Academy Programme on Synthetic Biology (FinSynBio)

Final Report

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ACADEMY OF FINLAND

Contents

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1 FinSynBio Academy Programme

The role of the Academy of Finland is to promote excellent, responsible and high-impact research as well as the practical utilisation of research in society. The Academy also produces high-quality science policy data and analyses with a view to enhancing the use of scientific knowledge in decisions about science policy. The Academy works in close consultation with other stakeholders in the Finnish research, education and innovation system.

The Academy Programme scheme is one of the instruments the Academy of Finland uses to achieve these goals. Academy Programmes are aimed at supporting scientific regeneration and increasing scientific and societal impact by providing funding for a collection of science-driven, thematic and target-oriented research projects. Academy Programmes support multi- and interdisciplinary research of the highest quality, promote networking between researchers and other stakeholders, and provide platforms for international research cooperation.

This report describes the background and execution of the Academy Programme on Synthetic Biology, FinSynBio, which was active in 2013–2019. It also presents an overview of the results and outputs produced from the research within the programme.

As a final step in the FinSynBio Academy Programme, a foresight workshop was organised in March 2019 by the Academy of Finland and VTT Technical Research Centre of Finland. The workshop presented a collective, future-oriented ending to the programme, bringing together many of the researchers funded by the programme for the last time. The aim of the foresight workshop was to gain insights into the possible futures of synthetic biology. What possibilities may synthetic biology offer in the future? Which research guidelines can be traced, what ethical issues might be faced, and how can we prepare ourselves for these changes?

The results of the foresight workshop may be used to assess the success of the programme, the attainment of desired objectives, the impact of the programme, and the future of synthetic biology, as well as the technical and ethical challenges. The results of the workshop are presented in Appendix 5.

This final report has been written by Programme Manager Sara Illman and the figures and tables compiled by Trainee Katja Kivikoski. For further information, please contact the Academy of Finland at academyprogrammes@aka.fi.

1.1. Background

Synthetic biology is a multidisciplinary research field integrating biosciences, physical and chemical as well as technical research fields with the aim of designing and building new biological components (e.g. biocatalysts and genetic circuits) and organising these into functional biological production systems. In 2011, when the FinSynBio programme was initiated, synthetic biology was a new research field rapidly increasing in international relevance and extent. World leaders in the field were found at the top universities in the US (MIT, UCSF, etc.) and at ETH in Switzerland. In Finland, the field was still underdeveloped, even though there was strong expertise in genetics, proteomics, metabolomics, systems biology and computer modelling. The vision was that combining the knowledge of these experts and simultaneously engaging in active cooperation with international leaders in synthetic biology would enable Finland to reach a strong position in the field.

Previous evaluations and foresights further pointed to the importance of launching a research programme on synthetic biology. In the evaluation report on the Systems Biology and Bioinformatics Research Programme (SYSBIO), run by the Academy of Finland in 2004–2007, the evaluation panel concluded that Finland had been particularly successful in disseminating systems biology thinking within the life science community and able to attract high-level computational and mathematical groups into life science application. However, despite this success, Finland had not yet achieved the critical mass required for long-term sustainability of systems biology. The panel emphasised the importance of sustained support for technical infrastructure and software platforms created within the programme as well as continuation of funding for systems biology and the training of young researchers in systems biology.

The European Science Foundation (ESF) conducted a Forward Look exercise on systems biology in 2004–2005, based on which the synthetic biology research programme EuroSYNBIO was launched. In the foresight exercise FinnSight 2015 carried out by the Academy of Finland and the Finnish Funding Agency for Technology and Innovation (Tekes), the panel mapping know-how in biosciences recommended seven focus areas for the future. Of these, four are directly linked to the theme of the FinSynBio programme: management and modelling of biological knowledge, development of bioproduction, new biotechnical production opportunities and drug development, and complete use of renewable natural resources.

1.2. Aims and objectives

The aims and objectives of the FinSynBio Academy Programme were formulated by a preparatory group and defined in the programme memorandum (Appendix 1). The aims of the programme were to:

- support high-level synthetic biology research in Finland

- promote cooperation among scientists and researchers based in Finland and working in different fields so as to facilitate the achievement of critical mass in the research community and international competitiveness in the synthetic biology field
- increase international collaboration to support the achievement of other programme objectives
- foster dialogue between the research community and the rest of society on sociocultural concerns and issues related to synthetic biology
- promote public understanding of synthetic biology research.

The programme attempted to answer such important questions as how biological components can be artificially constructed and how these building blocks can be reorganised to achieve specific biological functions. These questions could be approached through smaller, more carefully targeted projects, although each individual or consortium project must be able to demonstrate through the knowledge and competencies of its research team or through its active collaborations how it ties in with the field of synthetic biology research, that is, what it is that warrants the description of the project as a synthetic biology project.

The research programme was designed to cover three thematic areas, which were to be seen not as distinct and separate from one another, but rather as mutually complementary approaches. Projects were encouraged that addressed issues under more than one thematic area. In particular, the first two themes were closely interwoven with each other. The third theme was to be seen as providing an opportunity for the humanities and social sciences to play a crucial mediating role between natural sciences and engineering research, on the one hand, and medical research, on the other.

The programme's three thematic areas were listed in the programme memorandum as outlined below. The specific research areas indicated in each case were intended as examples only.

I. Modelling and simulation of biological reactions and systems

- Quantitative analysis and modelling of biological processes and process engineering aimed at creating new properties
- De novo process design
- Process optimisation

II. Synthetic biology: tools and production systems

- The manufacture of new synthetic genes and the creation of new genetic codes by means of unusual base pairs
- The development of new biosynthesis routes by combining natural and modified genes
- The development of new enzyme activities
- Self-assembling nanostructures, such as biological molecular engines and nanorobots
- Synthetic cell organelles and metabolic engineering of microbes by genotype editing
- Gene therapy vectors and new receptor-targeted drugs

III. Socio-cultural issues related to synthetic biology

- Science and technology research
- Ethical issues
- Intellectual property rights research

1.3. Application and review procedures

Four separate calls were arranged under the FinSynBio programme. In addition to the major programme call, the Academy of Finland participated in three international calls on themes related to the programme.

1.3.1. FinSynBio programme call 2012

The programme call itself, arranged by the Academy of Finland, was carried out as a two-stage call (Appendix 2). Applicants were invited to submit letters of intent in September 2012. The 43 submitted letters of intent were reviewed by the FinSynBio Steering Committee including five Academy of Finland research council members and three internationally esteemed experts.

The review of the letters of intent was based on two main items: (1) the research plan and (2) the competence of the applicant and the quality of the research environment (CV and list of publications). The key aspects to be considered in the review were:

- Relevance of the project to the synthetic biology research programme
- Scientific quality and innovativeness of the project
- Feasibility of the research plan
- Competence and expertise of the applicant(s)
- Research team and environment
- Significance of research collaborations and researcher mobility
- Added value of the research consortium (if relevant)
- Ethical aspects (if relevant).

The key issues in the review of the research plan were the scientific quality and innovativeness of the plan as well as the potential for breakthrough research. The relevance of the project to the programme was also considered an important criterion. The applicants were particularly asked to describe what made their project a synthetic biology approach.

According to the Steering Committee's rating, the FinSynBio Subcommittee selected 29 projects to be invited to submit full applications in February 2013. The full applications were reviewed by a panel with six international experts. The review was carried out according to the same criteria as stated for the initial round. Based on the review reports of the international panel, the Steering Committee decided to fund nine projects. The total amount of funding granted by the Academy of Finland was 7,851,573 euros (Table 1).

Table 1. Projects funded in the FinSynBio programme call 2013.

Principal Investigator	Org.	Project title	Consortium partners	Funding (€)
Aittokallio, Tero	UH	Synthetic controllability of biological networks through understanding and engineering their control elements	Petre, Ion Jones, Patrik Wennerberg, Krister	1,024,301
Aro, Eva-Mari	UT	Design and engineering of synthetic hybrid photo-electro organisms	Törmä, Päivi Jäntti, Jussi	1,066,134
Häyry, Matti	AU	Synthetic biology and ethics		482,408
Karp, Matti	TUT	Focused proteomic analysis of cell factories	Lamminmäki, Urpo Aho, Tommi	870,463
Knuuttila, Tarja	UH	Biological Knowledge through Modeling and Engineering: Epistemological and Social Aspects of Synthetic Biology		566,465
Linder, Markus	AU	Synthetic genetic circuits for programming the structure of materials	Ras, Robin Franssila, Sami	876,611
Poranen, Minna	UH	Prokaryotic virus as a tool for synthetic biology		702,665
Ruddock, Lloyd	UO	Gen2Co: 2nd generation E.coli protein cell factories		654,281
Vuorela, Pia	ÅAU	Fabricating bacterial biofilms via artificial nano(bio)components	Johnson, Mark Kulomaa, Markku Peltonen, Jouko Lindfelt, Mikael Varmanen, Pekka	1,608,245
Total funding by Academy of Finland				**7,851,573**

The chair of the panel included the following remarks in the memorandum on the panel's work:

"The panel felt that the focus and aim of the call was outstanding – allowing the fostering of synergies with other groups in parallel to the responsive mode. This allowed the writing of some imaginative and creative ideas. […] Panel members felt that the quality of proposals was very high – and comparable to the level found in their own countries. They felt that many of the proposals were innovative and to a similar level to applications they had reviewed in EU countries such as the UK, Germany, Austria and the Netherlands."

1.3.2. Funding cooperation with Indian Department of Biotechnology (DBT) 2013

In 2013, the Academy of Finland and the Indian Department of Biotechnology (DBT) agreed on funding cooperation to promote Indo-Finnish research cooperation within the FinSynBio programme and opened a joint international call as an extension of the national call opened in September 2012. The themes of this call could relate to any of the thematic areas of the FinSynBio programme. The Academy of Finland funded research teams in Finland, and DBT funded researchers in India.

In the joint call, funding could be applied for by individual research projects and by consortia composed of two or several research teams in Finland. Overlapping funding was not granted. The Finnish and Indian co-applicants developed one joint research plan. The applications were to include a statement on how the proposed collaboration was expected to bring added valued to both countries.

The eight applications submitted to the joint call were reviewed together with the applications of the programme call. Two applications were selected for funding (Table 2).

Table 2. Projects funded in joint call between Academy of Finland and Indian Department of Biotechnology (DBT)

Principal Investigator	Org.	Project title	Consortium partners	Funding (€)
Jäntti, Jussi	VTT	Control of in vivo polymerisation by synthetic biology approaches		407,931
Urtti, Arto	UH	Bio-active protein synthesis in vitro with cell free platform	Koivula, Anu	740,481
Total funding by Academy of Finland				**1,148,412**

1.3.3. ERASynBio – joint calls for transnational research projects

ERASynBio was a three-year programme funded under the European Commission ERA-NET scheme (contract number 291728) in the 7th Framework Programme. The objective of the ERA-NET scheme was to step up the cooperation and coordination of research and development activities carried out in EU Member States and Associated Countries.

ERASynBio brought together 16 funding and/or management organisations from 14 countries and two observer countries with important activities in the field of synthetic biology, aiming at coordinating national and regional funding programmes in synthetic biology (see www.era-learn.eu/network-information/networks/erasynbio).

A first joint call addressing "Building Synthetic Biology Capacity through Innovative Transnational Projects" was launched in 2013. Based on the scientific review of the proposals received, eight research consortia were selected for funding. The Academy of Finland funded one Finnish partner in one of these consortia (table 3).

Table 3. Projects funded in first joint ERASynBio call 2013.

