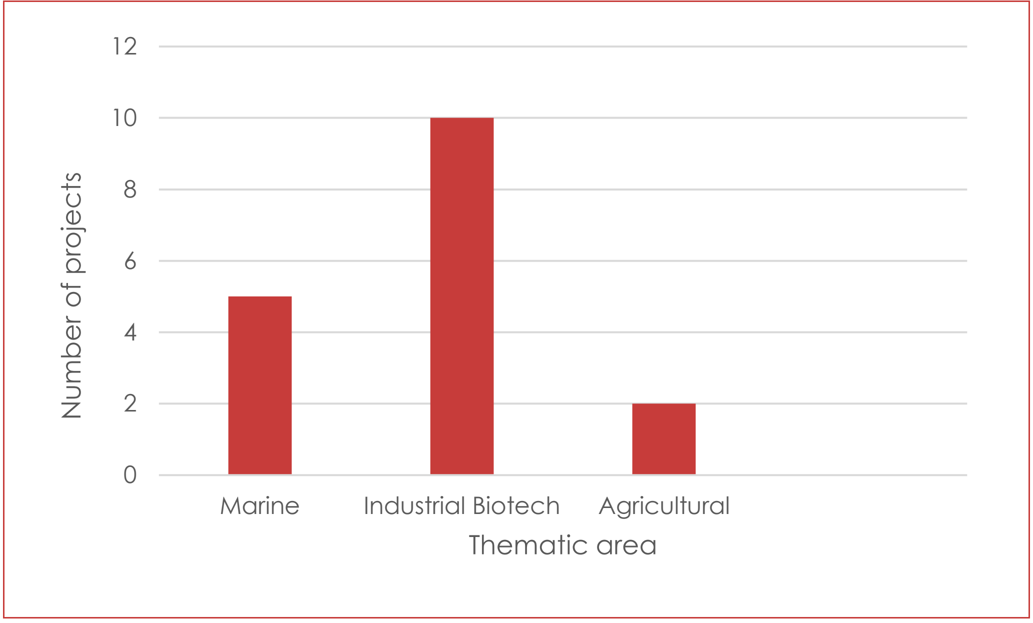
[57] There is a separate grant for running the research school

[58] DLN, Annual Report, 2019

Figure 14 Categorisation of current DLN projects into thematic areas



Source: DLN 2020. Note that the total number of projects shown is greater than 36 as some projects fall under more than one thematic area

The 16 so-called 'research projects' funded under the main DLN grant were obtained in three calls for proposals (2015, 2016 and 2018) while the partner projects came from calls in 2016 and 2019. The research projects are funded via RCN's 'Researcher Project' (forskerprosjekt) funding instrument and were selected after peer review based on four rather high-level criteria, with preference being given to projects led by women in the case of proposals being judged to be of equal quality.

- Relevance relative to the call
- The quality as a Researcher Project
- Relevance to industry and society
- Strategic basis and importance

The thematic relevance of research proposals was judged on the basis of a study of opportunities done during the first year of the DLN programme and published in 2017.[59]

The so-called 'partner projects' associated to the programme are not funded by it but were selected from among projects that applied to become associated with it in two calls, respectively in 2016 and 2019. This meant that they had better potential to be involved in the DLN networking activities.

Figure 15 shows the timeline of major activities in DLN.

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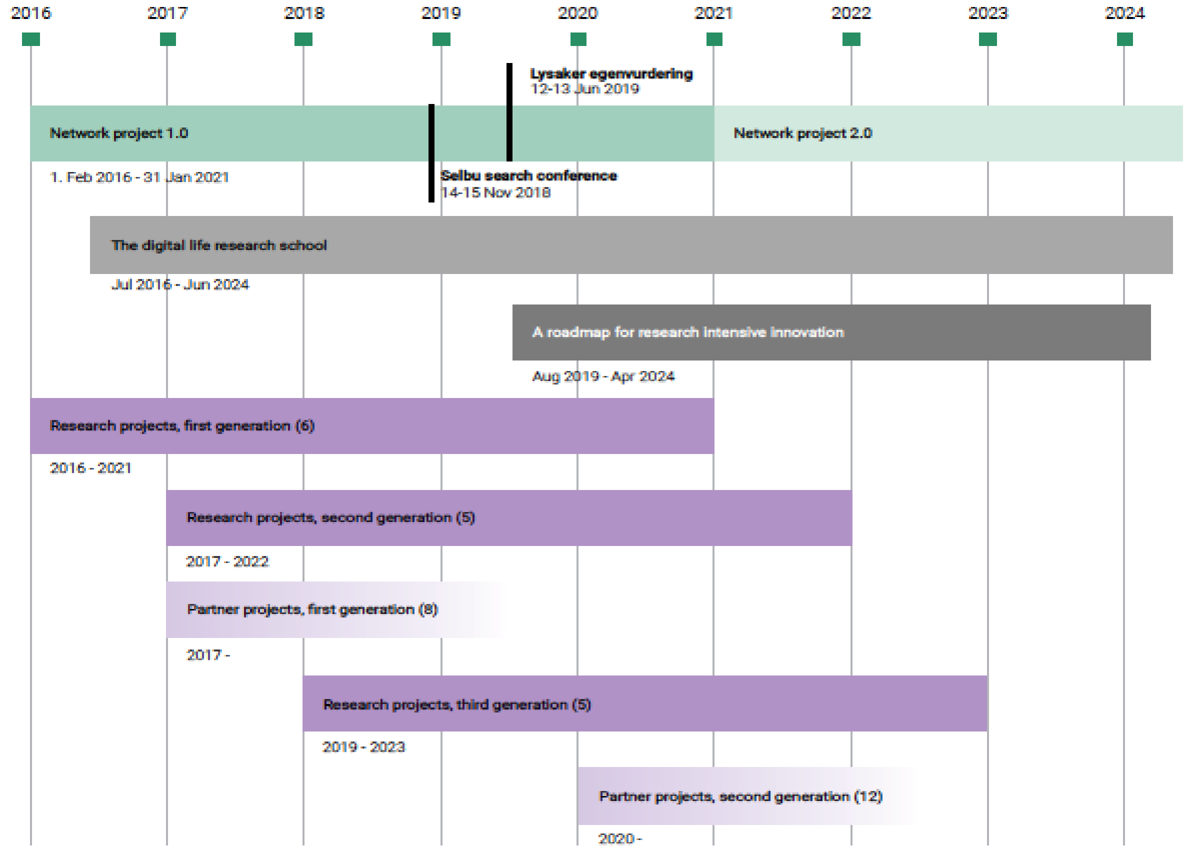
59 Tove Julie Evjen, Gunnar Dick, Erland Skogli ,Kaja Høiseth-Gilje, Kjetil Jakobsen og Kjetil Taskén, Den digitale bioteknologien i Norge Muligheter for verdiskaping, kompetansebehov og utfordringer i næringsutvikling, Senter for Digitalt Liv, 2017

Figure 15 The Digital Life time line



Source: DLN Annual Report, 2019

Figure 16 shows how DLN is organised. The DLN Board governs the centre and ensures alignment of DLN and institutional strategies. The board has one seat for each hub partner (UiO, UiB and NTNU), two seats for node partners (rotating between different nodes) and two seats for external members that may include industry or industry bodies. Advisory bodies are also in place to ensure inclusiveness and scientific excellence. These bodies are a Scientific Advisory Board, a Partner Forum and Project Leader Forum.[60] This governance form relies strongly on cooperation and voluntary coordination. Neither the DLN Board nor the centre leadership has any meaningful influence over the research agenda or the choice of research projects. It does influence the choice of partner projects to be associated to DLN, but this is in turn limited by the choices already made by reseachers and other funders. The networking project is, in effect, expected to work with whatever it gets, irrespective of its links to the demand side or its technological innovation potential.

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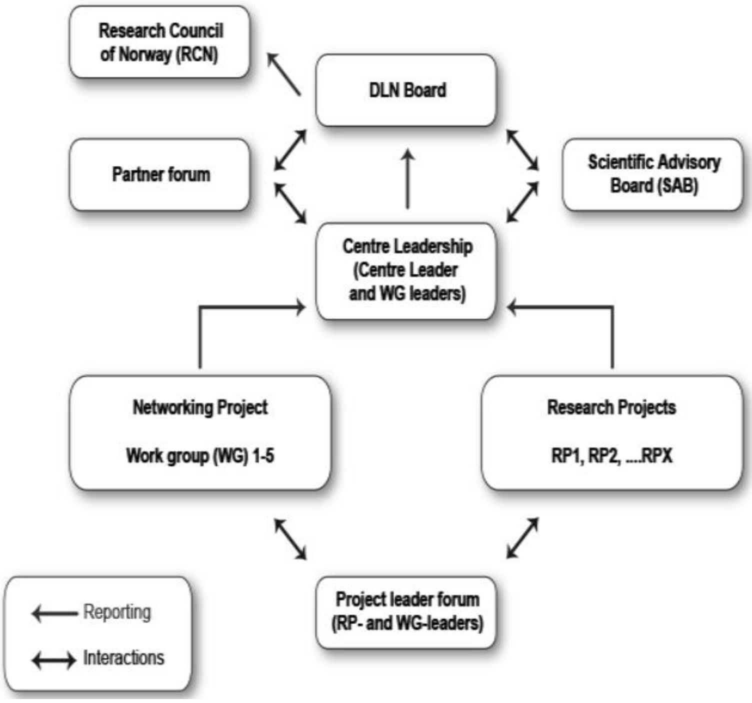
[60] https://digitallifenorway.org/gb/about-center/organisasjon

Figure 16 Organisation of Digital Life Norway



Source: DLN Website, accessed 23 May 2020

4.4 Testimony from our interviews

This section synthesis important messages from our interviews.

4.4.1 Absorptive capacity and the demand for innovation

Policymakers commented that the strong research effort in biotechnology and related areas is not matched by industrial structure.

> *We now have massive national activity in the biotech field in research and at universities, without having a strong industrial base in the field.*

Several university managers and researchers argued that there is a weak industrial base within the life sciences in Norway. This results in a lack of demand-driven innovation, and a lack of a market for research ideas to be commercialised.

> *There are certainly some gaps in the system, especially in the digital life sector. There is no industry in that sector, thus no receiver on the industrial side of scientific results. That is a weakness.*

It should however be noted that the digital life sector is broad and includes marine life sciences where there is absolutely a strong industrial base in Norway and a strong demand for knowledge-intensive ideas that can be turned into innovations.

Absorptive capacity – in effect, the ability to identify opportunities in science and technology, develop and apply them to business strategy and innovation (Cohen & Levinthal, 1990) – is a crucial precondition for companies to do research-based innovation. There were examples of DLN researchers who had an interest in or experiences of taking their research results further towards innovation, and among them, there were mixed views regarding the bridge towards industry (or business). Some had contacts with companies and felt positive about the possibilities to commercialise the research results, while others were not. Some parts of the marine industry in Norway are research-intensive, but large parts are less so, and the same can be said about the agriculture and food industry as well. The absorptive capacity within the digital life sector does consequently vary, both between industrial branches as well as within larger branches like the marine industry.

One university manager argued that there is in fact a rather well-developed biotechnological sector, but the weakness is the lack of a more comprehensive pharmaceutical industrial base.

4.4.2 Valleys of Death in research and financing

Comparisons are often made with the other Nordic countries, where Denmark and Sweden are exemplified as countries with a stronger life science sector in general, and especially a pharmaceutical industry. But it is at the same time also noted by several that there are many new companies being formed in Norway, many start-ups, which indicates that the innovation system is not that poor. The challenge however is how to scale up the businesses. One person at leading university management level said:

> *It is often pointed at a gap when it comes to the innovation chain, with respect to the step with testing and demo and that. Enova is trying to work with this. The hard part is to scale it up; there are many good small start-ups and small businesses. We have a good creation and input of ideas, but do not manage to commercialise and scale them up.*

When trying to detect what works reasonably well in the innovation system with respect to the digital life sector and what works less well, a specific viewpoint emerges. Regardless of the function, almost everyone that we have interviewed pointed to a perceived (or clearly identified) gap along the innovation chain where research results are step by step handled and brought further along the TRL scale towards commercialisation. The gap is early in the process of translation of research to innovation, at the point when a result is identified as having potential for further innovation. There is very little support available for a researcher – or someone else – to explore a promising result or a good idea just a little bit in order to see if it may hold for a more extensive or refined development – or so it is at least said.

The interviews with policymakers confirmed the picture that is presented above; that there is a gap in the innovation system. The projects that are supported by DLN are often projects on early TRL levels, maybe levels 2–4. And the TTOs operate much further along the TRL scale.

4.4.3 Lack of innovation culture in the universities

Many interviewees related the strengths (or weaknesses) of idea-creation to the academic merit system. It is well known that in academia, it is research results that count, and that means publications first and foremost. Many interviewees pointed to this circumstance and also that interaction with society including cooperation with the private sector, does not provide much credit for a researcher. It may even be counter-productive. While it has often been said that academia should honour outreach-related merits, it can be probably be safely concluded that when appointing or promoting staff, it is still 'pure' scientific criteria that count.