Principal Investigator	Org.	Project title	Consortium partners	Funding (€)
Taipale, Jussi	UH	MirrorBio, Establishment of a fully synthetic, mirror-image biological system		387,494
Total funding by Academy of Finland				**387,494**

A second ERASynBio call was launched in 2014. The Academy of Finland had reserved funding to support successful researchers based in Finland, but none were among the consortia selected for funding.

A third ERASynBio call was launched in 2015 together with the ERA-NET Marine Biotechnology (ERA-MBT) network. This was the 7th and last transnational joint call for multilateral research projects using industrial biotechnology (IB). Based on the scientific review of the proposals received, nine research consortia were selected for funding. The Academy of Finland funded three Finnish partners in these consortia (Table 4). As the funding for these projects is still operative, these projects have not been included in the further analysis of the programme.

Table 4. Projects funded in third joint ERASynBio call 2015.

Principal Investigator	Org.	Project title	Consortium partners	Funding (€)
Auvinen, Petri	UH	Development of novel industrial process for safe, sustainable, and higher quality food, using biotechnology and cybernetic approach		450,002
Richard, Peter	VTT Ltd	Engineering of the yeast Saccharomyces cerevisiae for bioconversion of pectin-containing agro-industrial side-streams		350,000
Uusitalo, Jaana	VTT Ltd	Novel BIOrefinery platform methodology for a driven production of CHEMicals from low-grade biomass		299,998
Total funding by Academy of Finland				**1,100,000**

1.4. Facts on the funded projects

Altogether twelve projects funded through three separate calls arranged within the FinSynBio programme are included in this report. Six of the projects were carried out by consortia with several investigators receiving funding, whereas six were projects carried out by one single principal investigator. In all, 27 researchers received funding through the programme. The researchers represented nine different research organisations (Fig. 1) and 22% were female. The division of the funding between the different organisations is shown in figure 2.

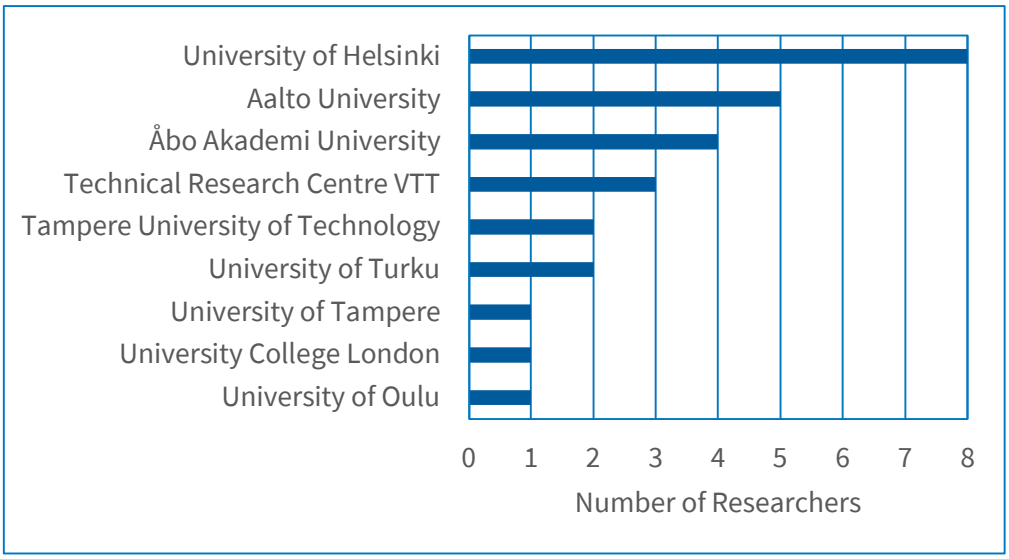

Figure 1. Organisations of researchers funded in the FinSynBio programme.

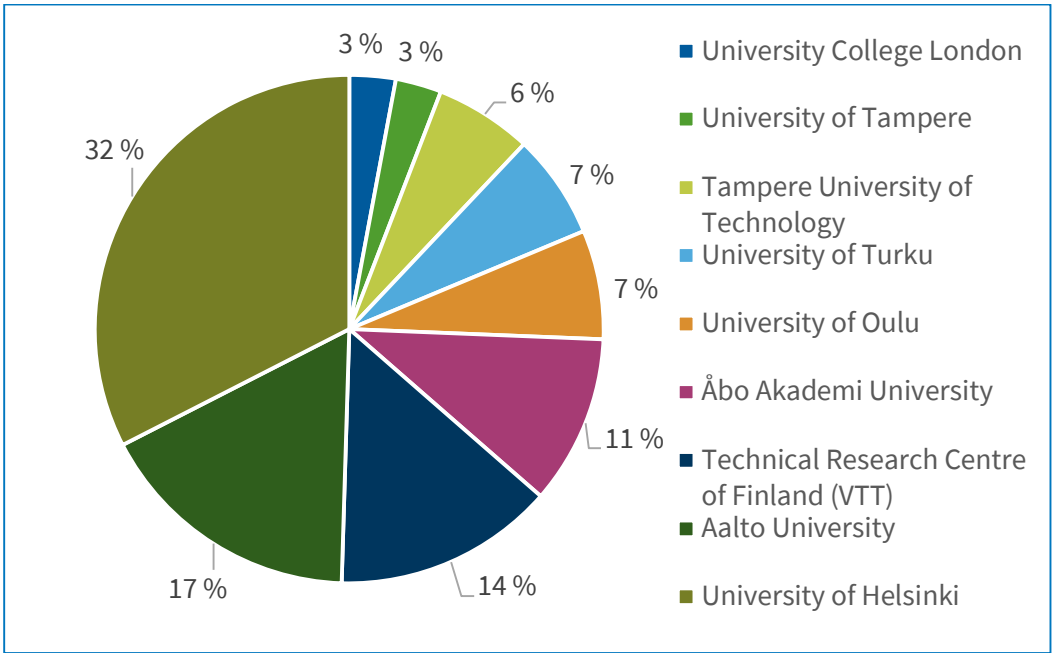

Figure 2. Division of funding between research organisations in the FinSynBio programme.

The projects funded in the programme represented a number of different and diverse research fields, as demonstrated in Figure 3, where the size of each box reflects the number of times the research field is mentioned as a key field of research by one researcher funded in the FinSynBio programme.

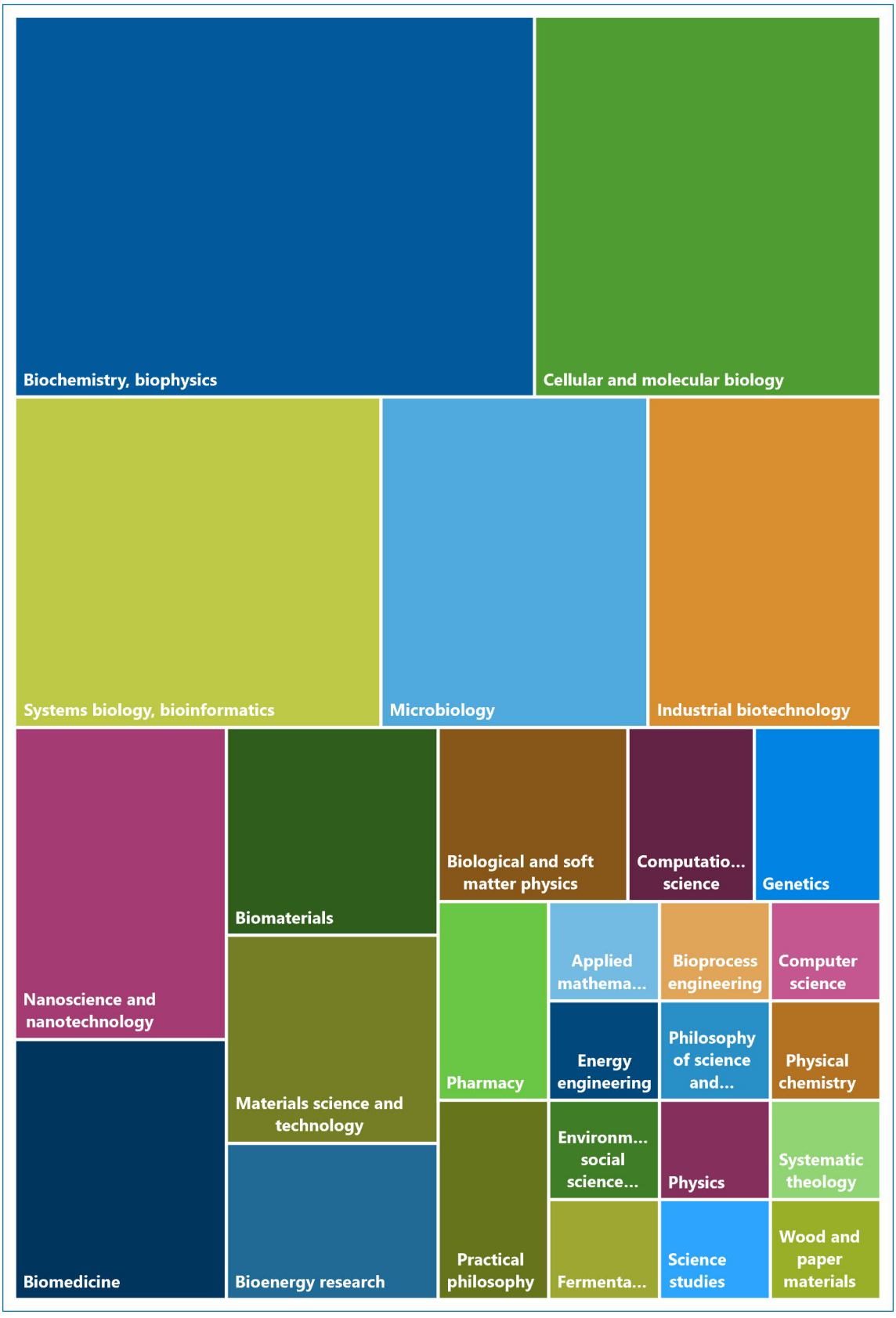

Figure 3. Research fields represented in the FinSynBio programme.

1.5. Steering Group

The research programme was run by a steering group composed of members of the Academy's research councils and other expert members (Table 5). A steering group may also include additional experts. The duties of the Steering Group were:

- to prepare the programme and submit to the programme sub-committee a proposal on projects to be funded
- to make a proposal to Academy research councils and other funding bodies on any new calls and/or additional funding
- to manage and monitor the programme
- to steer and support programme coordination
- to be responsible for the final evaluation of the programme
- to promote the application of the programme's results.

Table 5. Steering groups of the FinSynBio programme.
(RCBE = Research Council for Biosciences and Environment, RCNSE = Research Council for Natural Sciences and Engineering, RCH = Research Council for Health, RCCS = Research Council for Culture and Society)

Appointment	Members
2012	Professor Jaana Bamford, RCBE (Chair) Professor Heikki Tenhu, RCNSE (Vice Chair) Professor Liisa Laakso, RCCS Professor Reijo Lahti, RCBE Professor Johanna Myllyharju, RCH Professor Martin Warren, University of Kent, UK Professor Hanne Andersen, Aarhus University, DK Professor Vitor Martins dos Santos, Wageningen University, NL
2013–2016	Professor Kalervo Hiltunen RCBE (Chair) Professor Minna Kellomäki, RCNSE (Vice Chair) Professor Johanna Myllyharju, RCH Professor Matti Sintonen, RCCS Professor Heikki Tenhu, RCNSE
2016–2018	Research professor Kristiina Kruus, RCBE (Chair) Professor Päivi Ojala, RCH (Vice Chair) Professor Leena Paavilainen, RCNSE Professor Sami Pihlström, RCCS Professor Matti Sintonen, University of Helsinki Professor Kalervo Hiltunen, University of Oulu

1.6. Coordination

The aim of the research programme was to support and promote the development of the selected projects into a coherent and cohesive structure through cooperation and exchange of information. Programme coordination was the responsibility of the Steering Group and the programme managers and project official appointed by the Academy (Table 6). They were

responsible for ensuring this development and worked closely with the projects to facilitate the attainment of the objectives set for the programme. The aim was to ensure that the projects reinforced each other and that the programme generated new multidisciplinary research knowledge.

Consequently, the principal investigators of the projects selected to take part in the programme were required to commit themselves to the programme objectives and to cooperate actively throughout the programme and during the programme evaluation upon its completion.

The principal investigators of the projects were required to:

- assume responsibility for and report on the scientific progress of the project and the use of the funds in accordance with the instructions of the programme manager and relevant funding bodies
- see to that the whole research team attended all meetings, seminars and workshops organised by the programme coordination, and facilitate cooperation and exchange of information between the research teams within the programme
- take part in producing reviews, syntheses and information material around the research programme, and actively disseminate information about the programme's progress and results on public and scientific forums.

Table 6. Programme managers of FinSynBio programme

Appointment	Programme Manager
2011	Tiina Kotti and Mika Tirronen
2012–2014	Tiina Jokela and Jukka Reivinen
2015–2018	Jukka Reivinen
2018–2020	Sara Illman

1.7. Programme events

During the course of the programme, the research projects participated in events arranged together with end-users of the research results and in any other activities designed to provide information to different stakeholders (Table 7).

Table 7. Events of FinSynBio programme 2013–2019.

Date	Event
4 Nov 2011	**Exploratory Workshop of the Research Programme on Synthetic Biology (in Finnish)** This exploratory workshop was open to all researchers interested in the field. Keynote introductions were given by Professor Merja Penttilä (VTT) and Professor Matti Sintonen (UH). The researchers worked in three groups with the topics: 1. Systemic modelling and simulation of biologic reactions 2. Tools and production systems for synthetic biology

	3. Sociocultural questions related to synthetic biology. Each group produced a description of the current state of research on the topic as well as current needs and aims within the programme.
23 Apr 2012	**Research Programme on Synthetic Biology – Information and Networking Event** The purpose this networking event was to present the programme memorandum and introduce the programme's themes and objectives as well as its application, review and decision-making process. Questions concerning the programme's application process were also answered. In addition, a Learning Café was arranged where the researchers had the opportunity to visit different chat points and meet other researchers interested in the same topics. The aim was to provide an opportunity to exchange thoughts and ideas, meet potential project partners, consider new joint ideas, and recruit researchers and be recruited.
23 Jan 2014	**Opening Seminar: Synthetic Biology Research Programme (FinSynBio)** The aim of the opening seminar was to introduce leading scientists on synthetic biology field in Finland and provide extraordinary possibilities for networking. A keynote introduction with the title "Perspectives in Synthetic Biology" was given by Professor Vitor Martins dos Santos, Wageningen University. In addition, all funded research projects were presented.
25 Nov 2014	**Synthetic Life? Open discussion (in Finnish)** Some of the researchers funded in the FinSynBio programme participated in an open discussion at the University of Helsinki Think Corner, facilitated by the Committee for Public Information. Questions that were raised were, among others: • What is synthetic biology? What is it not? • What kinds of new opportunities does the re-arrangement of the building blocks of life bring – wellbeing for a larger share of the population? • Are there any risks involved in the research, and if then what?
18 Mar 2015	**ChemBio 2015: Synthetic Biology – Synteettinen Biologia** The annual seminar for the FinSynBio programme was held at the ChemBio Finland fair. The seminar was arranged together with the Advisory Board on Biotechnology. In addition to presentations by the funded research projects, two keynote addresses were given: "Advantages of modularity for synthetic biology – from engineering logic functions into cells to the design of new protein folds", Professor Roman Jerala, National Institute of Chemistry, Slovenia "Industrial perspective on Synthetic Biology", Professor Roel Bovenberg, University of Groeningen, the Netherlands

	The seminar was concluded with a panel discussion on the benefits and risks of synthetic biology.
4 Nov 2015	**Wikipedia Workshop** An intensive and inspiring workshop where the researchers within the FinSynBio programme were introduced to the opportunities of using Wikipedia in research communication.
26 Apr 2017	**Synthetic Biology (FinSynBio) Final Seminar** At the final seminar all of the funded research projects presented their results. In addition, two keynote addresses were given: "Synthetic control of transcription: a decade's perspective on synthetic promoter design", Professor Hal Alper, Department of Chemical Engineering, University of Texas at Austin, USA "Synthetic biology and the brave new world", Professor Steen Rasmussen, University of Southern Denmark & Santa Fe Institute, USA Further, the Synthetic Biology Roadmap for Industrial Biotechnology was presented by Research Professor Merja Penttilä, VTT.
19 Mar 2019	**Synthetic Biology Foresight Workshop** As part of the final evaluation of the FinSynBio programme, researchers interested in the field were invited to a foresight workshop creating visions for the future of synthetic biology. The workshop was arranged together with the Technical Research Centre of Finland VTT. The aim was to create visions of what synthetic biology could achieve in the future and how these goals could be reached with the aim of creating a better understanding of what future possibilities there are within synthetic biology, what challenges can be expected and how these could be addressed in research policies and strategies (see Appendix 5). The workshop was centred around two tasks: 1. How to build valuable collaboration networks? Elaborate on effective and fruitful ways to build multidisciplinary and innovative collaboration networks. 2. What kinds of solutions may synthetic biology offer to solve global challenges?

2 Outcomes and results of the programme

Researchers who have received funding from the Academy of Finland must report on their project following the end of the funding period. Monitoring the impact of Academy funding has become increasingly important; the information is also used when the Academy reports on its own activities. It is therefore essential that the final report is carefully completed in all respects. More detailed information on the reporting procedure are found on the Academy's website (see also www.aka.fi/en/research-funding/apply-for-funding/report--your-project/).

The principal investigator of the research project is responsible for the scientific reporting. Three times a year, the site of research must submit to the Academy an account of the use of the funding (by type of expenditure) and data on FTEs (staff according to the proportion of full-time hours they work), as part of the request for payment. The two sets of data are combined in the final report to allow for comparisons between the use of funds and the results produced with those funds.

This chapter presents data from the reports of the projects funded in the FinSynBio programme. The popular descriptions of the projects and their results are found in Appendix 3.

2.1. Funding

The funding data are entered on the report form to give a good overall picture of the project and its implementation. The projects in the FinSynBio programme reported an average funding of 70% from the Academy of Finland, whereas 30% of the funding had been received from other sources (Fig. 4). This is in accordance with the Academy's full cost model in which each organisation contributes to the total costs of a co-funded funded project with a self-financing percentage of at least 30%.

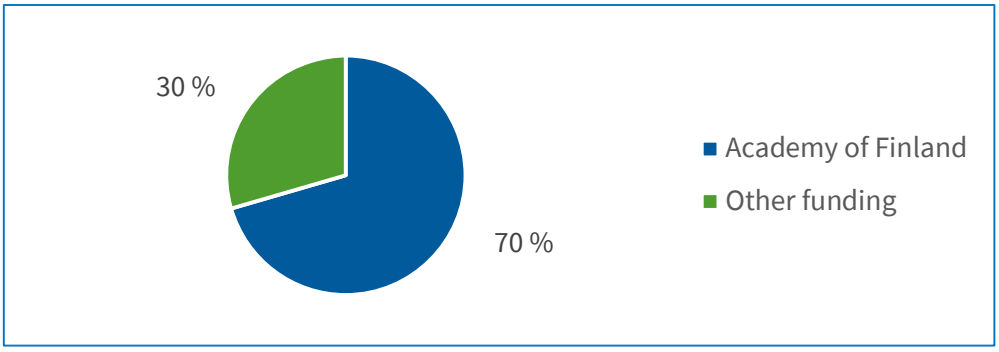

Figure 4. Funding from Academy of Finland vs other funding sources in the FinSynBio programme.

The primary source for the self-financing was the own research organisation, but funding from other domestic sources and EU funding was also included (Fig. 5).

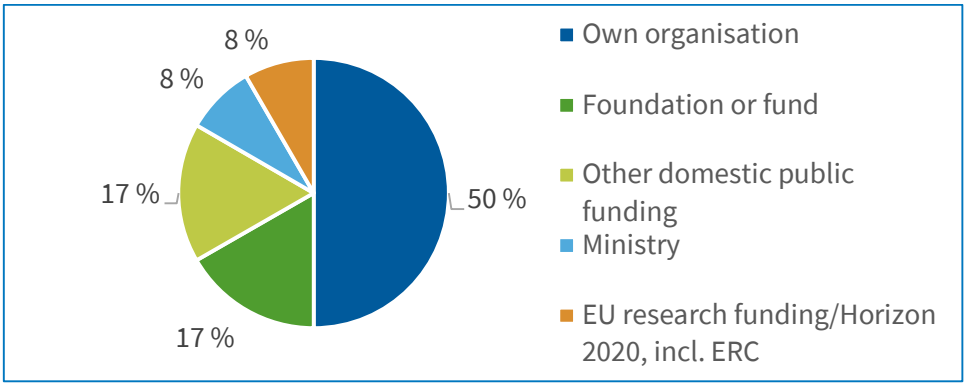

Figure 5. Other funding sources in the FinSynBio programme.

2.2. Personnel and degrees

The information on persons who have worked on the project are included in the report to give the reader a good overall picture of the project and its implementation. The research career stages follow the four-tiered classification of the Finnish Ministry of Education, Science and Culture, supplemented by “assisting personnel/other”.

Most of the work in the FinSynBio programme was performed by postgraduate students (45%), but the input from postdoctoral and other researchers was also prominent (38%). Of the work, 5% was performed by professors (Fig. 6).

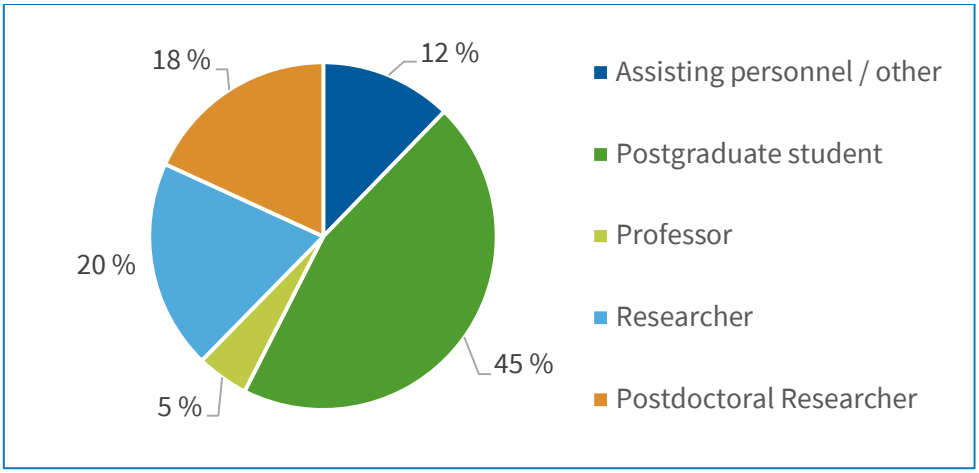

Figure 6. Division of FTE working time in the FinSynBio programme.

Altogether, 27 doctoral degrees and eight Master’s degrees were completed within and in connection with the programme (Fig. 7).