The whole focus on creating innovation from the research projects was also criticised by some. Some researchers (with funding from DLN) argued that its focus should simply be on good research, and then innovation will be inevitably generated. They pointed to the large number of innovations that have come from basic research like that which is supported by ERC, suggesting that the focus ought to be on the good ideas; innovation should not be DLN's task. But several returned to the point that DLN should simply support the best projects and engage less in innovation. One said that the very idea of an 'innovation strategy' is a contradiction in terms; the point is that the best ideas will be 'innovated' anyway.

One observer pointed out that the lack of career opportunities in Norwegian industry for DLN-related PhD graduates tended to work against the creation of innovation culture. In these circumstances, PhD graduates had little choice but to pursue academic careers and therefore to focus on the aspects of their work that were most likely to secure academic jobs.

4.4.4 TTOs

The weaknesses related to demand-driven innovation in the digital life sciences sector and the lack of large pharmaceutical industry connect to another theme that emerged from the interviews: the TTOs and their way of working. We interviewed representatives of the TTOs at UiO (Inven2), UiB (VIS), NTNU (NTNU Technology Transfer), SINTEF, UiT (Norinnova), and NMBU (ARD Innovation). We also asked the researchers about the TTOs.

As described earlier in this report, the TTOs are organised as private companies, and even if they are partly owned by the university which they serve, they still must operate according to sound business principles, meaning that they need to be profitable. We have heard many people who believe that the TTOs therefore choose to work with ideas or projects that are already well-defined and well-developed, rather than working with ideas/projects that are in an early phase. They may also be quick to sell a licence to ensure profit at once, rather than developing an idea for several years, and then make a profit, potentially many times larger. They are often felt to try to generate a financial return from ideas too early.

The TTOs operate at a point on the innovation chain beyond the proof-of-concept stage, where it is already confirmed that a result or an idea has technical and commercial potential. Researchers explained that when they go to the TTO with an idea, they tend to get the answer "good idea, please develop it a bit more and then come back". There is little or no funding available to take that step. Nor are there career incentives for the individual researcher. Circumstances differ among universities, but we have heard the above-mentioned critique regardless of institution.

But not all researchers are as happy with the TTOs. Many of those we spoke to voiced criticism, and it almost always related to disinterest or lack of engagement when a researcher has an idea. Interestingly, several of the university managers also pointed to a gap in the very early phases of innovation, when a researcher comes up with an idea. It can very well be that there is a real gap in the system in this phase, where many good ideas are never tested, or never explored and developed further and then tested.

One researcher captured many of the challenges when trying to develop an idea in the following quote:

> *We have been talking to companies and they are very excited. A PhD student was working with this and is now finishing the thesis. We would like to go down the innovation path but without starting our own company. We go to our faculty and tell them that we would like to keep the person for a year, so that we can do that innovation that they always tell us to do, but they say that there is no money for this. And we talk to the TTO and they say the same thing. So we feel left alone in this, they tell us to engage in innovation but no one is ready to pay for it. I would need to run demo tests and stuff at night without any pay. And the companies think it is not yet developed enough for them to enter. There is a gap between our research and the phase with licencing or starting a spin-off or what is needed. The gap consists of*

> *groundwork and proof of concept, and this is the same in many other projects and other fields too. So not unique for just this project.*

We have met researchers in the digital life sector who are both interested in taking their research to the market and have experience of doing so. They may be the type of people who can be both good researcher and good entrepreneur. But more common is the type of researcher who is neither an entrepreneur nor particularly business-minded. With the admirable examples of the first type in mind, it is still a lot to ask that a good researcher should also be a good entrepreneur and innovation manager. The TTOs do have a very important role to play in this view. It is possible that the TTOs should be given a clearer task to not only develop good ideas for commercialisation, but to also identify good ideas among the researchers for further exploration. A statement in support of those lines:

> *Some researchers will just be researchers, they may perhaps continue to be that. But there are some who want to operate also in the innovation sector, and they can be supported.*

Many of the TTOs themselves think that they work in much the right way. They point to the ownership of the TTOs by the universities and the close cooperation that they have. One TTO pointed out that the TTO can support researchers, when they apply for research grants, by helping to write the impact parts of the application. The same person added that researchers use the TTO to help in their search for industrial connections and users because the TTO has a large network of relationships with companies. Life science researchers are the most active users of the TTO's services.

The TTO at NMBU seems to differ a bit from the others, appearing to be more strongly connected to the university, and less focused on making profit. It also operates in earlier phases of the innovation chain. The TTO at NMBU does try to get licences out to the industry as they think this is a good way to achieve societal impact, but it does not have industrial partners and is not interested in establishing new start-up companies. If there are companies to be established, the TTO leaves that to the incubator, which is supposed to be responsible for the next part of the innovation chain.

> *We are part of the university for all that matters, even if we are a company. Our organisational status is purely a solution, we feel like we are part of the university and we do what is good for our two owners.*

The ownership and mandate of SINTEF's TTO were seen as clear. The other TTOs' ownership structure may be clear on paper, but in reality, they have to serve more diverse interests, which complicates their operations.

The TTOs rarely cooperate with each other, which could be a potential weakness. However, one person pointed out that the way they are set up, this would to some extent be like two competing companies cooperating – it is difficult.

There has been discussion in the media lately about the TTOs and their work. Few, if any, of the TTO representatives that we interviewed felt that that discussion was especially relevant to them. Most seemed quite satisfied and uncritical of their roles and achievements.

4.4.5 Innovation ecosystems

Few of our interviewees discussed innovation ecosystems in Norway relevant to DLN's work. Those who did so, argued that such ecosystems were either non-existent or were beyond the reach of the universities involved in DLN. UiO experienced particular problems.

> *In a normal department at UiO, there is no signs of industry at all, and industry will never show up in any activity. If there is a researcher who wants to explore an idea commercially, there are few opportunities. Invent2 will just say that it is a good idea, please develop it further, we cannot help more now, come back when it is more developed. And the industry has no interest to put their eyes to the university, which is strange.*

4.4.6 Room for improvement?

The researchers within the DLN network are mostly very happy with DLN. They mentioned for instance the networking opportunities and the support they get from the coordinator team at DLN. Certain individuals in the team were repeatedly mentioned in the most appreciative terms.

However, there is also criticism, or perhaps rather question marks. It is not always clear what those question marks are. One person said vaguely: "There is something missing in the DLN projects, DLN could go through the portfolio systematically…". Another one asked what the strategy is in a longer perspective; what will happen after the funding period, and how can the results be commercialised? Someone else thought that DLN should take the role between the researchers and the TTOs and create incentives for the researchers to become more innovative. And yet another questioned whether digital life sciences is really a viable way to go for Norway.

Several researchers, in effect, referred to the 'project fallacy' – the idea that the reason they are doing the research is the same as the reason the funder is funding their research. They said that DLN is not at the core of their research; they have funding from DLN, but they have funding from many other organisations as well. Some explained that they have simply tailored their research application so that it would fit the call. In reality, the DLN funding is just part of a larger pot of funding for their research, which they carry out with little intention to address 'digital life-criteria' (unless it suits them). This does not imply that they think DLN is doing anything wrong; they just point to the fact that their priority is to develop their own line of research. Some see very low potential for commercialisation of their DLN-funded research, but others see large potential, so there appears to be a wide spectrum among the DLN projects, with respect to their perceived commercialisation potential.

A particular point relates to the DLN Research School . Several of the interviewees, researchers as well as university managers and TTO representatives, thought that it is very important to foster the new generation of researchers in innovative thinking. If the young researchers have an eye on the innovation potential in their research, then things can really start to happen, thy argue. There are some 400 members at the research school, and both PhD candidates and postdocs can be members. The school tries its best to introduce a certain amount of innovation-mindedness to the members: Two years ago, a lean innovation workshop was organised by DLN, with financial support from the research school and possibility for some research school members to attend. There are also other examples when the research school has drawn on activities that DLN has organised, like an intellectual property seminar, and access to courses within health innovation, organised by NTNU, UiO and Karolinska Institutet. The school also supports with travel funds.

That said, interviewees were often sceptical about the degree of interest the PhD candidates have in innovation. There are few incentives for them to engage with innovation during their PhD training and limited enthusiasm for it. The research school leader noted:

> *Not that many applied for the lean innovation course. A handful were interested. At the yearly conference we forced everyone to assess the*

> *innovation potential in their research projects, but the response was 'so-so'. Innovation is a bit of a side-issue for them. We had 80 participants at the conference, and perhaps five had thought about innovation before. They are occupied with their academic research. I think they need some help to think in innovation terms. Some are super-interested and take part in all such activities, but they are few.*

The PhD candidates, and the postdocs who are also members of the school, are felt to be a critical pool of individuals, whom it would be beneficial to train in innovation thinking and to support when good ideas emerge. The research school could need yet further support in order to be able to work more with this, and to reach the PhD candidates. Possibly, the whole PhD training path needs revision with respect to creating incentives to engage in innovation.

In the interviews with the researchers, we asked what DLN could do to improve and what DLN should focus on in the future. Some elaborated on an intermediary role between the universities and the TTOs; some mentioned a DLN incubator that could be formed, and/or other types of 'small money' for various innovation related tasks and things that a researcher might need and which no one else provides. It was pointed out that different categories of people have different responsibilities. Researchers should not necessarily do innovation and should not be expected to be good at innovation. Furthermore, early stage entrepreneurs may not necessarily be the best ones at eventually taking a product to the market, they might be best at developing an idea, but less good at running a business. Thus, there may be several roles for different types of people with different skills during the innovation process. One researcher put the intermediary role that DLN could take like this:

> *When a researcher has an idea for innovation, then it is not certain that it is the researcher who should take it onwards. A first type of manager or CEO person is needed, but this person usually needs to have credibility in the academic field, and be in touch with the researcher, as the researcher has the knowledge required in that first phase. Then, later, that leader can hand over to more commercial people who really know how to make business out of it.*

DLN could then be responsible for that middle step before the ideas is handed over to "more commercial people who really know how to make business".

Others think the networking role is very important and also the research school; yet others think that all that is less relevant and that DLN should just focus on supporting the best research projects.

Several observers felt that DLN should take a clearer and stronger role 'politically' – going beyond convincing politicians that digital life sciences are important to Norway but also arguing for the digital life sector both towards RCN and in the Norwegian research community in general. It could relate to an international context as well; establishment of relations or development of existing relations, with the Scandinavian countries, were mentioned by several, and occasionally with other countries in Europe. It could also be to push for the digital life sector among the TTOs, or even towards the business sector.

Policymakers stressed that DLN's mandate is ultimately about innovation and were not certain that DLN was able to devote sufficient effort to that dimension of its work. The new, NOK30m Innovation project at DLN, is intended to help secure this innovation focus. There is a danger that the projects selected for funding in DLN are primarily aligned with institutional strategies of the respective universities. It was felt that DLN should focus more on anchoring the research in an innovation eco-system context in Norway, and also make the research better linked to international processes and to real missions. It was expressed that now, there is a need for institutional collaboration – creation of an innovation culture – not individual project results. Not all research has commercial potential – but that is why there is a need to know what support is needed to progress research towards innovation.

> *We now have massive national activity in the biotech field in research and at universities, without having a strong industrial base in the field. So, if we shall invest NOK30m in an innovation initiative, we cannot leave it to the researchers themselves to run it and to carry out things in a closed box, without building bridges towards other stakeholders and without much context.*

4.4.7 Governance

The interviews revealed a certain level of ambiguity about the extent to which DLN controls its own fate or is under the control of RCN. Naturally, DLN wants to control its own destiny, but it does not decide what research projects to fund. While that is formally decided by RCN, the hub universities strongly influence what proposals are submitted, exercising a considerable de facto power over the research agenda. The goals of DLN were also felt to be diffuse – for example, the lack of any specific KPIs was felt to cause ambiguity. There was some agreement that more clarity regarding the goal, the mandate, the expectations and the responsibility of DLN is needed. RCN needs to decide whether it shall exercise its steering through its representatives in the Steering Committee, or more directly. It should come as no surprise that it is difficult for DLN to have two masters who do not always send the same signals and speak the same language.

4.5 Preliminary conclusions about DLN based on evidence in this chapter

DLN was from the outset intended to address both research and innovation, coupling the significant Norwegian research effort in biotechnology and the life sciences to addressing societal challenges. We have not been able to find a well-articulated intervention logic for DLN (indeed, the programme design pre-dates the introduction of formal intervention logic in RCN programme design). That means that the programme's ambitions on the demand side are not very clear. Equally, the intermediate logical steps in moving from funding research and networking on the supply side to achieve the demand-side ambitions are not as evident as they might be. We have therefore constructed a tentative intervention logic (for comment) that aims to clarify these points and identified at least some of the assumptions made in programme design. The remainder of this section largely explores the extent to which these assumptions are valid.

While DLN does not fund any projects itself, and has no say in the selection of projects to be funded, DLN has succeeded in organising a substantial amount of innovation and networking activity, adding value to the Norwegian research base in biotechnology and related life and digital sciences. However, its organisation and governance mean that it has been hard to realise the ambition that DLN should have a "portfolio of research projects which together makes up an integrated whole"[61] and while the proposal assessment process requires that projects be socially relevant, it does not ensure that they are linked to specific societal challenges. DLN therefore has to work opportunistically with whatever projects it 'receives'. Much of what DLN does, therefore, has a 'science push' character.

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[61] RCN, Establishment of a "National Centre for Digital Life, Call for Proposals, Oslo 2015

Our interviewees were emphatic that the strength of the research supply available is not matched by demand for research-based knowledge – partly because in important sectors there are few domestic firms, and partly because in the Norwegian-dominated sectors the companies tend not to do much R&D. That leaves the programme, on the one hand, with limited information about actual and potential demand for knowledge outputs and, on the other, with the difficult prospect of helping to support the creation of new Norwegian firms in order to valorise research. It also means that there is limited absorptive capacity in the Norwegian business sector to make use of research-based knowledge from DLN.

The Norwegian universities have historically not had a strong innovation culture. This appears to be changing now, but our interviewees pointed out that academic incentives still take little account of contributions to innovation (as opposed to research). The strong role of the hub universities in setting the research agenda is therefore unlikely to promote greater innovation focus, and numbers of researchers pointed out that DLN provided a suitable source of funding (although it is RCN that is the actual source of the funding) for their 'real projects', irrespective of its ambitions regarding innovation.

Like any other programme, DLN is strongly dependent upon its context in the innovation system. While there appear to be strong research capabilities, the translation of research results into innovation appears to be hindered by important issues in the innovation ecosystem.

- Our interviewees were emphatic about the inadequacies of TTO arrangements in the Norwegian universities today. They were said to focus on activities after the proof-of-concept stage in translating research outputs into knowledge that can be used in innovation. That said, we observe that some of the objections we heard to the TTOs reflected the limitations of innovation culture among some scientists and therefore a lack of understanding of innovation processes
- While the literature suggests that there are Norwegian organisations supporting innovation ecosystems both in general and in DLN-relevant fields, our interviewees appeared to have limited knowledge of, or contact with, them. This suggests a systems failure. Whether this means that the relevant networks are ineffective or that the university research system is poorly connected to them is unclear
- Our interviewees' remarks were consistent with the analysis of the capital system in the previous chapter, which suggested that it focuses on more mature parts of the investment cycle, leaving a shortage of seed and early-stage venture capital that creates a financial 'valley of death'. They pointed to an equivale research 'valley of death' as a result of a lack of funding form translational and commercialisation research, despite the provision of 'optimisation' funding by DLN

5 Key ingredients of success in innovation in Life Sciences

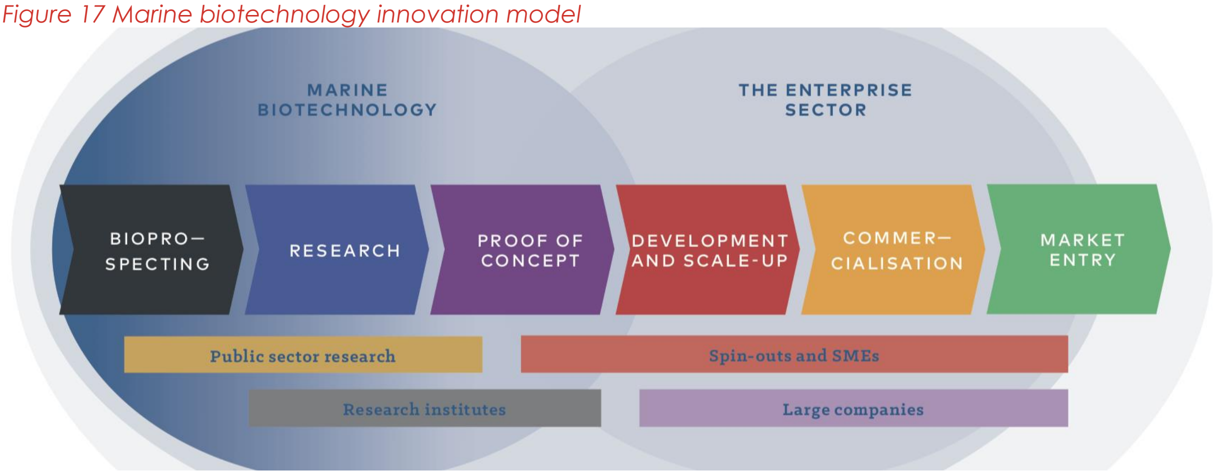
The following section will highlight key challenges and factors for success in two broad areas relevant for DLN. The first reviews marine biotechnology and the second translational research relevant for innovation in the health space. Firstly, the barriers and enablers will be explored before going into why collaboration, skills and education, infrastructure and incentives are needed for translational research success. No more specific literature examining pathways of academic research to innovation in the marine, agriculture or biotechnology industry spaces was identified. The same holds for 'digital' aspects of innovation which has become a rather common and broad term. This was the reason that we selected the field of biomedical innovation to identify existing enablers and barriers to innovation, as it is the area where this type of research on research has been conducted. We believe that barriers and enablers are similar in other fields.

5.1 Marine biotechnology

Biological resources are increasingly being used in new ways, creating a new biotechnology sector (Hurst *et al.*, 2016; European Commission, 2019). In the marine environment, new activities explore and exploit aquatic organisms to develop new products and services, eg to produce ‘smart food’, feed, biofuels, biomaterials, cosmetics, pharmaceuticals, and industrial enzymes.

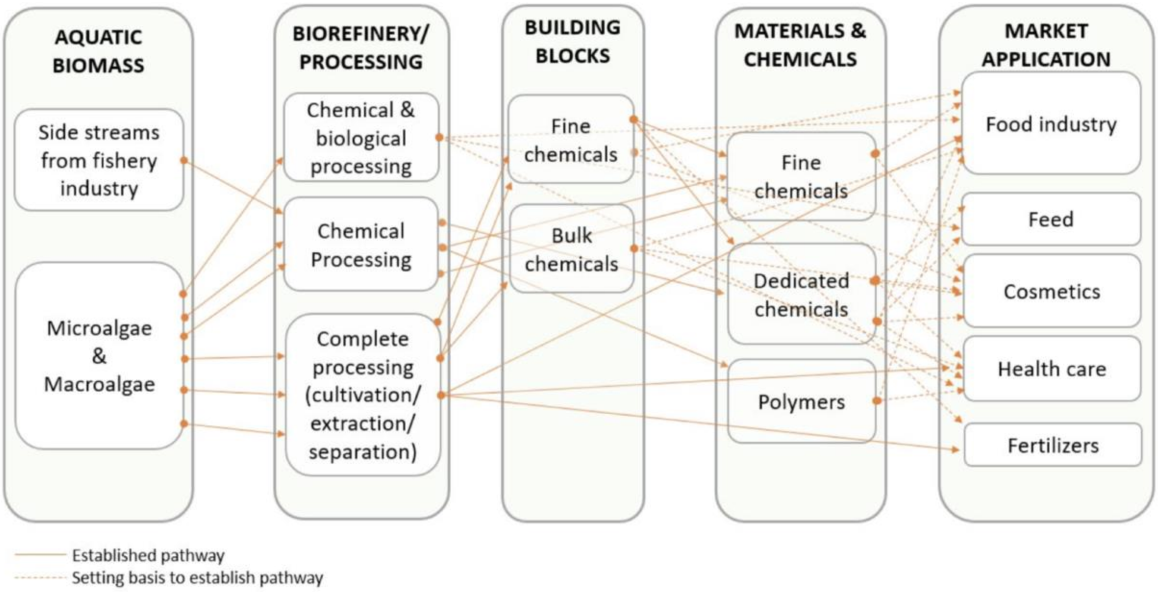
Marine biotechnology is a multi-disciplinary, knowledge and capital- intensive technology that spans different sectors, moving innovations from bioprospecting and research to proof-of-concept and development stages and into commercialisation and market entry (Hurst *et al.*, 2016) (Figure 17). An analysis of EU-funded aquatic biomass projects (bio-based industries Joint Undertakings) over the 2014-2017 timeframe further demonstrates the multi-sectoral nature of the innovation ecosystem (Figure 18).

Figure 17 Marine biotechnology innovation model



Source: (Hurst *et al.*, 2016)

Figure 18 Value chain of aquatic biomass R&D projects, with cross-sector interconnections



Source: (European Commission, 2019)

A recent study published by the OECD (Philp and Winickoff, 2019) analysed two bioeconomy value chains in Norway, based on biotechnology as the main enabler and supporting Norway's large marine sector. Challenges highlighted for both cases are skills gaps, the need to bridge disparate sectors, and the need to de-risk development to enable private sector take-up and investment. Policy actions to address these challenges were summarised as follows:

- Public funding for early stage research and competence building
- Long-term public strategies on industry regulations and open communication
- Raising awareness by facilitation of knowledge dissemination and networking across sectors
- Public incentives for industry collaboration and a holistic approach to new value chains.
- Public funding and support targeting mid-to-high TRL-levels (scale-up and demonstration). This can also include subsidies for smaller companies to carry out techno-economic analyses of potential technologies (as these may go beyond SME's capabilities and resources)
- Policies and incentives for product labelling and consumer information

A particular challenge for innovations moving from research into the enterprise sector (see Figure 17) is the need for infrastructure to allow testing and scale-up of the industrial processes under development – also termed the **demonstrator** phase (Philp and Winickoff, 2019). This step requires significant resource, at a stage in which the innovation is still subject to high risk of failure. Demonstrator plants are de-risking facilities, but their construction can be problematic as they may not have enough capacity to influence markets, and can end up being stranded assets. Their availability, or better: lack thereof, poses a barrier to investment from the private sector, particularly SMEs. Demonstrator plants hence play a key role in the innovation ecosystem, and government investment, eg the establishment of public-private partnerships to build demonstrator facilities, not only enables de-risking of innovation activities for the private sector, but can also serve to attract businesses and stimulate cluster formation.

Another critical aspect of biotechnology innovation, in the marine space and beyond, is **collaboration across sectors**. For example, marine exploration and bioprospecting largely draws on technologies developed outside the biological area, including devices such as remotely operated vehicles for sample collection, data mining techniques to identify areas of high marine biodiversity, and metagenomics to recover DNA from microorganisms that cannot be cultured in the laboratory (Hurst *et al.*, 2016). By adopting, and adapting, technologies developed in other fields, marine biotechnology innovators are able to expand the exploration of marine environments and gain greater access to novel marine organisms, thereby enlarging the discovery pipeline. Hence, links between the marine biotechnology research community and areas of fundamental and applied sciences are crucial - as are dedicated research tools and facilities to fully exploit marine biological resources.

A challenge identified for marine biotechnology researchers is the alignment of their discovery and development activities with the needs of target markets (Hurst *et al.*, 2016). To enable this alignment, innovation needs to be guided by linking researchers and end-users, eg by supporting **innovation networks**.

5.2 Innovation challenges in the bioeconomy

Many new value chains in the emerging bioeconomy suffer "systemic challenges", where each part of the value chain depends on the success of the other parts in a systemic manner, eg "when combining a novel, poorly characterised feedstock with a relatively immature conversion technology, in order to meet an unestablished customer need" (Hansen and Bjørkhaug, 2017; Philp and Winickoff, 2019). The same underlying issue is encountered when the profitability of a new value chain depends on the complete future mix of end products. Only when all players have successfully reached the far side of the 'valley of death' is sufficient value created to drive the system. Unless a single organisation can develop the whole product portfolio singlehandedly, the risk inherent in the system will deter investors from engaging (see example provided in Box 2).

A recent analysis of regional bioeconomy innovation ecosystems in ten countries using a case study approach, concluded that the way forward "might be public-private concerted action, involving coordinated innovation efforts and supportive policies throughout the whole chain" (Philp and Winickoff, 2019).

Box 2 Challenges in bioeconomy innovation – exploitation of mesopelagic fish

The study provides an example of this challenge for a Norwegian opportunity – the exploitation of mesopelagic fish. This would require concerted action spanning from marine research to market development. This includes:

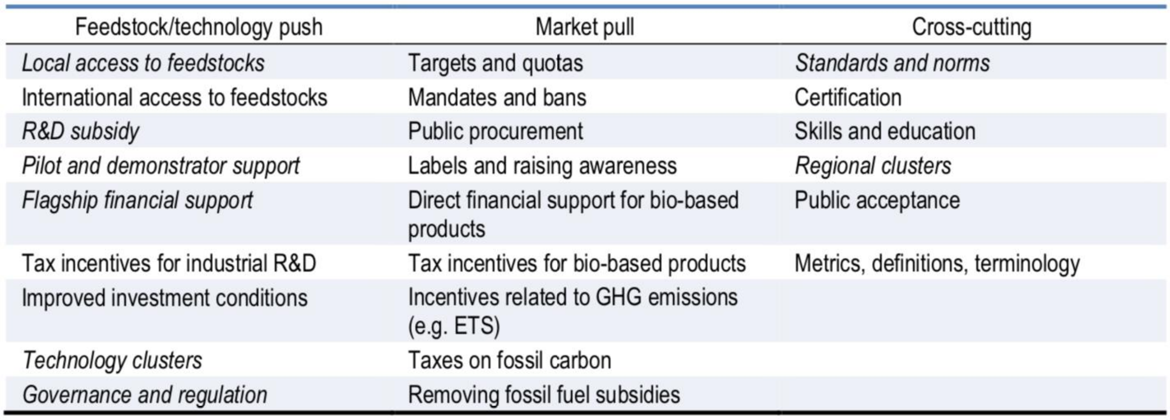
- Research to understand the marine ecosystems and development of more efficient fishing gear and avoidance of bycatch, supported by the development of improved detection systems at greater depths
- Research to determine the chemical composition of the organisms to enable identification optimal processing technologies and product opportunities
- The appropriate regulatory aspects and policies to steer resource management, as well as product approvals

Given these challenges spanning the system, fishing companies are not in a position to undertake expensive trial fisheries without assurance of future commercial licenses, suppliers of enabling equipment do not invest in innovation without a firm customer base, and bespoke processing technologies are not developed without an established market pull.