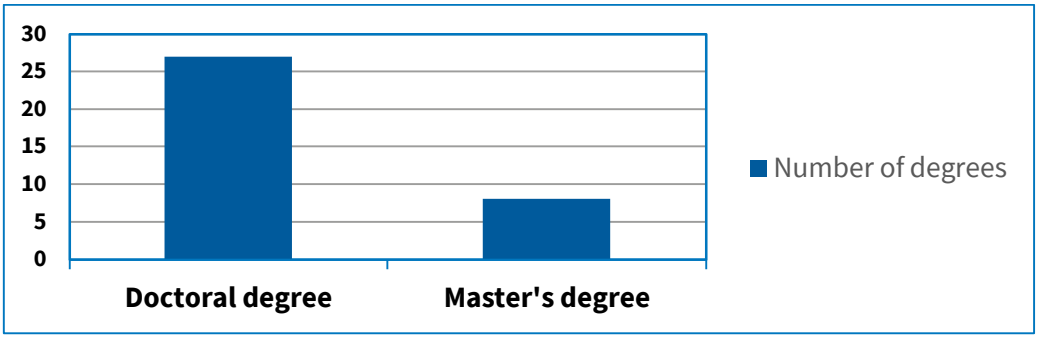

Figure 7. Degrees completed within and in connection with the FinSynBio programme.

2.3. Use of research infrastructures

In the final reports, the researchers were asked to indicate what kinds of equipment, resources or data reserves provided by national or international research infrastructures the project had used, reporting only infrastructures that had been used also by other researchers than those working at the host organisation of the site of research.

In all, 19 different national and international infrastructures were used in the FinSynBio programme (Table 8).

Table 8. Use of national research infrastructures and/or ESFRI roadmap infrastructures in the FinSynBio programme.

Infrastructure	Number of projects
Biocenter Finland	6
CSC RI	4
Bioeconomy	3
EMBL	2
ESRF	2
INSTRUCT	2
ELIXIR	1
EU-OPENSCREEN	1
OtaNano	1
Triton Cluster - high-performance computing cluster dedicated to scientific computing at Aalto University	1
Instruct-FI: Biocomplex purification	1
Instruct-UK: EM-Oxford	1
Diamond Light Source, UK	1
High-resolution magnetic tweezers, Delft University of Technology, NL	1
Optical tweezers, Department of Physics, University of Helsinki, FI	1
MicroScale Thermophoresis, University of Helsinki, FI	1
Beamline 4.2.2 at the Advanced Light Source, Lawrence Berkeley National Laboratory, USA	1
Central Animal Laboratory and Turku Bioimaging, University of Turku, FI	1
Electron microscope, University of Jyväskylä, FI	1

2.4. Project implementation

The research projects in the FinSynBio programme were further asked to describe the implementation of the project, using the research plan appended to the application as a baseline. They were asked to describe how the goals of the project had been achieved and what changes had been made to the research plan during the project. What problems had been met and how had the problems been solved?

All projects reported that the goals of the research project had been achieved to a satisfactory degree. Some of the projects had been implemented much as described in the original research plan, whereas others had had to make minor or major changes to the research plan. Some projects had been forced to adapt the implementation to changes in the personnel as researchers relocated during the programme. In other projects, adjustments had been necessary because only part-funding had been available for parts of the project, which had hampered the full attainment of goals. Other adjustments were related to technical problems in the planned experimental setups as well development of technologies and the emerging of new knowledge during the programme.

Most of the projects reported that the FinSynBio programme had promoted research careers of one or several of the researchers involved, as exemplified in one of the reports:

"The PI established herself as an independent researcher and obtained a permanent university position."

2.5. Research collaboration

The research projects in the FinSynBio programme reported a total 61 research collaborations with partners not a party of the same research consortium funded by the Academy of Finland (Fig. 8). Most of these collaborators were foreign research organisations. Domestic research organisations were also well represented, whereas the collaborations with private employers and non-research organisations were scarce. In all, 57% of the collaborations were with new partners, referring to a partner with whom collaboration had been started during the project (Fig. 9).

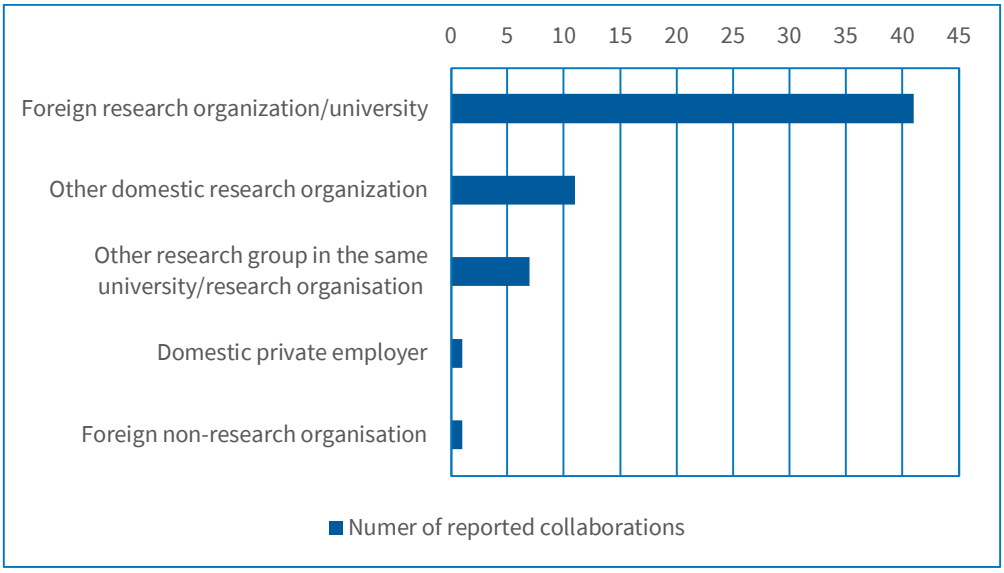

Figure 8. Collaborations with partners not a party of the same research consortium funded by the Academy of Finland.

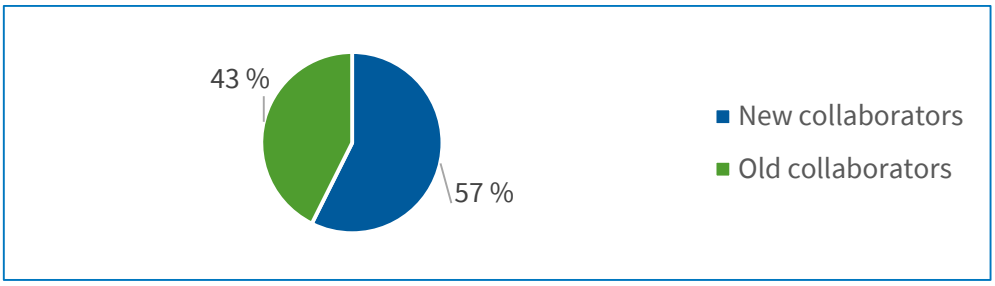

Figure 9. Share of new collaborations initiated in the FinSynBio programme.

2.6. Mobility

The researchers were asked to report mobility, both visits included in the original mobility plan and other project-related visits, in two different categories:

1) visits (in Finland or abroad) by project staff during the project (must be related to the research work)

2) visits (to site of research, from Finland or abroad) by experts and researchers other than those who worked on the project (must be related to implementation).

In the reporting guidelines, it was further clarified, that only visits that include research work counted as visits. For example, participation in a conference did not count as a visit.

In all, 24 separate visits from Finland were reported accumulating to a total of 44.5 months. Respectively, 12 separate visits to Finland were reported accumulating to a total of 30 months. The most frequently visited countries

were the UK and Switzerland, whereas research visits to Finland were made by researchers from Lithuania, India and the United States. (Fig. 10)

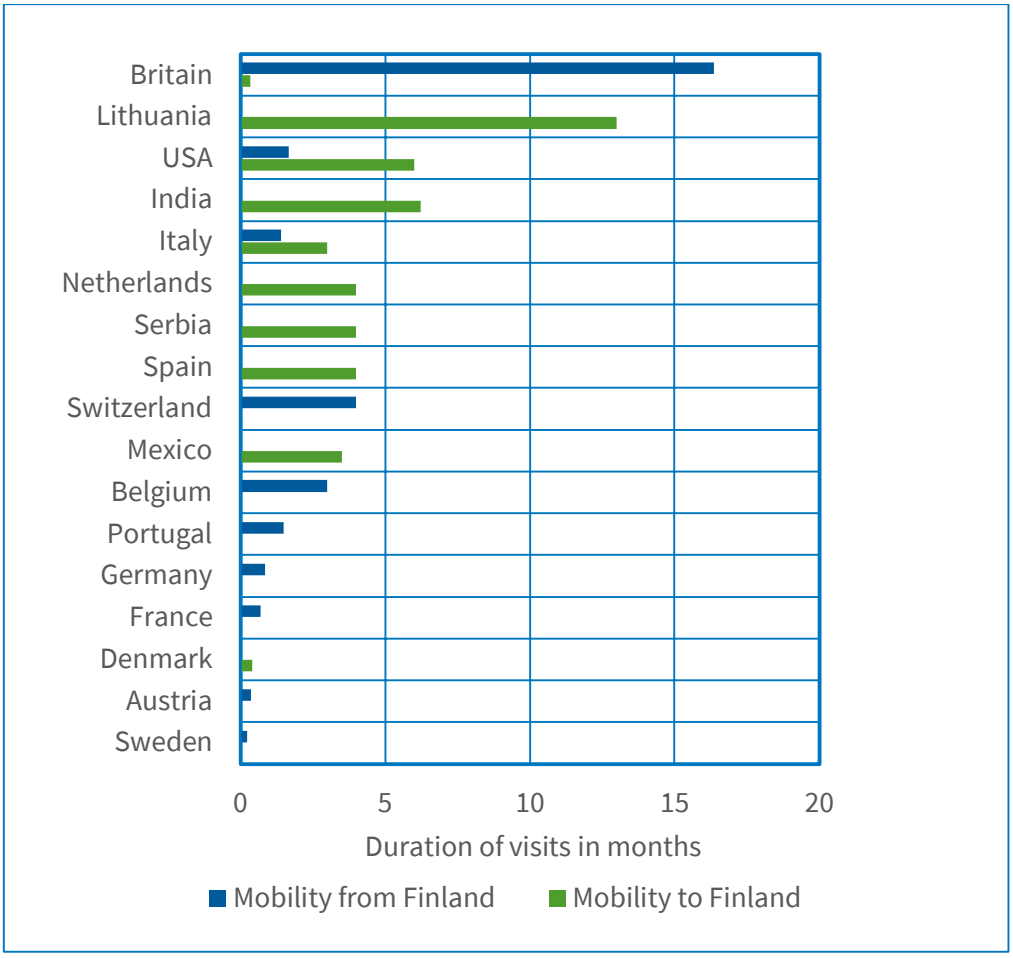

Figure 10. Research mobility in the FinSynBio programme.

The researchers were also asked to provide a free-form description of how the planned mobility had been realised and how possible changes had affected the attainment of the initial goals related to the research and the promotion of research careers. Only a few of the projects reported that the mobility had been realised according to the initial plan. In most of the projects, adjustments to the plans had been made due to practical reasons. Planned visits had in some cases been exchanged for other locations and new visits had been added as the work proceeded and new opportunities arose. Most projects (66%) reported that the goals of the mobility plan had been achieved. Three projects reported that no mobility plan had been included in the project.

2.7. Interaction

FinSynBio projects reported numerous interactions during the programme without actual research cooperation (Fig. 11). Interaction refers to activity to exchange information and views about, for instance, research topics, research questions or (preliminary) research results and their utilisation. Typically, the other party is a stakeholder who is interested in the contents of the research but who does not hold an interest in or possess the

knowledge or resources required to carry out the research. Interaction often also includes activity that can be categorised as communications. The increasing ubiquity of social media has blurred the boundaries between communications and interaction.