Source: Adapted from (Philp and Winickoff, 2019)

An analysis of support policies for bioeconomy innovation across countries concluded that these tended to focus on supply-side measures rather than demand-side (market-making) measures (Philp and Winickoff, 2019) (Figure 19). The authors noted that while public procurement can represent a powerful instrument to facilitate market entry of innovative products, its fragmentation into a large number of procuring authorities (eg 2,100 in the EU at central government level) inhibits coordination, and industry-specific knowledge and capacity building. In addition, the largest share of bio-based products is chemicals and intermediates, which are only interesting to private industry in a business-to-business (B2B) market and do not concern the business-to-consumer (B2C) market in which public procurers normally operate (e.g. fuel and consumer products).

Figure 19 Policy measures supporting biotechnology innovation



Feedstock/technology push	Market pull	Cross-cutting
Local access to feedstocks	Targets and quotas	*Standards and norms*
International access to feedstocks	Mandates and bans	Certification
R&D subsidy	Public procurement	Skills and education
Pilot and demonstrator support	Labels and raising awareness	*Regional clusters*
Flagship financial support	Direct financial support for bio-based products	Public acceptance
Tax incentives for industrial R&D	Tax incentives for bio-based products	Metrics, definitions, terminology
Improved investment conditions	Incentives related to GHG emissions (e.g. ETS)	
Technology clusters	Taxes on fossil carbon	
Governance and regulation	Removing fossil fuel subsidies	

In italics: Policy options cited more frequently in case studies. Source: (Philp and Winickoff, 2019)

5.3 Barriers to translational research

A number of studies have investigated barriers to innovation (research translation) as a result of knowledge and skills gaps, as well as other 'non-scientific' barriers, i.e. factors preventing outputs of 'successful research projects' to progress along the TRL pathway (see Staff et al. 2014).

Cultural barriers may stem from blue skies researchers simply having a lack of interest in engaging with the private sector. A survey regarding the use of societal impact considerations into the peer review of grant proposals suggested that researchers may resist using societal impacts due to a lack of desire (Holbrook & Hrotic, 2013). There may be greater cultural preference to stick with basic science and disregard engagement with the private sector, acting as a barrier to translation.

Key barriers to translation of promising leads from animal-based studies include a lack of both financial resources and of a commercially focussed partner. A systematic review of 416 pre-clinical animal model tissue engineering studies found that despite positive results suggesting potential for clinical application, few actually translated in practice (Cousin et al., 2016). Surveys were sent to the study authors to determine the reasons why the research was not translated. The main barriers were found to be:

- Lack of a commercial partner
- Insufficient financial resources
- A research programme not involved in translation

- A lack of expertise in regulatory affairs

The authors of the review suggested that these barriers could be partly overcome if translation is recognised as a part of academic success. Including translational methods and processes, education for Master and PhD research students could help to develop this culture. They also suggested that there needs to be a paradigm shift away from grants and publications being used as an indicator of success. Active collaborations between basic scientists, clinicians and clinical investigators that demonstrate improvement in community health should be used as indicators of success.

A narrative synthesis examined publications on clinical and basic scientists' perspectives of enablers and barriers of translational research (Fudge et al., 2016). Five themes emerged from the 26 papers included in the study.

1. **Concepts of translational research.** Translational research is often seen as a linear pipeline from an institutional perspective when in practice, for scientists, research is a far more iterative process. A bilateral understanding of translation perspectives, between institutions and researchers is needed.
2. **Research processes.** Complex regulatory processes, including governance over ethics and research have served as barriers to translational research, often slowing it down. A lack of IT infrastructure can also slow translation processes. A grant for the provision of bioinformatic infrastructure where it did not previously exists has proved to be an enabler (Kotarba et al., 2013).
3. **Research versus clinical care.** There is a cultural divide between basic and clinician scientists that acts as a barrier to translation. The divide was often perceived to be due to organisational and structural factors including additional training being time intensive, and expectations to combine clinical services and research were unrealistic.
4. **Interdisciplinary collaboration.** Multi-disciplinary teams were seen to be an enabler of knowledge exchange, but only if there was a balance of members at different experience levels. In instances where there was a professor with many students, multi-disciplinary teams became a hinderance.
5. **Entrepreneurial science.** The existence of an institutional policy agenda for translational research that uses health and wealth-based metrics for success encourages translation. If there is a lack of institutional policy agenda of such kind, then translation may be inhibited.

Cancer-related research barriers have been noted as expenses needed for commercialisation, limited amount of time given other responsibilities, lack of quality infrastructure and lack of industry partners. University policy or procedures may often act as a barrier to researchers even attempting to commercialise (Vanderford et al., 2013). Clinical researchers in emergency care have indicated that barriers to the translation of their work is often cultural (Homer-Vanniasinkam & Tsui, 2012). They suggested that there was a shortage of trained clinical investigators, a lack of role models and training opportunities, inadequate protected research time, poorly defined research-based career paths, and a culture of valuing clinical care over research. Similar barriers to those outlined in cancer-related research and Fudge et al's narrative synthesis were also highlighted. They included a lack of infrastructure enabling commercialisation, a lack of multi-disciplinary teams, and ethical and regulatory issues slowing processes.

With direct relevance to digital life sciences, a lack of data capabilities has also been recognised as a barrier to biomedical innovation. For example, academic researchers and companies in the biomedical space consulted in a recent UK study stressed that the R&D community lacked skills related to data, such as data science, AI, machine learning, and bioinformatics (Ipsos MORI and Technopolis Group, 2019). These skills were considered essential to benefit from the large amount of health-related data that becoming available. Similarly, a 2019 survey of the UK biopharmaceutical industry highlighted the skills gap across a range of computational disciplines as "becoming the biggest priority for the pharmaceutical industry" (ABPI, 2019).

5.4 Enablers of translational research

A recent evaluation of the UK Medical Research Council's (MRC) translational research portfolio examined changes in the translational research environment and key factors that have led to improvements in the way research can progress along the innovation pathway ((Ipsos MORI and Technopolis Group, 2019). Key individuals in the UK medical research community, such as heads of university and industry research departments and investors, pointed to the UK government's requirement for funders to demonstrate impact as an important driver of the increase of public research funders' focus on translation. This in turn was passed on to the research community through the introduction of the ResearchFish impact measures, the requirement for 'impact statements' as a component of proposals submitted to the MRC, and the inclusion of impact categories in ResearchFish reporting. Other drivers are considered to be the inclusion of individuals from non-academic backgrounds on proposal review panels, the emergence of 'TR success stories' from academia which could function as models, and enhanced general awareness of progress elsewhere, e.g. in the US TR ecosystem (Boston, US West Coast).

As a result:

- The culture of the academic research community has shifted, with many PIs now interested in conducting TR and open to collaboration with industry, and an increase in TR skills in the academic community. Academic researchers who want to engage in TR now have the opportunities to do so; commercialisation and entrepreneurship are no longer frowned upon or considered 'low grade science' (but barriers remain, see section 'Culture and incentives'). One interviewee also commented that a lot more interdisciplinary research is taking place now, e.g. medical researcher partnering with engineers or directly applying for engineering research grants.
- The boundary between industry and academia has become more 'porous', with better engagement from both sides and an enhanced understanding of the value each can bring to one another. Academics now also have a better understanding of the importance of factors associated with commercialisation such as IP compared to 10 years ago. Academia can access some of the industrial R&D infrastructure, which was not the case 10 years ago.
- As a result, the volume of 'translatable' research coming out of academia has increased. Representatives from TTOs as well as the investor community explained: The quality and quantity of translatable discoveries, and maturity of projects that investors see has improved tremendously over the last couple of years as a result of increased funding in the ecosystem along with an increase in sources of non-private financing (allowing innovations still too risky for private investment to be taken a bit further until it is taken on by Venture Capitals). Another investor said: "In principle, I would say that the quality and the state of projects that come out of renowned research institutions like the MRC or Max Planck or Helmholtz has certainly improved since I started in the industry 20 years back. […] The biggest change has been really since 2010.". Academic researchers are increasingly using the spin-out route to commercialisation, generally to develop a technology to the point where it becomes interesting for a third-party corporate entity.

- A number of UK universities have increased their capabilities to support commercialisation, such as TTOs and TROs (e.g. UCL, Imperial, Cambridge) – but others have not.
- A few interviewees from academic institutions felt that the increased emphasis on TR and impact had led to 'locking down of findings' through patents, hindering progress in discovery science by making it increasingly difficult to share information and collaborate. However, another described the academic researchers as "much more up now for just posting [their research] on a preprint server and letting other people see it, much less paranoid".

5.5 Fundamentals of translational research

An understanding of the skills, knowledge and infrastructure must be combined to successfully deliver translational research. Skills specific to translational research may require additional time and resources. Knowledge and expertise can be accessed through collaborations, networks and advisory functions. Physical infrastructure may take the form of research facilities and platforms. In addition to these requisites, incentives must be in place and properly balanced to motivate researchers and institutions to engage with translation. This section will explore these factors in further depth and outline fundamentals to translational research.

5.5.1 Collaboration

Successful translational research necessitates bringing many different skills together. As such collaboration is crucial. Collaboration facilitates pooling of knowledge, skills, tools and infrastructure across the translation chain. Barriers to collaboration may be physical, such as compartmentalisation within universities and research institutes, or they may be cultural, such as divergence of interests between basic and clinical scientists.

Particularly important aspects of collaboration are those within academia, and those between industry and academia. A growing use of academic collaboration is evidenced through an increasing average number of authors on each publication; the average number of authors per MEDLIINE/PubMed citation increased from 3–4 in the 1990's to 5–6 in 2010 (The Academy of Medical Sciences, 2016). There has also been an increased proportion of biomedical and clinical journals in which two or more co-authors claim first authorship and a greater number of international collaborations reported on biomedical publications.

Transdisciplinary research areas, such as digital biotechnology, inherently require collaboration to progress. For example, researchers proficient with biomedical or laboratory skills may need to collaborate with other researchers who have computational biology proficiency. Other reasons as to why collaboration is fundamental is that the value of larger projects that generate powerful datasets are being realised (The Academy of Medical Sciences, 2016). Larger studies, such as multi-centre randomised controlled trials that can be applied on population levels, require high levels of co-ordination and co-operation on a national or multi-national scale.

The UK Academy of Medical Sciences made the following 10 recommendations for effective collaboration:

1. All research outputs and grants should include open, transparent, standardised and structured contribution information.
2. The most effective way of providing contribution information will be an open and transparent research information infrastructure which links all research inputs and outputs to individual contributors.
3. Information infrastructure must minimise researchers' overall administrative burden and should be interoperable.

4. The use of ‘key’ positions on publications and grants as the primary indicator of research performance, leadership and independence in team science projects should be replaced by transparent, fair processes
5. Team science funding should provide the length, breadth and magnitude of support required by recognising the longer timescales often needed to achieve outputs and additional costs associated with effective team working.
6. Team science grant proposals need to be appraised holistically, as well as from the perspective of the relevant disciplines
7. The value of project leadership should be evaluated when appraising team science grant proposals.
8. Researchers should drive change through their crucial roles as team members, peer reviewers and participants on recruitment, promotion and funding panels.
9. Focused and appropriate training in team skills should be provided.
10. Clear career paths and development opportunities should be provided for researchers outside of the ‘PI track’ who play key roles in (and provide key competencies to) team science, such as skills specialists.

Collaborations between industry and academia may take a variety of different forms. Historically, companies have collaborated with entire universities or institutions, however, there has been a shift towards more targeted project-based collaborations. The latter form of collaboration is favoured as it is easier to identify common goals and intended outcomes. A common problem with industry-academia collaboration is a disparity between researchers' views of what an industry partner actually requires. For example, data produced in academic labs often falls short of what industry standards require for pre-clinical validation (Fishburn, 2014). A way to overcome this is to create working groups with industry and researcher representatives.

Some pharmaceutical companies have enabled this form of collaboration through the establishment of their own innovation centres. Pfizer’s Centre for Therapeutic Innovation (CTI)[62] was established in 2010 and focuses on Oncology, Inflammation & Immunology, Rare Diseases, and Internal Medicine. CTI assesses promising academic research internally and works with academic investigators to provide hands-on support via company experts and also its life-sciences network. The provided support helps academic research to overcome early stage translation problems. Crucially, the Centre overcomes traditional problems of collaborative advantages favouring academia (usually in the form of capital provision). The “Participation Agreement” model that CTI runs has resulted in 16 jointly filed patent families, where intellectual property rights are shared. A number of challenges have been identified, however. These include coordinating aligning industry timelines in drug development to academic ones, and legal issues in setting up contracts between partners (Yildirim et al., 2016 and references within).

In addition to the broad and more focused industry academic collaborations is the open innovation model. Open innovation combines internal (e.g. within a company) and external (e.g. a research body outside of the company) ideas to advance innovation and new technologies. These models increase the likelihood of resolution of a problem incentivising a wide research network to dedicate resources towards it. InnoCentive,[63] created by Eli Lilly, was the first example of open innovation in the biopharmaceutical industry. InnoCentive is a web-

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[62] https://www.pfizercti.com/

[63] https://www.innocentive.com/

based platform that functions as a global innovation marketplace where financial rewards are offered for solutions to problems posed on the platform. For example, InnoCentive is currently offering $2,500 for a piece of research into the most useful solutions or services people are offering in support of those impacted by COVID-19. Open innovation is advantageous in that it avoids lengthy negotiations and provides clear ownership of information produced.

The Open Discovery Innovation Network (ODIN),[64] located in Denmark, is an example of open innovation being piloted in a European setting. The network currently comprises of researchers from Aarhus University and industry partners from Novo Nordisk A/S, Leo Pharma A/S, H. Lundbeck A/S, Boehringer Ingelheim and Nordic Bioscience. It is an 'open' network and as such, is open to other companies and researchers. All participants can offer solutions to projects in collaboration with other participants. The Novo Nordisk Foundation will cover funding over three years for any participation by Aarhus University researchers. News of the pilot was only released in 2020, so no evaluation of its success has yet been undertaken.

5.5.2 Skills and education

There remains a scarcity of professionals with specific training to facilitate successful translational research (Petrelli et al., 2016). Basic science in undergraduate education may often not be taught with the context of how it may be applied in a broader sense. This is important in biomedical subjects in order to understand research in the context of human health and disease and appreciate unmet clinical needs or the clinical context in which potential interventions would operate (Hobin et al., 2012). It has been suggested that in terms of translation, basic science courses in the life sciences would benefit from education in biostatistics, bioinformatics, clinical research design and regulatory processes. A multi-disciplinary education with these elements helps to breakdown the traditional atomised approach that also inhibits collaboration.

Translation Together[65] is a collaboration of leading translational research organisations that facilitate translation of biomedical research. The organisation has defined seven characteristics of a successful translational research scientist that suggest useful skills. These broad skills should be implemented in the education of a successful translational workforce.

1. **Boundary crosser:** Breaks down disciplinary silos and collaborates with others across research areas and professions to collectively advance the development of a medical intervention
2. **Domain Expert**: Possesses deep disciplinary knowledge and expertise within one or more of the domains of the translational science spectrum ranging from basic to clinical to public health research and domains in between
3. **Team Player:** Practices a team science approach by leveraging the strengths and expertise and valuing the contributions of all players on the translational science team
4. **Process Innovator:** Seeks to better understand the scientific and operational principles underlying the translational process, and innovates to overcome bottlenecks and accelerate that process

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[64] https://novonordiskfonden.dk/en/news/aarhus-university-and-the-pharmaceutical-industry-join-forces-on-open-innovation-a-pathway-to-new-medicines/

[65] http://www.translationtogether.org/

5. **Skilled Communicator:** Communicates clearly with all stakeholders in the translational process across diverse social, cultural, economic and scientific backgrounds, including patients and community members
6. **Systems Thinker:** Evaluates the complex external forces, interactions, and relationships impacting the development of medical interventions, including patient needs and preferences, regulatory requirements, current standards of care, and market and business demands
7. **Rigorous Researcher:** Conducts research at the highest levels of rigor and transparency within their field of expertise, possesses strong statistical analysis skills, and designs research projects to maximize reproducibility

Studies on the impact of skills and education on translational research are scarce although there have been some efforts. An analysis of The National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT), which supports students in STEM disciplines that participate in multidisciplinary training, suggested that participation in the traineeship led to greater likelihood of choice of a multidisciplinary dissertation topic. IGERT graduates were also more likely than non-IGERT graduates to be "integrating multiple disciplines" as part of their current work (84 percent vs. 73 percent), more likely to be teaching courses requiring them to integrate two or more disciplines (63 percent vs. 50 percent), and had a higher probability of working and networking with scientists or technologists in other disciplines (92 percent vs. 84 percent).

Another study set out to assess how involvement in multidisciplinary translational teams (MTT) promotes translational career development (Ameredes et al., 2015). In the study results from a survey of scholars suggested that membership in an MTT was associated with increased confidence in skills such as study design, research implementation and statistical analysis.

5.5.3 *Infrastructure and institutional support*

In the biomedical sciences, complete translational research institutions should be able to address three core areas: preclinical development, clinical development, and business development and licensing (Grunseth et al., 2014). These were the conclusions of survey of 20 US research institutions. The authors set out a minimum set of capabilities that an institution should have to be able to cover the three core areas (as shown in bold in Table 12). In addition to the minimum set of capabilities (considered to be Level 1) that translational institutions should have, the authors set out two further levels of increasing capabilities. Level 2 should be what all translational research institutions should aim for in terms of available infrastructure. Modest additional investments give institutions at this level greater proficiency in project management personnel, centralised lead-optimisation facilities and gap-funding programmes. Of those surveyed, only 25 percent of institutions had all level 2 capabilities although many could attain this status by hiring project managers and regulatory affairs personnel. Level 3 institutions demonstrate the highest capabilities in translational research. They will have a robust business development team, multiple GMP (good manufacturing practice) facilities and large-animal and non-primate animal testing facilities. However, the additional investment that these facilities require mean that an annual budget in excess if USD 250 million is needed.

Table 12 Translational infrastructure by category

Preclinical development	**Clinical development resources**	**Business development and licensing**
High-throughput screening capabilities	On-campus GLP and **GMP facilities**	**IP and licensing personnel**

Preclinical development	**Clinical development resources**	**Business development and licensing**
In silico and/or bioinformatics modelling capabilities	**Quality assurance** and quality control expert teams	Contract negotiation team
Structure-activity relationship research group	**Regulatory affairs personnel** to prepare and advance IND applications	Continuity of basic researchers, clinicians, regulatory affairs personnel, and GLP and GMP facilities
In vitro validation capabilities	Hospital facilities and patient base to support **clinical trials**	Connections to other academic TTOs and/or academic institutions
Toxicology and early stage pharmacokinetic capabilities	Broad clinical expertise	Connections to big pharma, biotech, start-ups and incubators
Small-animal, large-animal and non-primate facilities		Access to gap funding

In bold: Minimum set of capabilities for translational research institutions

Source: adapted from (Grunseth et al., 2014)

The process of commercialisation can be highly challenging for those who are unfamiliar with it. After the establishment of intellectual property commercialisation can be pursued independently through a new start-up, or through a licensing agreement with an existing company. Both of these routes offer their own challenges. For example, setting up a start-up requires personnel that not only have the requisite skills for translation, but can work effectively as a team also. Negotiating licensing agreements may often present legal hurdles in balancing the interests of researchers, the academic institution and company. Such problems underline the importance of TTOs that can assist those wanting to commercialise and overcome business and regulatory hurdles.

TTOs have become essential infrastructure to manage collaborations, contracts, intellectual property and spin-out activities. Although TTOs have undoubted benefits in aiding translational research, how they should sit with respect to other stakeholders varies. TTOs are often run as subsidiaries wholly owned by universities. The benefits of running a TTO as a separate company are that other businesses, such as potential licensing partners, may perceive a company to be more competent with commercialisation than would be the case for in-house university teams.[66] For similar reasons, researchers may also prefer to trust a company in helping them to commercialise. Operating a TTO as a separate company provides academic institutions with legal 'firewalls' that can mitigate risks. Governing members of subsidiary TTOs should report regularly to university boards to ensure alignment of goals.

Stanford University is among the top performers in Reuter's list of the world's most innovative universities. A large factor in this is the success of the Stanford University Office of Technology Licensing (OTL), which operates as a wholly owned limited liability corporation. In the financial year of 2019 Stanford University received USD 49.3 million in gross royalty revenue across 875 different technologies (Stanford OTL, 2019). The range of royalties received for technologies was between USD 10 and USD 16.5 million; 49 technologies generated royalties of USD 100,000 or more whilst only five generated more than USD 1 million. Stanford OTL distributes 85 percent of royalties to inventors, their departments and their schools, with the remaining 15 percent

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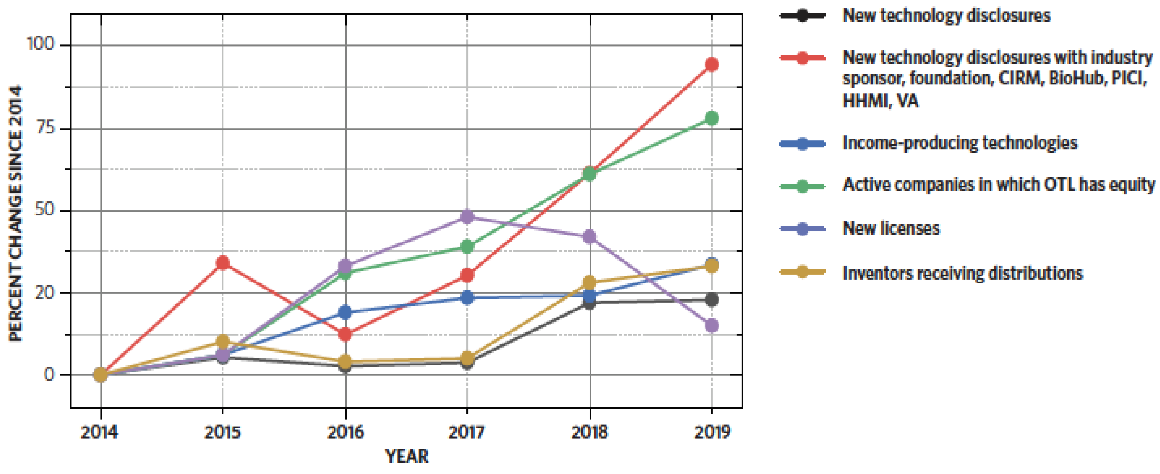
[66] http://www.technologytransferinnovation.com/tto-structure.html

being used for OTL administrative expenses. In an acknowledgement to the importance of navigating legal and regulatory hurdles, a total of USD 13.7 million was spent on legal expenses, although 58 percent of this was reimbursed by licensees or royalty payments. In order to add protection to the Stanford University name and associated logos, The Stanford Trademark Enforcement Fund (STEF) has been set up. Policy requires that 6 percent of royalties paid to the department and school are used to fund STEF. The technology trends that Stanford OTL has experienced over the past five years are shown in Figure 20.

Figure 20 Stanford OTL technology trends



Source: (Stanford OTL, 2019)

5.5.4 Incentives

Promotion within academia relies on traditional incentives, such as publications, grants and presenting at conferences. Use of these metrics to determine career progression may inhibit engagement in translational research. This is because translational researchers may be part of large team where it is difficult to demonstrate in what capacity they took part in the research. Furthermore, it may take longer to produce translated output than basic science research and investigators may be working outside of their normal discipline (Homer-Vanniasinkam & Tsui, 2012).

Incentives are needed to shift the paradigm so that translational research is something researchers aspire to be associated with, rather than it being considered as a potential barrier to career progression. Annual innovation awards may help to incentivise translational research and create a culture where the field is celebrated. Specialist funding for translational research may also help to relive anxieties that engagement in translational research comes at the expense of career progression due to traditional funding methods. Success in specialist finding has been demonstrated by the Koch Institute's The Bridge Project[67] (part of Massachusetts Institute of Technology). The project brings together bioengineering, advanced cancer science, and clinical oncology to solve problems in cancer research through seed funding. In

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[67] https://ki-bridge.mit.edu/

only eight years since the first interdisciplinary team received funding there have been seven new companies started, 72 joint publications and USD 39 million raised in joint philanthropic funds.

A study of biomedical researchers in the UK found that the reward system was geared towards individual and small-team scholarship (The Academy of Medical Sciences, 2016). This was not in keeping with an increase in collaborative team working. More specifically, researcher track records are often defined by the number of publications that they are first or last authors on, and how many times they have been a lead principal investigator on grants. These sorts of incentives provide positive feedback loops for those who are deemed successful in these metrics, whilst others are disincentivised to engage in teamwork as they are less likely to be rewarded. The results suggest that current incentive systems that reward grants may not be keeping pace with newer ways of working. Incentive systems that reward individual *contribution* to research are more rarely used.

Strategic planning may help to align the incentives for those involved in translational research. Planning can help to ensure that multiple actors collectively carry over new knowledge and technologies to development phases, even when the academic principal investigators responsible for these advances are not interested in this work. Project planning methods with specific needs of the translational research pathway in mind may help to encourage researchers to engage (Vignola-Gagné et al., 2013).

Whilst industry-based R&D consider commercial and regulatory processes at all times, this is not always the case in academia. Production of novel insights or discoveries is highly valued in academia; however, this may come at the expense of considerations into scalability, reimbursement issues and reproducibility (Schwartz & Macomber, 2017). These issues can prove to inhibit industry interest in academia. However, these issues are not chosen to be ignored by academia, rather it may be that the incentive structure does not reward those who consider factors important for commercialisation.