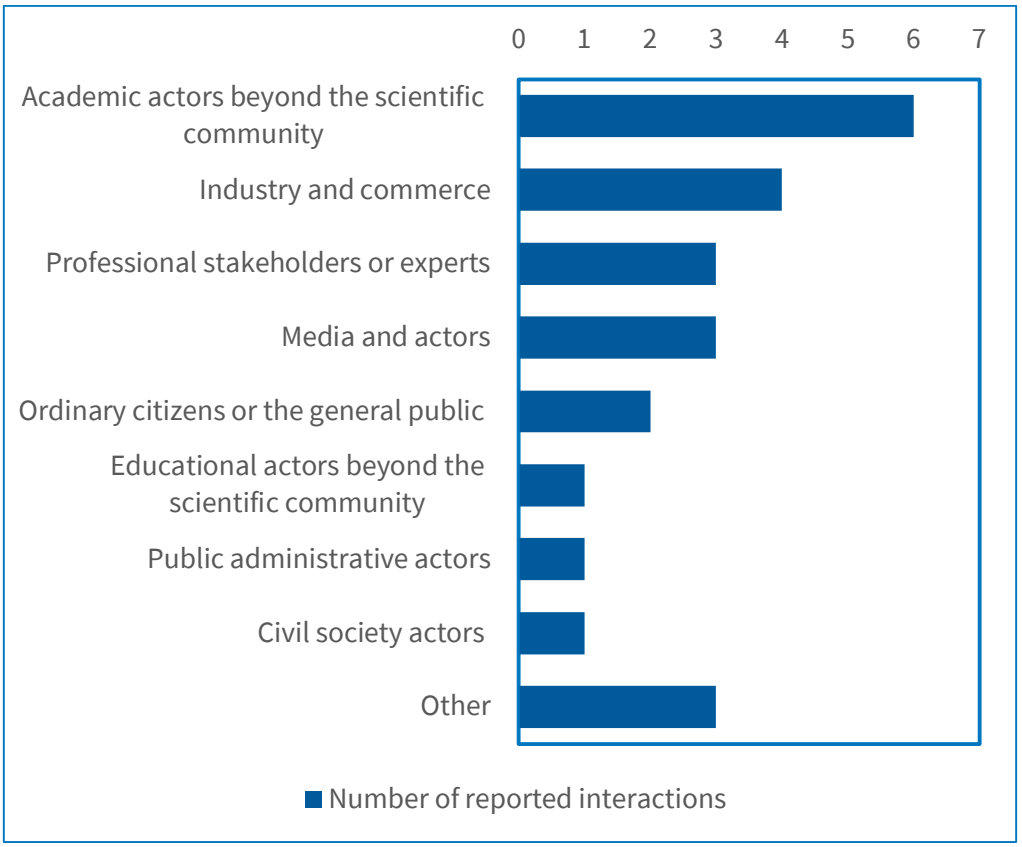

Figure 11. Interactions without actual research cooperation in the FinSynBio programme.

Most interactions were reported with academic actors beyond the scientific community. In this category, seminars for graduate students as well as oral and poster presentations at different meetings and symposia were mentioned. A number of interactions with industry and commerce were also reported, mostly with national and international companies in the pharmaceutical industry.

Three projects reported interactions with the media (including media directed to general and professional/specialist audiences). These interactions have been listed in Appendix 4; many of the interviews can be found online.

2.8. Publications and data management

The publications that have been produced from the research within the FinSynBio programme are a key research output. In all, close to 230 publications were reported (Table 9). Only publications that meet the criteria set by the Ministry of Education, Science and Culture and that had been published at the time of reporting are accepted as publications for the report. Unpublished (e.g. accepted for publication, or in press) articles,

works or other publications related to the project's results can be entered under Results (section 2.11).

Most of the reported publications were original scientific articles (Fig. 12), of which 60% were open-access (OA) publications.

Table 9. Publications produced from the research within the FinSynBio programme.

Publication type	Publications (N)	OA publications (%)
A1. Original scientific article	169	60%
A2. Review	16	56%
A3. Contribution to book/other compilations	7	57%
A4. Article in conference publication	4	50%
B1. Writing in scientific journal	9	67%
B2. Contribution to book/other compilations	1	0%
C2. Edited book, compilation, conference proceeding or special issue of journal	4	100%
D1. Article in professional journal	1	100%
D3. Article in professional conference proceedings	1	0%
D4. Published development or research report	1	100%
G2. Master's thesis, diploma work, upper higher vocational diploma	7	100%
G5. Doctoral Thesis, articles	9	78%
Total	229	62%

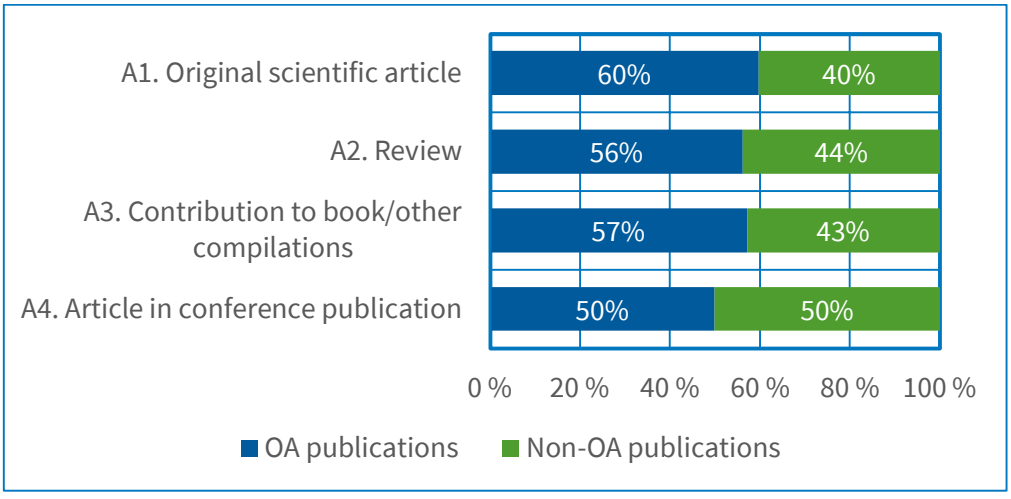

Figure 12. Percentage of open-access publications in the FinSynBio programme.

In the final reports, the researchers were also asked to indicate how the data used and produced in the project had been stored and protected, how they had been made available for subsequent use and to other researchers, and how the rights of ownership and usage to the data had been distributed. In

all, 83% of the data used and produced in the FinSynBio programme was reported as being openly available (Fig. 13).

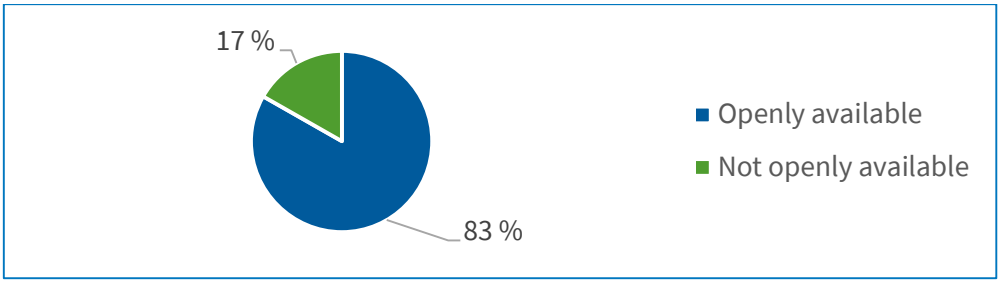

Figure 13. Percentage of open-access data reported in the FinSynBio programme.

2.9. Intellectual property rights (IPRs) and other outputs

The researchers also included information on intellectual property rights (IPRs) connected to the FinSynBio projects. In all, three patents were reported as granted and two patents had at the time of reporting been applied for. Two invention disclosures had been registered with the employer.

The researchers further reported a number of other documented outputs resulting from the FinSynBio programme, in addition to IPRs. These included research data and databases, methods, tools and software that were made openly or commercially available as a result of the project. In this section a number of events (e.g. seminars) targeted at a non-scientific audience were also included, for example:

"European Plant Science Organization (EPSO) organizes and sponsors every second year a Fascination of Plants Day. The goal of the day is to get as many people as possible around the world fascinated by plants and other photosynthetic organisms like cyanobacteria and enthused about the importance of plant science for agriculture and blue bioeconomy, in sustainability producing food, as well as for horticulture, forestry, and all of the non-food products such as paper, timber, chemicals, energy, and pharmaceuticals. In May 2015 UTU team was actively participating in the event by arranging a Fascination of Plants theme-week where there were lectures arranged for general public in the library and at the university, as well as a drawing competition for elementary school students with the theme "Lumoudu kasveista" [Fascination of plants]".

2.10. Continuation of research

All projects reported that research into the same topic, research question or problem would continue after the end of the project (Fig. 14). Half of the projects reported that the research would continue within the same research team, and half of the projects reported that the research would continue also somewhere else.

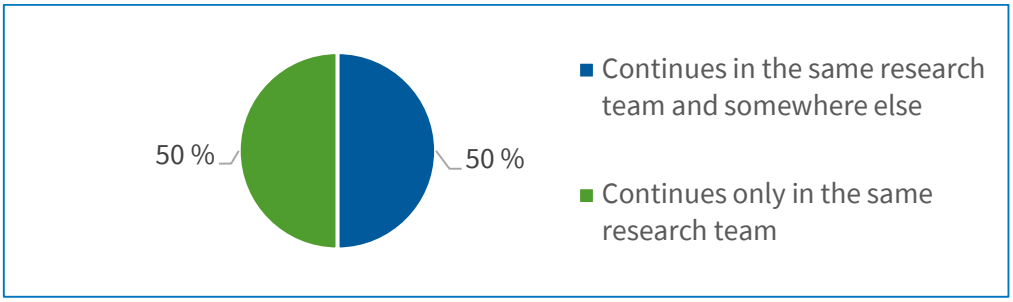

Figure 14. Continuation of research in the FinSynBio programme.

2.11. Results and justification of the significance of results

The researchers were asked to name and describe no more than three of the most important results of the project. Altogether, 29 different results were described in the reports (Fig. 15). Of these, 18 (62%) had already been published at the time of reporting. Six results (21%) were reported as being in the process of being published. Either the results had already been submitted for publication or manuscripts were in preparation.

The researchers were further asked to provide relevant justifications for the significance of the results by choosing one or several justifications for each reported result: scientific impact, impact on research methods and practices, and societal Impact. The effects and impact of the results are described in more detail under the item Effects beyond scientific community (section 2.12.).