6 Preliminary conclusions and next steps

6.1 Conclusions

Digital life sciences could realise more of the potential of IT, biotechnology and life sciences and support future sustainable economic growth. Capturing and analysing large datasets about biological system requires the development of new knowledge and tools. The academic sector has an important role to play in providing ideas, proofs of concept and prototypes that industry can progress to the next level. This requires an ecosystem approach where public and private actors (as well as society) are connected across disciplines, organisational boundaries within and beyond Norway.

The innovation literature in general, and particular studies of the parts of the Norwegian innovation system relevant to DLN, provide both overall principles important to success and specific information about strengths and weaknesses of the Norwegian situation. A key idea is the interdependence of the supply and demand sides in connecting scientific and technological opportunities to the innovation process, generating economic and social benefits. Innovation is a social process of co-production, so it is not enough to consider actors and actions on their own; the context with which they interact is an important enabler of – or sometimes a barrier to – innovation. These interactions can be consciously managed.

Norwegian research in fields relevant to DLN is strong, even if – like Norwegian research more generally – little of it is at the highest level of global excellence. (That would be a lot to ask of a very small country.) Our analysis points to a significant mis-match between the capabilities and thematic foci of the university sector, on the one hand, and the business sector on the other. Where there is industry relevant to DLN in Norway, its ability to do R&D in Norway and its absorptive capacity are limited. That leaves DLN with the difficult task of addressing a demand side that may not be very clear about its knowledge needs and that has a limited ability to exploit new, research-based knowledge. It drives a need to help give birth to some of the 'unborn industry' that has been discussed in Norwegian policy in recent years. But that is something that depends a lot on the context rather than being something DLN has the capabilities or resources to do.

Fortunately, the Norwegian state support organisations and instruments for supporting research and innovation are strong. The SkatteFUNN scheme is particularly supportive of small and start-up companies. The missing ingredient in the policy mix seems to be a dedicated commercialisation or translational research scheme aimed at the university sector. Outside the state system, there are quite a number of clusters and potential innovation ecosystems relevant to DLN, though the literature we were able to review suggests that the universities – and especially UiO – are poorly connected to it.

Norway's TTO system has been much analysed in the last five years and generally found to be wanting. It works on the early (1980s/1990s) TTO model that focuses on patenting and then generating income through licensing – and to some degree through spin-offs. The Norwegian model of organising the TTOs as companies separate from their parent universities leads to short-termism. This model typically does well in biotechnology and pharmaceuticals but is not so appropriate to other, less science-based industries. The modern conception of the TTO function integrates it with the university's wider pattern of knowledge exchange. It also requires a greater shift towards innovation culture in the universities than has taken place so far in Norway.

Although it spends most of its budget on research, DLN was intended from the start to drive innovation. However, its ambitions on the demand side and its expectations of how it can intervene effectively there are insufficiently developed and specified.

DLN has launched a significant amount of research and networking activity but its organisation and governance mean that it is difficult to assemble the integrated research portfolio originally envisaged or to link its research and networking activities. Research funding decisions are made based on high-level quality and relevance criteria that do not allow portfolio-building but appear substantially to reflect the research interests of the major university participants, not all of which are well connected to innovation. As a result of this and the paucity of systematic information about needs on the demand side, DLN has something of a 'science push' character, rather than achieving the coupling between demand and supply that characterises much successful innovation.

Our interviews support the conclusions we drew from the literature: that the TTO function needs to be reformed (though without losing its ability to handle biotechnology and pharmaceuticals, which are central to the DLN mission); that more needs to be done to connect the universities with innovation ecosystems and to help those ecosystems to develop further; and that there is a need to address the 'valley of death', both in seed-corn funding and in translational and commercialisation research.

6.2 Next steps

This AS IS report has served to explore the current scientific and innovation situation for digital life in Norway and to provide a firm basis for the next steps of the DLN innovation project toward developing a roadmap for academic research-intensive innovation.

This diagnostic picture has identified gaps in the current innovation support system in Norway relevant for converging technologies. These identified challenges now need to be validated with the Steering Committee of the project and other key stakeholders in Norway.

The next phase of the project aims to explore the 'desired future situation' to achieve the full potential of DLN and to build a vibrant and interconnected digital life ecosystem in Norway. This requires an analysis of international good practices in various contexts to understand how they have dealt with the challenges that currently exist in Norway and what were the key success factors. This will help us to develop a 'toolbox' of possible actions that may be combined into a functioning innovation support system in Norway.

These feasibility of the suggested solutions will rely on key actors in the Norwegian innovation systems and therefore at this stage we will engage very closely with the Anchoring Group before we continue with the development of a roadmap and associated actions.

In practice, we will first review the examples of relevant international research and innovation environments and create a longlist of these, based on our earlier desk research and interview programme. We will expand and organise the information as one-page fiches that sets out the basic facts (geography, theme, funding, stakeholders) as well as key success metrics and enabling factors of innovations if relevant evaluations are available. The prioritisation and selection of the shortlist of environments to be explored will be conducted in close collaboration with the Steering Committee and the secretariat function.

One point of note is related to the changed international context to travel, perform site visits and conduct face-to-face meetings due to the COVID-19 pandemic. Some of the four visits planned in Europe may be possible in the coming months but overseas travel could be restricted for some time. This would most likely necessitate adapting our approach and organise virtual meetings with key informants, and in any case definitely cause delays. We have experience in facilitating virtual workshops and provide a suitable interactive platform with breakout rooms and electronic whiteboards to take notes. But it should be underlined that our recent experience of doing 'virtual site visits' (in other projects) has led us to the conclusion that while this is essentially possible, it does not provide the same in-depth insight and understanding – the same feel for the environment – as physical site visits do. And in this project, the feel for what it is in the environment that leads to successful translation, is very important. We therefore hope that physical visits will be possible in the autumn. The engagement of key personnel at the various innovation environments will be crucial and we will use our networks as best serves the project to support this effort.

The workshop structure and key lines of enquiry (as interview guides) will be developed based on our understanding of the current situation in Norway; where are the weaknesses and how others dealt with such challenges? The discussions of the (possibly/partly virtual) workshops will be recorded, analysed and reported on.

The next step in the process, TO BE, is akin to a foresight exercise where we will build a scenario (or scenarios) for Norway based on statements collected in the site visits. This scenario will provide a narrative for the future state with key dimensions and parameters highlighted in a SWOT-type analysis. This will then be discussed with the Steering Committee to select a realistic scenario with specific goals that can be anchored with other key stakeholders of digital life in Norway.

A gap analysis will follow where we identify the strategic actions necessary (and inherent structural limitations) to move from the current state to one where academic innovation culture is embedded and innovation potential of research is exploited for the benefit of society and economy.

7 Bibliography

Accenture Consulting. (2017). Patients want a heavy dose of digital. https://www.accenture.com/_acnmedia/PDF-8/Accenture-Patients-Want-A-Heavy-Dose-of-Digital-Infographic-v2.pdf

Accenture Consulting. (2019). *Digital Health Consumer Survey Norway*.

Ambrosino, L., Tangherlini, M., Colantuono, C., Esposito, A., Sangiovanni, M., Miralto, M., Sansone, C., & Chiusano, M. L. (2019). Bioinformatics for marine products: An overview of resources, bottlenecks, and perspectives. *Marine Drugs*, *17*(10). https://doi.org/10.3390/md17100576

Ameredes, B. T., Hellmich, M. R., Cestone, C. M., Wooten, K. C., Ottenbacher, K. J., Chonmaitree, T., Anderson, K. E., & Brasier, A. R. (2015). The Multidisciplinary Translational Team (MTT) Model for Training and Development of Translational Research Investigators. *Clinical and Translational Science*, *8*(5), 533–541. https://doi.org/10.1111/cts.12281

Angelis J, Swenning A, Håkansson A. (2017). *Evaluation of the RCN's BIOTEK2021 programme,* Final report. Technopolis Group.

Arnold, E. et al., 2019. *Raising the Ambition Level in Norwegian Innovation Policy,* Oslo: Research Council of Norway.

Arnold, E. et al., 2012. *Knowledge Transfer From Public Research Organisations,* Brussels: STOA, European Parliament.

Arnold, E., Kuhlmann, S. & van der Meulen, B., 2001. A Singular Council: Evaluation of the Research Council of Norway, Oslo: Royal Norwegian Ministry of Education, Research and Church Affairs.

Arnold, E. & Mahieu, B., 2012. A Good Council? Evaluation of the Research Council of Norway, Oslo: Ministry of Research and Higher Education.

Beard, T. R., Ford, G. S., Koutsky, T. M. & Spiwak, L. J., 2009. A Valley of Death in the innovation sequence: an economic investigation. Research Evaluation, 18(5), p. 343–356.

Bes-Rastrollo, M., Schulze, M. B., Ruiz-Canela, M., & Martinez-Gonzalez, M. A. (2013). Financial Conflicts of Interest and Reporting Bias Regarding the Association between Sugar-Sweetened Beverages and Weight Gain: A Systematic Review of Systematic Reviews. *PLoS Medicine*, *10*(12), e1001578.

BioVerdi. (2014). *BioVerdi - Slik kan bioøkonomien bli den nye oljen*.

Boekholt, P. et al., 1995. *Quick Scan Public Policies to support 'Hot Spots' in Europe,* Amsterdam: Technopolis BV.Brandt, A. M. (2012). Inventing Conflicts of Interest: A History of Tobacco Industry Tactics. *Am J Public Health*, *102*(1), 63–71.

Burgwinkel, D., & Bergstroem, R. (2018). Blockchain in Digital Health and Life Sciences. *Eurohealth*, *24*(3), 11–13.

Bush, V., 1945. *Science, the Endless Frontier: A Report to the President on a Program for Postwar Scientific Research,* Washington DC: NSF

Buvailo, A. (2018). *Pharma R&D Outsourcing Is On The Rise*. BiopharmaTrend.Com. https://www.biopharmatrend.com/post/30-pharma-rd-outsourcing-is-on-the-rise/

Chunming, X., & Jackson, S. (2019). Machine learning and complex biological data. *Genome Biology*, *20*, 76.

Cohen, W. M. & Levinthal, D. A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly , 35(1), pp. 128-152.

Cook, C. E., Lopez, R., Oana Stroe, Cochrane, G., Brooksbank, C., Birney, E., & Apweiler, R. (2019). The European Bioinformatics Institute in 2018: tools, infrastructure and training. *Nucleic Acids Research*, *47*, D15–D22.

Cousin, M. A., Greenberg, A. J., Koep, T. H., Angius, D., Yaszemski, M. J., Spinner, R. J., & Windebank, A. J. (2016). The Value of Systematic Reviews in Estimating the Cost and Barriers to Translation in Tissue Engineering. *Tissue Engineering Part B: Reviews*, *22*(6), 430–437. https://doi.org/10.1089/ten.teb.2016.0060

CRISP. (2019). *CRISP Final Report*.

DAMVAD. (2018). *Evaluation of the Scheme for Research-based Innovation (SFI) Report for The Research Council of Norway. January.*

de Vrueh, R. L. A., & Crommelin, D. J. A. (2017). Reflections on the Future of Pharmaceutical Public-Private Partnerships: From Input to Impact. *Pharmaceutical Research*, *34*(10), 1985–1999. https://doi.org/10.1007/s11095-017-2192-5

Decker, S., Harman-Ware, A., Happs, R., Wolfrum, E., Tuskan, G., Kainer, D., Oguntimein, G., Rodriguez, M., Weighill, D., Jones, P., & Jacobson, D. (2018). High Throughput Screening Technologies in Biomass Characterization. *Front. Energy Res.*, *6*, 120.

Devol, R., & Lee, J. (2017). *Concept to Commercialization The Best Universities for Technology Transfer*. *April*, 52. https://assets1b.milkeninstitute.org/assets/Publication/ResearchReport/PDF/Concept2Commercialization-MR19-WEB.pdf

Dinh-Le, C., Chuang, R., Chokshi, S., & Mann, D. (2019). Wearable health technology and electronic health record integration: Scoping review and future directions. *Journal of Medical Internet Research*, *21*(9). https://doi.org/10.2196/12861

Driscoll, D., Farnia, S., Kefalas, P., & Maziarz, R. T. (2017). Concise Review: The High Cost of High Tech Medicine: Planning Ahead for Market Access. *Stem Cells Translational Medicine*, *6*(8), 1723–1729. https://doi.org/10.1002/sctm.16-0487

Edmunds, L. D., Gluderer, S., Ovseiko, P. V., Kamerling, R., Ton, J., Vis, L., Jenni, M., Tutton, G., Lawton-Smith, H., Nadabán, M. V., Rab, M., Rees, J., Anson, J., Rushforth, A. D., Allen, M., Buchan, A. M., Vendrell, M., Casta, A., Mehes, G., … Hassan, A. B. (2019). New indicators and indexes for benchmarking university-industry-government innovation in medical and life science clusters: Results from the European FP7 Regions of Knowledge HealthTIES project. *Health Research Policy and Systems*, *17*(1), 10. https://doi.org/10.1186/s12961-019-0414-5

Eichler, H. G., & Sweeney, F. (2018). The evolution of clinical trials: Can we address the challenges of the future? *Clinical Trials*, *15*(1_suppl), 27–32. https://doi.org/10.1177/1740774518755058

Engel, J. S. & del-Palacio, I., 2011. Global clusters of innovaytion: The case of Israel and Silicon Valley. California Management Review, 53(2), pp. 27-49.

Evans, A., & Ratcliffe, E. (2017). Rising influence of synthetic biology in regenerative medicine. Eng. Biol., 1(24–29).

Evjen, T. J., Dick, G., Skogli, E, Høiseth-Gilje K., Jakobsen K., Taskén K. (2017). Den digitale bioteknologien i Norge. Muligheter for verdiskaping, kompetansebehov og utfordringer i næringsutvikling. Senter for digitalt liv Norge, 2017

EY. (2017). Biotechnology Report 2017: Beyond borders - Staying the course. https://doi.org/10.5051/jpis.2010.40.1.1

fDiIntelligence. (2019). Biotech Locations of the Future 2019/20.

Fishburn, C. S. (2014). Translational balance. *Science-Business EXchange*, *Cic*, 1–2. https://doi.org/10.1038/scibx.2014.1395

Lisbeth I. Flateland, Erik W. Jakobsen, Rune G. Nellemann, Erland Skogli and Marcus G. Theie (2017). The value of the health industry. *Menon publication* no. 29/2017.

Flier, J. S., & Loscalzo, J. (2017). Categorizing biomedical research: The basics of translation. *FASEB Journal*, *31*(8), 3210–3215. https://doi.org/10.1096/fj.201700303R

Fort, D. G., Herr, T. M., Shaw, P. L., Gutzman, K. E., & Starren, J. B. (2017). Mapping the evolving definitions of translational research. *Journal of Clinical and Translational Science*, *1*(01), 60–66. https://doi.org/10.1017/cts.2016.10

Freedman, S., & Mullane, K. (2017). The academic–industrial complex: navigating the translational and cultural divide. *Drug Discovery Today*, *22*(7), 976–993. https://doi.org/10.1016/j.drudis.2017.03.005

Freeman, C., 1987. *Technology Policy and Economic Performance: Lessons from Japan.* London: Frances Pinter.

Fudge, N., Sadler, E., Fisher, H. R., Maher, J., Wolfe, C. D. A., & McKevitt, C. (2016). Optimising translational research opportunities: A systematic review and narrative synthesis of basic and clinician scientists' perspectives of factors which enable or hinder translational research. *PLoS ONE*, *11*(8), 1–23. https://doi.org/10.1371/journal.pone.0160475

Fuentes, L., Lebenkoff, S., White, K., Gerdts, C., Hopkins, K., Potter, J. E., Grossman, D., Project, P. E., & Sciences, R. (2016). *Putting Translational Science onto a Global Stage*. *93*(4), 292–297. https://doi.org/10.1016/j.contraception.2015.12.017.Women

Galkina Cleary, E., Beierlein, J. M., Khanuja, N. S., McNamee, L. M., & Ledley, F. D. (2018). Contribution of NIH funding to new drug approvals 2010–2016. *Proceedings of the National Academy of Sciences*, *0*, 201715368. https://doi.org/10.1073/pnas.1715368115

Gautam, A., & Pan, X. (2016). The changing model of big pharma: Impact of key trends. *Drug Discovery Today*, *21*(3), 379–384. https://doi.org/10.1016/j.drudis.2015.10.002

Gauthier, J., Vincent, A., Charette, S., & Derome, N. (2018). A brief history of bioinformatics. *Briefings in Bioinformatics*, 1–16.

Gendoo, D. M. A. (2020). Bioinformatics and computational approaches for analyzing patient-derived disease models in cancer research. *Computational and Structural Biotechnology Journal*, *18*, 375–380. https://doi.org/10.1016/j.csbj.2020.01.010

Glasgow, R. E., Vinson, C., Chambers, D., Khoury, M. J., Kaplan, R. M., & Hunter, C. (2012). National institutes of health approaches to dissemination and implementation science: Current and future directions. *American Journal of Public Health*, *102*(7), 1274–1281. https://doi.org/10.2105/AJPH.2012.300755

Good, M. (2019). *I . TECHNOLOGY TRANSFER SUPPORT AT UNIVERSITIES : AN ECOSYSTEM DESIGN APPROACH*.

Grunseth, M., Chen, C., Kelly, R., Cook, S. B., Megaw, G., & Couture, L. (2014). Surveying the best in translation. *Nature Biotechnology*, *32*(5), 415–418. https://doi.org/10.1038/nbt.2887

Hagel, J., Brown, J. S., Samoylova, T., & Lui, M. (2013). From exponential technologies to exponential innovation. *Deolitte University Press*. https://www2.deloitte.com/content/dam/Deloitte/es/Documents/sector-publico/Deloitte_ES_Sector-Publico_From-exponential-technologies-to-exponential-innovation.pdf%5Cnhttp://dupress.com/articles/from-exponential-technologies-to-exponential-innovation/?id=us

Hagen, J. (2000). The origins of bioinformatics. *Nature Reviews Genetics*, *1*, 231.

Hobin, J. A., Deschamps, A. M., Bockman, R., Cohen, S., Dechow, P., Eng, C., Galey, W., Morris, M., Prabhakar, S., Raj, U., Rubenstein, P., Smith, J. A., Stover, P., Sung, N., Talman, W., & Galbraith, R. (2012). Engaging basic scientists in translational research: identifying opportunities, overcoming obstacles. *Journal of Translational Medicine*, *10*(1), 72. https://doi.org/10.1186/1479-5876-10-72

Holbrook, J. B., & Hrotic, S. (2013). Blue skies, impacts, and peer review. *Roars Transactions*, *1*(1), 1–24. https://doi.org/10.13130/2282-5398/2914

Homer-Vanniasinkam, S., & Tsui, J. (2012). The continuing challenges of translational research: Clinician-scientists' perspective. *Cardiology Research and Practice*, *1*(1). https://doi.org/10.1155/2012/246710

Hughes, J., Rees, S., Kalindjian, S., & Philpott, K. (2011). Principles of early drug discovery. *Br J Pharmacol*, *162*(6), 1239–1249.

Hulsen, T., Jamuar, S. S., Moody, A. R., Karnes, J. H., Varga, O., Hedensted, S., Spreafico, R., Hafler, D. A., & McKinney, E. F. (2019). From big data to precision medicine. *Frontiers in Medicine*, *6*(MAR). https://doi.org/10.3389/fmed.2019.00034

Iman K Al-Azwani, H. (2016). Integration of Wearable Technologies into Patient's Electronic Medical Records. *Quality in Primary Care*.

Ipsos MORI and Technopolis Group. (2019). *MRC Translational Research 2008-2018*.

IRIS Group. (2017). *A comparative analysis of seven world leading biotech clusters (English Summary)*. *June*. www.irisgroup.dk.

Izmailova, E. S., Wagner, J. A., & Perakslis, E. D. (2018). Wearable Devices in Clinical Trials: Hype and Hypothesis. *Clinical Pharmacology and Therapeutics*, *104*(1), 42–52. https://doi.org/10.1002/cpt.966

Kaloudis, A., Aspelund, A., Koch, P. M., Lauvås, T. A., Mathisen, M. T., Strand, Ø., Sørheim, R., & Aadland, T. (2019). *How Universities Contribute to Innovation : A Literature Review-based Analysis*.

Karr, J., Sanghvi, J., Macklin, D., Gutschow, M., Jacobs, J., Bolival, B. J., Assad-Garcia, N., Glass, J., & Covert, M. (2012). A whole-cell computational model predicts phenotype from genotype. *Cell*, *150*, 389–401.

Khanna, I. (2012). Drug discovery in pharmaceutical industry: Productivity challenges and trends. *Drug Discovery Today*, *17*(19–20), 1088–1102. https://doi.org/10.1016/j.drudis.2012.05.007

Kotarba, J. A., Wooten, K., Freeman, J., & Brasier, A. R. (2013). The Culture of Translational Science Research: Participants' Stories. *International Review of Qualitative Research : IRQR*, *6*(1), 127–142. https://doi.org/10.1525/irqr.2013.6.1.127

Kunnskapsdepartementet. (2011). *Nasjonal strategi for bioteknologi (Strategi 2011-2020)*.

Laney, D. (2001). *3D data management: controlling data volume, velocity and variety*. Gartner.

Larkin, A., & Hystad, P. (2017). Towards Personal Exposures: How Technology Is Changing Air Pollution and Health Research. *Curr Environ Health Rep*, *4*(4), 463–471.

Lee, C., Johnson, R., Wichterman-Kouznetsova, J., Guha, R., Ferrer, M., Tuzmen, P., Martin, S., Zhu, W., & DePamphilis, M. (2012). High-throughput screening for genes that prevent excess DNA replication in human cells and for molecules that inhibit them. *Methods*, *57*(2), 234–248.

Lekve, K., 2019. Adding value: From world leading research to profitable commercialization Findings from the site visits of seven universities and one research organization in Western Europe, Oslo: Simula.

Lichten, C. A., Ioppolo, B., D'Angelo, C., Simmons, R. K., & Morgan Jones, M. (2018). Citizen Science: Crowdsourcing for Research. *The Healthcare Improvement Studies Institute, University of Cambridge*.

Life, D. (2020). *Centre for Digital Life Norway (DLN) 1 . Relevance to the strategic effort Digital Life – Convergence for Innovation*.

LMI. (2019). *Tall og fakta 2019*.

Loftus, P. D., Elder, C. T., D'Ambrosio, T., & Langell, J. T. (2015). Addressing challenges of training a new generation of clinician-innovators through an interdisciplinary medical technology design program: Bench-to-Bedside. *Clinical and Translational Medicine*, *4*(1), 15. https://doi.org/10.1186/s40169-015-0056-3

Lokers, R., Knapen, R., Janssen, S., van Randen, Y., & Jansen, J. (2016). Analysis of Big Data technologies for use in agro-environmental science. *Environmental Modelling and Software*, *84*, 494–504. https://doi.org/10.1016/j.envsoft.2016.07.017

Lundvall, B. Å., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. London: Frances Pinter.

Margolis, R., Derr, L., Dunn, M., Huerta, M., Larkin, J., Sheehan, J., Guyer, M., & Green, E. D. (2014). The National Institutes of Health's big data to knowledge (BD2K) initiative: Capitalizing on biomedical big data. *Journal of the American Medical Informatics Association*, *21*(6), 957–958. https://doi.org/10.1136/amiajnl-2014-002974

Martin, H., Innovation, V., Fund, E. I., & As, A. (2018). *Innovasjon Norge arsrapport 2018*.

McKinsey & Company. (2019). *Biotech in Europe : A strong foundation for growth and innovation* (Issue August).

Ministry of Education and Research. (2018). *Long-term plan for research and higher education 2019-2028*.

Mol, M., & Singh, S. (2015). Computational Design of Biological Systems: From Systems to Synthetic Biology. In *Frontiers in Computational Chemistry, Vol. 1* (pp. 158–196).

Mowery, D. C. & Rosenberg, N., 1979. The Influence Of Market Demand Upon Innovation: A Critical Review Of Some Recent Empirical Studies. Research Policy, 8(2), pp. 102-153.

NEJM Catalyst. (2018). Healthcare Big Data and the Promise of Value-based Care. *NEJM Catalyst*, 1–8.

Nelson, M. R., Tipney, H., Painter, J. L., Shen, J., Nicoletti, P., Shen, Y., & Sanseau, P. (2015). The support of human genetic evidence for approved drug indications. *Nature Genetics*, *47*(8), 856–860.

Nelson, R. R., 1993. *National Innovation Systems.* New York: Oxford University Press.

Nelson, R. R. & Winter, S. G., 1982. An Evolutionary Theory of Economic Change. Cambridge, Mass and London: Belknap Press and Harvard University Press.

Norwegian Ministries. (2016). *Familiar resources – undreamt of possibilities*. https://www.regjeringen.no/contentassets/5b2dc02e8dd047adba138d7aa8b4dcc1/nfd_biookonomi_strategi_engelsk_uu.pdf

Norwegian Ministry of Education and Research. (2011). *National Strategy for Biotechnology*.

OECD/Eurostat. (2018). *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition*.

OECD. (2015). Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development. In *The Measurement of Scientific, Technological and Innovation Activities*. OECD Publishing.

OECD. (2017). *OECD Reviews of Innovation Policy: Norway*.

OECD. (2020). The Digitalisation of Science, Technology and Innovation. In *The Digitalisation of Science, Technology and Innovation*. https://doi.org/10.1787/bd16d851-en

Olafsen, T., Winther, U., Olsen, Y., & Skjermo, J. (2012). Value created from productive oceans in 2050. *The Royal Norwegian Society of Sciences and Letters*, 1–83.

Oliveira, A. L. (2019). *Biotechnology , Big Data and Arti fi cial Intelligence*. *1800613*, 1–6.