All projects reported that their research had had scientific impact, and all but one project also reported impact on research methods and practices. Societal impact was reported in half of the projects (Fig. 16)

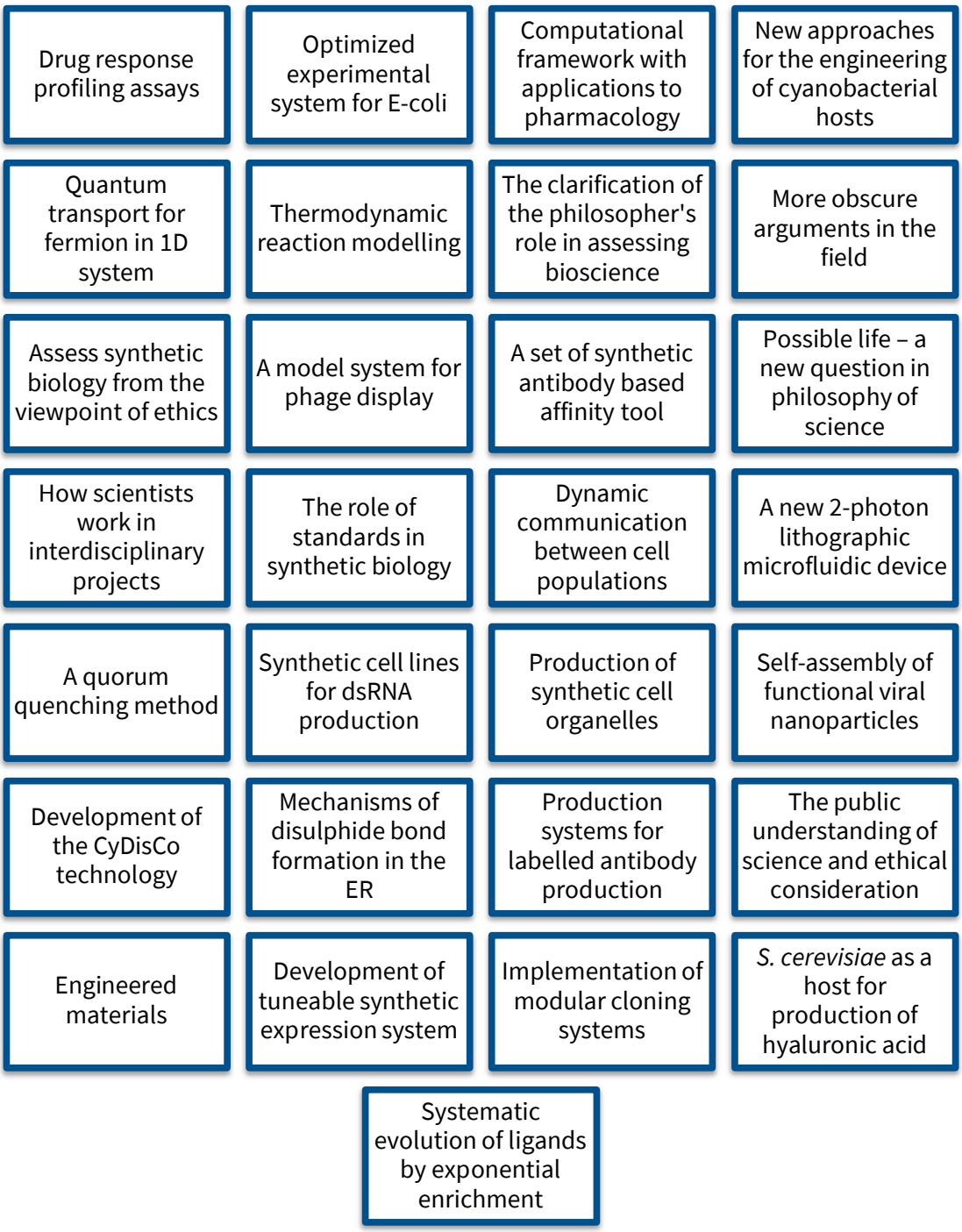

Figure 15. Results of the FinSynBio programme.

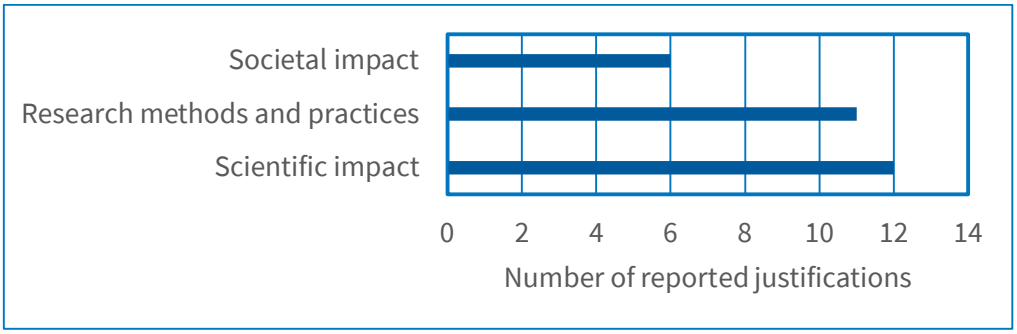

Figure 16. Justification of the results of the FinSynBio programme.

2.12. Effects beyond scientific community (impact)

In the final reports, the projects were asked to describe the project's impact beyond academia by assessing how and where the broader impact of the research is or can be seen. Effects can possibly be identified during the project or immediately after project completion. The effects may refer to the utilisation of knowledge and/or expertise generated from the research, or to the research work (activity) itself. The broader impact of research often appears after a longer time and through complex chains of events.

The instructions were to assess the impacts from five perspectives based on the possible directions of impact. There was also a separate heading for impact that manifests itself through other ways (Fig. 17).

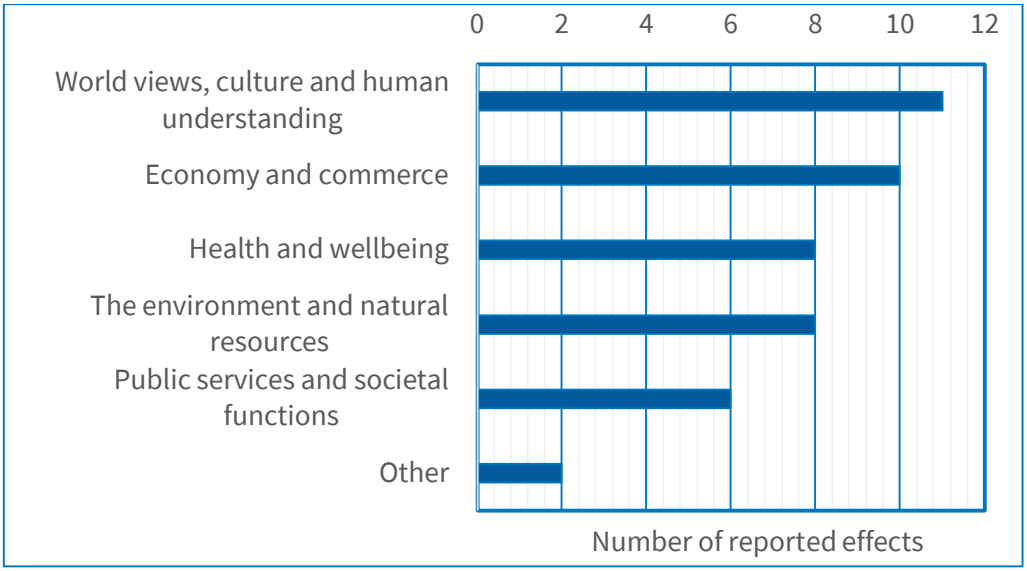

Figure 17. Effects of project beyond the scientific community.

2.12.1. World views, culture and human understanding

Almost all projects reported that their research had made an impact on world views, culture and human understating. Several of the projects reported that their aim had been to increase the overall awareness in society of the possibilities of synthetic biology and thus increase the understanding of future technological possibilities and provoke public discussion on these themes. As stated by one of the investigators:

"Synthetic biology is part of a development that makes the world more scientific and more technological, and we have tried to show this. Whether the development is good or bad, right or wrong, falls outside our remit. Our results simply prompt people to think about these issues, preferably in a reflective and systematic way."

Impact was also reported related to scientific research methods and training. One group reported that their research had led to the development of group interview methods and procedures that are and have been used in interdisciplinary research projects with special focus on research ethics and communication. Other groups have had the opportunity to involve students in their research:

"Involving young students and disseminating knowledge regarding science will create interest and new scientists."

Several investigators brought forward that their research had demonstrated the power of basic scientific research and the value of deep molecular biology knowledge and know-how in providing innovative solutions related to different aspects of everyday life. Carbon neutral options for fuel production, monitoring of pathogens in food and practises for protecting crop are examples of processes that have been improved in FinSynBio projects.

2.12.2. Economy and commerce

As most of the funded projects worked around very basic scientific questions, many investigators reported that the potential for commercial use of the results were there, but that the work was still in the early stages and needed further development before direct economic impact could be evaluated. Two projects, however, reported the establishment of spin-off companies based on the research results from the project. New technologies have also been patented and licensed by companies, improving their R&D work related to industrial biotechnology and bioeconomy, among others.

2.12.3. Health and wellbeing

One area where FinSynBio projects will have impact on health and wellbeing is in the design and production of protein therapeutics:

"Protein therapeutics have fundamentally changed medicine over the last two decades, complementing traditional small molecule drugs with reagents that can be equipped with cell specificity. However, the translation of this elegant approach to the clinic has been hampered by the fact that the immune system is guarding against any foreign protein, as it is designed to protect from infectious agents. [Our approach] might enable the creation of non-immunogenic protein drugs, and thus provide solution to overcome one of medicines biggest challenges."

The generation of synthetic agents effective against viruses and bacteria was also mentioned in some projects as well as the development of prediction

tools identifying personalised drug-target combinations for the development of robust, safe and effective synthetic biology therapies in the future.

Research improving both diagnostics and materials used in healthcare was also reported. Further, the long-term goal of one of the FinSynBio projects is to introduce new solutions for crop protection strategies in agriculture:

"[Our research] will potentially reduce the use of traditional pesticides and thus improved the environmental friendliness of agricultural production, and the safety and quality of food. This will have direct effects on human health and wellbeing."

2.12.4. The environment and natural resources

Several of the FinSynBio projects identified positive effects that their research may have on the environment and natural recourses. Many of these effects are related to the development of more environment-friendly technologies for sustainable production and recycling of materials.

"In 2016, world plastics production totalled around 335 million metric tons. Only a minor fraction of this is produced from other that oil based raw materials. In order to fight climate change and generate sustainable solutions for polymer production bioproduction systems are of high demand. The project contributed to this by generating novel, enabling tools for engineering of microbes for sustainable polymer precursor production with microbes."

Opportunities for positive effects on the environment were also identified in the development of efficient large-scale platforms for the production of different carbon-based chemicals directly from abundant sources, such as sunlight and CO2. Other processes that may be improved were identified in the fields of analytics and bioremediation, as well as in the development of strategies to replace or complement the use of traditional pesticides and fungicides in the future. Another important aspect that was highlighted was the contribution of the results to advance the development of circular economy, where all kinds of waste material is converted into valuable products such as energy.

2.12.5. Public services and societal functions

Several projects reported that their research had had impact through education by involving and inspiring students in the projects as well as educating the general public (see above). Especially the project lead by Dr Tarja Knuuttila investigated how future education in synthetic biology should be structured to meet the future demands on interdisciplinary approaches to research questions.

Appendices

Appendix 1: FinSynBio Programme Memorandum

1 BACKGROUND

In the past thirty years, gene technology has contributed significantly to our understanding of biological processes and to the development of new biotechnical applications. With the evolution of various -omics techniques such as genomics, transcriptomics and proteomics, we have gained important new insights into the function of genes, the structure of genomes and the expression of gene products. Research into the structure and function of proteins has demonstrated the association between biochemical reactions occurring within genes and the cell. Systems biology and mathematical modelling have in turn shown how entire cells function.

Synthetic biology is a new area of multidisciplinary research that combines biosciences, medical sciences, physical and chemical sciences, engineering and other disciplines. One of the goals of this fast evolving field of research is to build and tailor new biological components such as biocatalysts or genetic circuits and to assemble them into biological devices and production systems (e.g. cells). Synthetic biology research provides the tools needed for the design and fabrication of self-organised biocomposites, devices and systems, and the reorganisation of natural mechanisms, for instance. It will also facilitate the introduction of new kinds of technologies, such as more freely scalable, environmentally less damaging and more efficient industrial processes, as well as new environmental, nutritional and health-related applications. One key area of interest for synthetic biology is the quantitative analysis and modelling of biological processes and process engineering aimed at creating new properties. The Synthetic Biology Research Programme is designed to create a new, more broadly based platform for the closer integration of molecular biology, biochemical, computational and computer-aided modelling, process and materials technologies as well as chemical and physical approaches. The idea is to bring them together to form a genuinely multidisciplinary perspective.

Synthetic biology and the applications developed in this field involve many social and ethical issues that need to be addressed from the start. One fundamental ethical issue has to do with the creation of artificial life. Synthetic biology is a good example of how the problems addressed in research and its objectives have changed and shifted with advances in technology. Research in the field of synthetic biology has important implications for the public perception of science. New technology and the prospect of creating artificial life have changed our views about the nature of biosciences and what they can achieve. From a science research point of view, the debate surrounding the dividing line between basic and applied research is also interesting, given the concern in these fields to cure diseases

and develop other applications. These factors underscore the importance of a multidisciplinary approach.

1.1 SYNTHETIC BIOLOGY RESEARCH IN FINLAND AND ELSEWHERE

The current world leaders in synthetic biology research are the Massachusetts Institute of Technology (MIT) in Cambridge, US, the University of California Berkeley, Harvard University, the University of California San Francisco (UCSF) and the Eldgenössische Technische Hochschule Zurich in Switzerland (ETH). Numerous synthetic biology applications have already been published and patented. In Finland, the field is still in its relative infancy, even though we do have many competent researchers and research teams in such areas as gene technology, proteomics, metabolomics, systems biology and computer modelling. For Finland to achieve a strong future position in the synthetic biology field it is important to pool the competencies and resources of these experts and at once to support their networking with colleagues based at world-leading universities. The Academy of Finland is also involved in the three-year ERASynBio project (2012–2014) in the synthetic biology field, which is designed to facilitate the networking of Finnish and other European researchers and to promote cooperation among European research funding agencies.

Recent assessments and foresight projects have clearly underlined the need for a research programme in the synthetic biology field. The 2009 evaluation of the Academy of Finland Systems Biology and Bioinformatics Research Programme (2004–2007) recommended that steps be taken to support the networking of systems biology research with a view to integrating it more closely with biological and other research. In 2004–2005, the European Science Foundation (ESF) conducted a “Forward Look” project in the systems biology field, which led to the launch of the EuroSYNBIO programme focusing on synthetic biology. The FinnSight 2015 panel of experts who conducted a review of expertise in the biofield identified seven key areas of competence that they felt warranted further investment. At least four of these areas are directly related to the themes covered in the Synthetic Biology Research Programme: the management and modelling of biological knowledge, the development of bioproduction, new biotechnical products, and pharmaceuticals development.

2 AIMS

The aims of the Synthetic Biology Research Programme are to:

- support high-level synthetic biology research in Finland
- promote cooperation among scientists and researchers based in Finland and working in different fields so as to facilitate the achievement of critical mass in the research community and international competitiveness in the synthetic biology field
- increase international collaboration to support the achievement of other programme objectives

- foster dialogue between the research community and the rest of society on socio-cultural concerns and issues related to synthetic biology
- promote public understanding about synthetic biology research.

3 PROGRAMME THEMES

The research programme will set out to answer such important questions as how biological components can be artificially constructed and how these building blocks can be reorganised to achieve specific biological functions. These questions can be approached through smaller, more carefully targeted projects, although each individual or consortium project must be able to demonstrate through the knowledge and competencies of its research team or through its active collaborations how it ties in with the field of synthetic biology research, i.e. what it is that warrants the description of the project as a synthetic biology project.

The research programme covers three thematic areas, which should be seen not as distinct and separate from one another, but rather as mutually complementary approaches. Projects are encouraged that address issues under more than one thematic area. In particular, the first two themes ("Modelling and simulation of biological reactions and systems" and "Synthetic biology: tools and production systems") are closely interwoven with each other. The third theme ("Socio-cultural issues related to synthetic biology") should be seen as providing an opportunity for the humanities and social sciences to play a crucial mediating role between natural science and engineering research, on the one hand, and medical research, on the other.

The research programme's three thematic areas are listed below. The specific research areas indicated in each case are intended as examples only.

1. MODELLING AND SIMULATION OF BIOLOGICAL REACTIONS AND SYSTEMS

- Quantitative analysis and modelling of biological processes and process engineering aimed at creating new properties
- De novo process design
- Process optimisation

2. SYNTHETIC BIOLOGY: TOOLS AND PRODUCTION SYSTEMS

- The manufacture of new synthetic genes and the creation of new genetic codes by means of unusual base pairs
- The development of new biosynthesis routes by combining natural and modified genes
- The development of new enzyme activities
- Self-assembling nanostructures, such as biological molecular engines and nanorobots
- Synthetic cell organelles and metabolic engineering of microbes by genotype editing
- Gene therapy vectors and new receptor-targeted drugs

3. SOCIO-CULTURAL ISSUES RELATED TO SYNTHETIC BIOLOGY

- Science and technology research
- Ethical issues
- Intellectual property rights research

4 IMPACT OF RESEARCH PROGRAMME

Synthetic biology is interested in researching and developing biological components and processes that do not necessarily occur in the natural environment. The aim is to put these “molecule-machines” to use in various industrial manufacturing processes, sensors, diagnostic methods, pharmaceuticals development, etc. Synthetic biology research is a high-visibility and high-impact undertaking because its applications have widespread use in everyday life. From a welfare point of view, the creation of synthetic life will probably lead to numerous applications both in the field of medicine, environmental and industrial engineering as well as in nanosciences. Strong competencies in the synthetic biology field provide a solid foundation for sustainable development based on bioexpertise as well as for innovative future growth.

One aspect of synthetic biology research concerns the philosophy and ethics of science. Synthetic biology research involves the creation of completely new biological structures, which will inevitably raise questions about the essence of life and about what it is that makes the physical and chemical world a living, biological one. The Research Programme thus serves as a multidisciplinary forum that will stimulate debate between a broad spectrum of the research community and the rest of society on future production methods and attitudes towards the instrumental use of biological knowledge.

5 IMPLEMENTATION

The programme’s thematic areas cover bioscience, natural science and health science as well as social science approaches. Interdisciplinary cooperation is of key importance in terms of attaining the programme objectives. At the Academy, the Research Council for Biosciences and Environment, the Research Council Culture and Society, the Research Council for Natural Sciences and Engineering and the Research Council for Health have all contributed to the preparation of the programme.

5.1 FUNDING

The Synthetic Biology Research Programme (FinSynBio) is funded and coordinated by the Academy of Finland. The programme is scheduled to run for four years, with funding provided for the projects from 2013 to 2017. Through the programme, the Academy provides funding for multidisciplinary research conducted by research projects and consortia. A research consortium is a collaboration of independent fixed-term projects working under a joint research plan by combining different methods and research fields with a view to achieving greater added value than is normally

achieved from project collaboration. The budget authority planned for the programme in 2013 is EUR 10 million. In addition, a further EUR 2 million is planned to be earmarked for the programme for any additional international calls to be launched at a later stage (see 5.3).

5.2 NATIONAL COOPERATION

The Synthetic Biology Research Programme will support the grand challenges defined by the Academy Board as areas that will be given priority focus in research, including A Healthy Everyday for All; the Ageing Population and Individuals; the Dialogue of Cultures; and Knowledge and Know-how in the Media Society. The programme's thematic areas have a number of interests in common with other Academy research programmes, such as Nanoscience Research Programme (FinNano), Computational Science Research Programme (LASTU), Responding to Public Health Challenges (SALVE) and Research Programme on the Human Mind (MIND). Synthetic biology research may also share common interests with the research strategies of several of the Strategic Centres for Science, Technology and Innovation (Finnish acronym SHOK), such as Health and Wellbeing (SalWe Ltd), Energy and the Environment (CLEEN Ltd) and Forestcluster Ltd.

5.3 INTERNATIONAL COOPERATION

The research programme aims to support international collaboration and networking. The aim is to establish and actively strengthen cooperation contacts with countries that carry out leading-edge synthetic biology research. The programme aims to establish long-term funding cooperation with national research funding agencies in countries that are considered relevant to Finnish researchers in synthetic biology. Countries that are tentatively identified as attractive target countries with respect to synthetic biology research and cooperation include the US, Canada, the UK, Germany, Switzerland and India. The Academy has planned to launch funding cooperation with the Indian Department of Biotechnology (DBT) in connection with the programme's first call for research grants (see 5.3.1). Decisions on later international cooperation and any separate calls for international joint projects will be made separately.

The Academy participates in the ERA-NET ERASynBio that was launched in January 2012. Any Finnish projects possibly funded through ERASynBio calls will be linked by the programme coordination with the Synthetic Biology Research Programme.

5.3.1COOPERATION WITH INDIAN DEPARTMENT OF BIOTECHNOLOGY (DBT)

This section will be supplemented on the basis of the funding negotiations.

5.4 TIMETABLE

The Academy will fund individual projects and consortium projects within the programme for a maximum of four years during 2013–2017. The funding period is normally four years, starting 1 September 2013 and ending 30 August 2017. A detailed timetable for the call and the review of applications

is described in Chapter 6. A kick-off seminar will be arranged in autumn 2013. The final evaluation of the programme will be carried out in 2018 at the earliest. For more information for the implementation of the evaluation, see 5.7.

5.5 STEERING GROUP

The research programme is run by a steering group composed of members of the Academy's Research Councils and other expert members. Additional experts may also be invited to the group. The duties of the steering group are:

- to prepare the programme and submit to the programme sub-committee a proposal on projects to be funded
- to make a proposal to Academy Research Councils and other funding bodies on any new calls and/or additional funding
- to manage and monitor the programme
- to steer and support programme coordination
- to be responsible for the final evaluation of the programme
- to promote the application of the programme's results.

5.6 COORDINATION

The research programme strives to support and promote the development of the selected projects into a coherent and cohesive structure through cooperation and exchange of information. Programme coordination is the responsibility of the steering group and the programme managers and project official appointed by the Academy. They are responsible for ensuring this development, and work closely with the projects to facilitate the attainment of the objectives set for the programme. The aim is to ensure that the projects reinforce each other and that the programme generates new multidisciplinary research knowledge. Consequently, the principal investigators of the projects selected to take part in the programme will be required to commit themselves to the programme objectives and to cooperate actively throughout the programme and during the programme evaluation upon its completion.

The principal investigators of the projects shall:

- assume responsibility for and report on the scientific progress of the project and the use of the funds in accordance with the instructions of the programme manager and relevant funding bodies
- see to that the whole research team attends all meetings, seminars and workshops organised by the programme coordination, and facilitate cooperation and exchange of information between the research teams within the programme
- take part in producing reviews, syntheses and information material around the research programme, and actively disseminate information about the programme's progress and results on public and scientific forums.

During the course of the programme, the research projects will participate in events arranged together with end-users of the research results and in any other activities designed to provide information to different stakeholders.

5.7 EVALUATION

The implementation and results of the research programme will be evaluated upon its completion. The implementation of the evaluation will be planned in detail as the programme progresses, but the evaluation is likely to consider at least the following aspects:

- attainment of programme objectives
- programme implementation (coordination, role of steering group, participation in programme)
- evidence of impacts pursued by the programme
- national and international cooperation
- publicity and visibility of research conducted within the programme.

The evaluation may be carried out as part of a more extensive evaluation of several Academy research programmes or other national programmes, and in cooperation with other national and international actors.

The research teams receiving funding are required to report on the progress of their projects on an annual basis in line with the decision of the steering group, and to submit a research report to the Academy of Finland upon project completion. The reports shall include information on, for example, scientific publications produced and theses and doctoral dissertations completed within the programme.