Pastorino, R., De Vito, C., Migliara, G., Glocker, K., Binenbaum, I., Ricciardi, W., & Boccia, S. (2019). Benefits and challenges of Big Data in healthcare: An overview of the European initiatives. *European Journal of Public Health*, *29*, 23–27. https://doi.org/10.1093/eurpub/ckz168

Perea-Moreno, M. A., Samerón-Manzano, E., & Perea-Moreno, A. J. (2019). Biomass as renewable energy: Worldwide research trends. *Sustainability (Switzerland)*, *11*(3). https://doi.org/10.3390/su11030863

Perez, M. V., Mahaffey, K. W., Hedlin, H., Rumsfeld, J. S., Garcia, A., Ferris, T., Balasubramanian, V., Russo, A. M., Rajmane, A., Cheung, L., Hung, G., Lee, J., Kowey, P., Talati, N., Nag, D., Gummidipundi, S. E., Beatty, A., Hills, M. T., Desai, S., … Turakhia, M. P. (2019). Large-scale assessment of a smartwatch to identify atrial fibrillation. *New England Journal of Medicine*, *381*(20), 1909–1917. https://doi.org/10.1056/NEJMoa1901183

Petrelli, A., Prakken, B. J., Rosenblum, N. D., Ali, S., Bonaventura, P., Duurland, C. L., Gohar, A., Gohar, F., Kondapuram, M., Maschmeyer, P., Mfarrej, B. G., Popp, D., Triffaux, E., van der Burgh, R., van Dijkhuizen, P., Leu, C., & Vastert, S. (2016). Developing translational medicine professionals: The Marie Skłodowska-Curie action model. *Journal of Translational Medicine*, *14*(1), 1–4. https://doi.org/10.1186/s12967-016-1088-1

Philp, J., & Winickoff, D. E. (2017). Clusters in Industrial Biotechnology and Bioeconomy: The Roles of the Public Sector. *Trends in Biotechnology*, *35*(8), 682–686. https://doi.org/10.1016/j.tibtech.2017.04.004

Planes-Satorra, S., & Paunov, C. (2019). The digital innovation policy landscape in 2019. *Technology and Industry Policy Papers*, *71*. https://www.oecd-ilibrary.org/docserver/6171f649-en.pdf?expires=1562081542&id=id&accname=guest&checksum=5F0980640A1A43B06C0F135CED8D1E59

Porter, M. (1998). *Clusters and the New Economics of Competition*. https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition

Porter, M. E., & Emmons, W. M. (2003). *Institutions for Collaboration: Overview*.

Rajan, A., Sullivan, R., Bakker, S., & van Harten, W. H. (2012). Critical appraisal of translational research models for suitability in performance assessment of cancer centers. *The Oncologist*, *17*(12), e48-57. https://doi.org/10.1634/theoncologist.2012-0216

RCN. (2019). *Midway evaluation of seven Centres for Research-based Innovation (SFI-II)*. http://www.forskningsradet.no/prognett-sfi/Midway_evaluation/1253954491796

Rigden, D., & Fernández, X. (2018). The 2018 Nucleic Acids Research database issue and the online molecular biology database collection. *Nucleic Acids Research*, *46*, D1–D7.

Ristevski, B., & Chen, M. (2018). Big Data Analytics in Medicine and Healthcare. *Journal of Integrative Bioinformatics*, *15*(3). https://doi.org/10.1515/jib-2017-0030

Roy, A. (2018). Early Probe and Drug Discovery in Academia: A Minireview. *High-Throughput*, *7*(1), 4. https://doi.org/10.3390/ht7010004

Rothwell, R. et al., 1974. SAPPHO updated – Project SAPPHO phase II. Volume 3, pp. 258-291.

Samfunnsøkonomisk analyse AS. (2017). *Evaluation of Norwegian Innovation Clusters*.

Sanchez-Pinto, L. N., Mosa, A. S. M., Fultz-Hollis, K., Tachinardi, U., Barnett, W. K., & Embi, P. J. (2017). The emerging role of the chief research informatics officer in academic health centers. *Applied Clinical Informatics*, *8*(3), 845–853. https://doi.org/10.4338/ACI-2017-04-RA-0062

Sarpebakken, B., & Ubisch, S. S. (2011). *Ressursinnsatsen til marin FoU og havbruksforskning i 2015*. https://doi.org/978-82-327-0256-5

Saxenian, A., 1994. Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Cambrudge, Mass.: Harvard University Press.

Schneider, F., Buser, T., Keller, R., Tribaldos, T., & Rist, S. (2019). Research funding programmes aiming for societal transformations: Ten key stages. *Science and Public Policy*, *46*(3), 463–478. https://doi.org/10.1093/scipol/scy074

Schuhmacher, A., Gassmann, O., & Hinder, M. (2016). Changing R&D models in research-based pharmaceutical companies. *Journal of Translational Medicine*, *14*(1), 1–11. https://doi.org/10.1186/s12967-016-0838-4

Schuhmacher, A., Gassmann, O., McCracken, N., & Hinder, M. (2018). Open innovation and external sources of innovation. An opportunity to fuel the R&D pipeline and enhance decision making? *Journal of Translational Medicine*, *16*(1), 1–14. https://doi.org/10.1186/s12967-018-1499-2

Schwartz, J., & Macomber, C. (2017). So, You Think You Have an Idea: A Practical Risk Reduction-Conceptual Model for Academic Translational Research. *Bioengineering*, *4*(2), 29. https://doi.org/10.3390/bioengineering4020029

Schwarze, K., Buchanan, J., Taylor, J. C., & Wordsworth, S. (2018). Are whole-exome and whole-genome sequencing approaches cost-effective? A systematic review of the literature. *Genetics in Medicine*, *20*(10), 1122–1130. https://doi.org/10.1038/gim.2017.247

Shimshoni, D., 1970. The mobile scientist in the American instrument industry. *Minerva,* Volume 8, pp. 59-89.

Spilling, O. R., Borlaug, S. B., Iversen, E., Rasmussen, E., & Solberg, E. (2015). *Virkemiddelapparatet for kommersialisering av forskning - status og utfordringer. Sluttrapport fra evalueringen av virkemiddelapparatet for kommersialisering av offentlig finansiert forskning*.

Spolaor, S., Gribaudo, M., Iacono, M., Kadavy, T., Komínková Oplatková, Z., Mauri, G., Pllana, S., Senkerik, R., Stojanovic, N., Turunen, E., Viktorin, A., Vitabile, S., Zamuda, A., & Nobile, M. S. (2019). Towards Human Cell Simulation. In J. Kołodziej & H. González-Vélez (Eds.), *High-Performance Modelling and Simulation for Big Data Applications: Selected Results of the COST Action IC1406 cHiPSet* (pp. 221–249). Springer International Publishing. https://doi.org/10.1007/978-3-030-16272-6_8

Sridharan, S., Priestman, W., & Sebire, N. J. (2018). Chief information officer team evolution in university hospitals: Interaction of the three 'C's (CIO, CCIO, CRIO). *Journal of Innovation in Health Informatics*, *25*(2), 88–91. https://doi.org/10.14236/jhi.v25i2.997

Staff, N. P., Runge, B. K., & Windebank, A. J. (2014). Breaking Down Translation Barriers: Investigator's Perspective. *Science*, *6*(252).

Stanford OTL. (2019). Stanford University Office of Technology Licensing - Opportunity. *Global Alliance Report*, *1*(1), 96. http://techfinder.stanford.edu/technologies/S11-476_fostrap-and-arctrap-mouse-strains

Surkis, A., Hogle, J. A., DiazGranados, D., Hunt, J. D., Mazmanian, P. E., Connors, E., Westaby, K., Whipple, E. C., Adamus, T., Mueller, M., & Aphinyanaphongs, Y. (2016). Classifying publications from the clinical and translational science award program along the translational research spectrum: A machine learning approach. *Journal of Translational Medicine*, *14*(1), 1–14. https://doi.org/10.1186/s12967-016-0992-8

Teie, M. G., Hvide, H., Spilling, O., & Borlaug, S. (2018). *Insentiver for kommersialisering av forskning*. 9.

The Academy of Medical Sciences. (2016). *Improving recognition of team science contributions in biomedical research careers*. *March*, 1–69. https://www.acmedsci.ac.uk/viewFile/56defebabba91.pdf

The European Institute for Biomedical Imaging Research (EIBIR). (2019). Strategic research agenda for biomedical imaging. *Insights into Imaging*, *10*(7).

The Research Council of Norway. (n.d.). *A Framework for Responsible Innovation - Under BIOTEK2021, IKTPLUSS, NANO2021 and SAMANSVAR: Version 1.0*.

The Royal Society. (2018). *Delivering novel therapies in the 21st century - conference presentation*.

Trochim, W., Kane, C., Graham, M. J., & Pincus, H. A. (2011). Evaluating translational research: A process marker model. *Clinical and Translational Science*, *4*(3), 153–162. https://doi.org/10.1111/j.1752-8062.2011.00291.x

UK Office for the Life Sciences. (2017). *Strength and Opportunity 2017: The landscape of the medical technology, medical biotechnology, industrial biotechnology and pharmaceutical sectors in UK*.

University of Oslo. (2017). *Mottakere Alle deltakere i arbeidsgruppene*. *april*.

van der Laan, A. L., & Boenink, M. (2015). Beyond Bench and Bedside: Disentangling the Concept of Translational Research. *Health Care Analysis*, *23*(1), 32–49. https://doi.org/10.1007/s10728-012-0236-x

Valkokari, K., 2015. Business, Innovation, and Knowledge Ecosystems: How They Differ and How to Survive and Thrive within Them. Tecvhnology Innovation Management Review, 5(8), pp. 17-24.

Vanderford, N. L., Weiss, L. T., & Weiss, H. L. (2013). A Survey of the Barriers Associated with Academic-based Cancer Research Commercialization. *PLoS ONE*, *8*(8). https://doi.org/10.1371/journal.pone.0072268

Vignola-Gagné, E., Rantanen, E., Lehner, D., & Hüsing, B. (2013). Translational research policies: Disruptions and continuities in biomedical innovation systems in Austria, Finland and Germany. *Journal of Community Genetics*, *4*(2), 189–201. https://doi.org/10.1007/s12687-012-0130-0

von Hippel, E., 1975. *The Dominant Role of Users in the Scientific Instrument Innovation Process,* Cambridge, Mass: MIT.

Vu, P., Vaskov, A., Irwin, Z., Henning, P., Lueders, D., Laidlaw, A., Davis, A., Nu, C., Gates, D., Gillespie, R., Kemp, S., Kung, T., Chestek, C., & Cederna, P. (2020). A regenerative peripheral nerve interface allows real-time control of an artificial hand in upper limb amputees. *Science Translational Medicine*, *12*(533), eaay2857. https://doi.org/10.1126/scitranslmed.aay2857

Weis, J., Bashyam, A., Ekchian, G. J., Paisner, K., & Vanderford, N. L. (2018). Evaluating disparities in the U.S. technology transfer ecosystem to improve bench to business translation [version 1; referees: 3 approved]. *F1000Research*, *7*(May), 1–18. https://doi.org/10.12688/f1000research.14210.1

Weiss, M., Jacob, F., & Duveillerc, G. (2020). Remote sensing for agricultural applications: A meta-review. *Remote Sensing of Environment*, *236*, 111402.

Yildirim, O., Gottwald, M., Schüler, P., & Michel, M. C. (2016). Opportunities and challenges for drug development: Public-private partnerships, adaptive designs and big data. *Frontiers in Pharmacology*, *7*(DEC), 1–13. https://doi.org/10.3389/fphar.2016.00461

Zekun, Y., Haidon, L., Guangming, T., Mian, L., Athanasios, V., & Weiguo, L. (2017). Computing Platforms for Big Biological Data Analytics: Perspectives and Challenges. Comput Struct Biotechnol J., 15, 403–411.

8 List of interviewees

Name	Organisation
Eli Aamot	SINTEF
Krishna Agarwal	UiT
Tone Bathen	NTNU
Ivar Bergland	UiO
Steinar Bergseth	RCN
Trygve Brautaset	DLN, NTNU
Morten Egeberg	UiO
Vincent Eijsink	NMBU
Reinold Ellingsen	NTNU
Mattijs Elschot	NTNU
Helga Ertesvåg	NTNU
Anne Kjersti Fahlvik	RCN
Liv Falkenberg	DLN, NTNU
Arnoldo Frigessi	DLN, UiO
Anders Goksøyr	UiB
Victor Greiff	UiO
Elisabeth Gulbrandsen	RCN
Margareth Hagen	UiB
Anders Haugland	VIS Innovation
Ira Hebold Haraldsen	OUS
Raffael Himmelsbach	DLN, NTNU
Ole Kristian Hjelstuen	Inven2
Øystein Johnsen	NMBU
Anders Lian	SINTEF TTO
Dirk Linke	UiO
Toril A. Nagelhus Hernes	NTNU
John Sigurd Mjøen Svedsen	UiT
Astrid Hilde Myrset	Self-employed consultant
Hilde Irene Nebb	UiO
Alexandra Patriksson	DLN, UiO
Jorun Pedersen	ARD Innovation

Kenneth Ruud	UiT
Øystein Rønning	RCN
Inger Sandlie	UiO
Per Morten Sandset	UiO
Renate Simonsen	RCN
Christian Skattum	OUS
Ragnhild Solheim	NMBU
Tonje S. Steigedal	NTNU TTO
Pål Vegar Storeheier	UiT
Jon Olav Vik	NMBU
Eirik Wasmuth Lundblad	Norinnova

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