6 APPLICATION GUIDELINES AND REVIEW CRITERIA

The Academy will fund individual projects and consortium projects within the programme for a maximum of four years during 2013–2017. The funding period starts 1 September 2013 and ends 30 August 2017. The research programme has a two-stage call. At the first stage, applicants submit letters of intent including short plans of intent (see guidelines in the Academy's September 2012 call for applications, Appendix 1B). The call for letters of intent will be opened in connection with the Academy's September 2012 call. The steering group will make a proposal to the programme sub-committee appointed by the Academy Board on projects that, on the basis of the letters of intent, would best fit in with the programme objectives. In the review of the letters of intent, the steering group will consult scientific experts. The projects selected to proceed to the second stage (to submit full applications) will be notified of the steering group's decision in December 2012.

Applicants requested to submit full applications shall prepare a complete research plan and submit it in the Academy's online services in January-February 2013 (tentative timetable). Guidelines on how to draft full applications will be available in the Academy's September 2012 call for applications (Appendix 1A). The full applications will be reviewed by an

international expert panel. On the basis of the scientific review of the applications and considering the programme objectives, the steering group will prepare a proposal to the programme sub-committee on the projects to be funded. The programme sub-committee will make the funding decisions in May-June 2013 at the latest.

Any international joint calls will be carried out according to a timetable to be agreed upon separately with the funding partners.

The applications are reviewed in accordance with the Academy's general review criteria for research programmes (see www.aka.fi/eng > For researchers > Processing and reviewing applications, and www.aka.fi/eng > For researchers > Review of applications).

7 MORE INFORMATION

This programme memorandum is available in PDF format on the Academy's website at www.aka.fi/FINSYNBIO.

Appendix 2: FinSynBio call for applications

SYNTHETIC BIOLOGY (FinSynBio) – LETTERS OF INTENT

Synthetic biology is a new area of multidisciplinary research that combines biosciences, medical sciences, physical and chemical sciences, engineering and other disciplines. One of the aims of this internationally fast-evolving field of research is to build and tailor new biological components, such as biocatalysts or genetic circuits, and to assemble them into biological devices and production systems (e.g. cells).

Synthetic biology research provides tools needed for the design and fabrication of self-organised biocomposites, devices and systems, and the reorganisation of natural mechanisms, for instance.

The field represents a genuinely multidisciplinary approach. The Synthetic Biology Research Programme is designed to create new, more broadly-based platform for the closer integration of different perspectives and approaches. These should not be seen as separate or independent areas but as seamless cooperation.

The approaches can cover, for example, the following areas:

- molecular biology
- biochemistry
- computational and computer-aided modelling
- process and materials technologies
- chemical and physical approaches.

Synthetic biology and the applications developed in this field involve many social and ethical issues that need to be addressed from the very start. Issues closely related to synthetic biology include the creation of artificial life and related ethical questions.

The content and aims of the research programme have been described in detail in the programme memorandum (PDF).

The aims of the research programme are

- to support high-standard synthetic biology research in Finland
- to promote cooperation among scientists and researchers based in Finland and working in different fields so as to facilitate the achievement of a critical mass in the research community and international competitiveness in synthetic biology
- to increase international collaboration with a view to supporting the achievement of other programme objectives
- to foster dialogue between the research community and the rest of society on socio-cultural concerns and issues related to synthetic biology
- to promote public understanding about synthetic biology research.

Applicant

Funding can be applied for by individual research projects and by consortia composed of two or more research teams. At the first application stage, only the consortium PI submits a letter of intent. At the second stage, the PIs of all consortium subprojects submit their own application.

Funding period

The projects within the research programme are granted funding for four years. The planned funding is EUR 10 million in 2013. Supplementary international calls may be launched at a later stage. As a rule, the funding period starts 1 September 2013.

Programme memorandum

The programme memorandum contains more detailed information on the programme's background, aims, thematic areas and evaluation criteria. The programme memorandum (PDF) is available on our website. Applicants should carefully read the memorandum in order to submit a competitive application.

How to apply

FinSynBio has a two-stage call. The deadline for letters of intent is 26 September 2012 at 16.15. The deadline is non-negotiable. Applications are drafted in the Academy's online services (select Open calls > FinSynBio 2012, letters of intent).

Draft the application so as to ensure that the Academy's contribution to funding comes to no more than 70% of the estimated total project costs. See more details on our website under Full cost model.

Projects proceeding to the second stage will be selected in December 2012 based on the plans of intent. Those invited to that stage shall submit their full applications to the Academy no later than 6 February 2013 at 16.15. The deadline is non-negotiable.

If the applicant is a consortium, see detailed guidelines on our website under Consortium application. At the first application stage, only the consortium PI submits a letter of intent. At the second application stage, the PIs of all consortium subprojects submit their own application. The application of the whole consortium can be processed only if the applications of all subprojects have been submitted by the deadline. The composition of the consortium cannot be changed after the deadline.

Appendix 3: Public descriptions of FinSynBio projects and their results

Principal Investigator: Tero Aittokallio
Project: Synthetic controllability of biological networks through understanding and engineering their control elements

The overall goal of the project was to improve our understanding of the fundamental principles of controllability of large, complex, biological networks, and thereafter to exploit these control principles in order to predict how to best engineer regulatory networks. The concept was tested in two grand challenge case studies: improving sustainable fuel production and multi-targeted anticancer therapeutics. The consortium made use of the unique and state-of-the-art bioengineering and chemical screening infrastructure and expertise of Jones and Wennerberg groups, combined with competence of Petre and Aittokallio groups in developing computational network models and methods for identifying their control principles. The first case study has so far inconclusive results, but the work is still ongoing. The approach developed for second case study has demonstrated its potential for predicting and understanding mechanisms of action of drug combinations for personalized cancer treatment.

Principal Investigator: Eva-Maria Aro
Project: Design and engineering of synthetic hybrid photo-electro organisms

SynCO2 focused on the evaluation of new strain engineering strategies for enhancing the production capacity of photoautotrophic cyanobacterial hosts as part of the development of future biotechnology applications. We introduced several variations of electron transfer pathways originating from Shewanella oneidensis in the cyanobacterium Synechocystis sp. PCC 6803, thus potentially allowing the cell to use external electricity current as energy.

In parallel, we successfully modified the distribution of electron flux in cyanobacterial cells and enhanced the production efficiency of specific carbon-based end-products in engineered strains. It was also found that light-harvesting complexes, the big molecules that collect light in plants and cyanobacteria, can interact very strongly with light, if they are placed near metal nanoparticles. This tells that the pigment molecule orientation and closeness to each other in a light harvesting complex is essential for strong interaction with light.

Principal Investigator: Matti Häyry
Project: Synteettinen biologia ja etiikka

The project aimed at clarifying the views of bioscientists on the ethicality of their work, and to study philosophically the ethical dimensions of synthetic biology. According to our results, bioscientists are well aware of the moral and social issues in their research but annoyed by the increasing research ethics bureaucracy. In the philosophical examination, synthetic biology and its ethics found their places in a historical continuum. The problems of gene

technology became a serious concern in the 1960s, and discussions have gained momentum every time scientific advances seem to threaten prevailing views on morality and humanity. Turning points have included the first steps in genetics, the cloning of Dolly the sheep, the possibility of stem cell research, the mapping of the genome, and, most recently, new methods of gene editing. Synthetic biology has not yet been a major cause of alarm, but it will be, when scientists learn to produce more complex organisms artificially.

Principal Investigator: Jussi Jäntti
Project: Control of in vivo polymerisation by synthetic biology approaches

The focus of the project was to study synthetic biology-approaches for the production of polymers e.g. hyaluronic acid (HA) in yeast Saccharomyces cerevisiae and in Lactococcus lactis. The project was a collaboration with Professor Guhan Jayaraman, Indian Institute of Technology Madras, India. Importantly, new synthetic biology tools were developed for controlled and tunable gene expression that works broadly in eukaryotic hosts. This system is currently used and tested in increasing number of hosts, including plants and mammalian cell lines. The system has been patented and licensed to several companies. Other tools, e.g. modular cloning systems for easy DNA assembly, were also implemented in the project. Expression of the HA-biosynthetic pathway in S. cerevisiae resulted only in low productivity, possibly due to incorrect protein translocation. Alternative production hosts are currently under evaluation and the project is continued with other funding.

Principal Investigator: Matti Karp
Project: Focused proteomic analysis of cell factories (proChassis)

In synthetic biology engineering principles are applied to biology to enable construction of predictable and modular production systems. A chassis is used as a platform on which standardized biocomponents are incorporated to create cell factories for applications. The optimal integration of component with host's systems is crucial for the productivity of the cell factory. Thus, more understanding of the interactions of cell factory is required to enable the full exploitation of the system. Simple and universal tools are required to enable the simultaneous study of the functionality of the cell factory in production conditions. Novel methodology (proChassis) for quantification of functional proteome of the cell factory (containing chassis and integrated biocomponents) was introduced. The proChassis toolset contains an easily genome-engineerable chassis, quantitative monitoring tools of cell factory (molecular binders), and computational approaches for system design and analysis.

Principal Investigator: Tarja Knuuttila
Project: Biological Knowledge through Modeling and Engineering: Epistemological and Social Aspects of Synthetic Biology (SynBioMode)

The project studied the emerging multidisciplinary field of synthetic biology from the point of view of philosophy of science. Its practice-oriented double-goal was to provide new conceptual resources for biological engineers and the general public to better understand the theoretical foundations of synthetic biology as well as to use insights gained from studying the field to tackle problems within philosophy of science.

Methodologically the project consisted of conceptual philosophical analysis combined with empirical methods, including interviews and strategic laboratory visits. These were used to build an integrated picture of synthetic biology as a field of applied biological engineering that nevertheless has a significant basic science dimension. The project produced new insights on how epistemic tools like models and standardized bio-bricks shape interdisciplinary knowledge-production. It also introduced a novel theme of possible life in the context of the philosophy of biology.

Principal Investigator: Markus Linder
Project: Synthetic genetic circuits for programming the structure of materials

We have worked on the general question of how structures and patterns form in biological systems. Such pattern and structure formation is for example useful to understand biological pathways for forming materials. Scientifically we have approached the problem by studying how bacterial cells communicate with each other. Through communications cells can interact and respond to each other. This will lead to bacterial production of component that is controlled in space and time which is an essential step to structure and pattern. As the main technique we used synthetic biology to design bacterial systems that produce and respond to chemical signals.

These signals were under genetic control in a way that led to expression in a time dependent manner. The results will be useful in constructing microbes to perform more complicated tasks than has been possible so far, and also gives tools to understand how microbes function in nature as parts of communities that interact with each other.

Principal Investigator: Minna Poranen
Project: Prokaryotic virus as a tool for synthetic biology

Viruses have evolved efficient mechanisms to reprogram their host cells and harness cellular functions to their own needs. The aim of this project was to use viral parts to develop synthetic bacterial cells. The new functions introduced into bacteria allowed bacteria to replicate double-stranded RNA molecules or produce intracellular membrane vesicles.

The established dsRNA production system was used to produce high-quality dsRNA molecules that share sequence identity with a viral plant pathogen and the protective effect of the dsRNA treatment against the viral infection was demonstrated. The project also resulted new molecular level information on the self-assembly processes of viruses.

Principal Investigator: Lloyd Ruddock
Project: Gen2Co: 2nd generation E.coli protein cell factories

Protein based drugs, such as insulin, are used by millions of people every day. While they are very effective, they are also difficult and costly to produce. One issue relates to modifications that occur to proteins after they are made including structure stabilizing bridges, called disulfide bonds

This project successfully worked on the development of new technology for the efficient production of disulfide bond containing proteins. We were able to scale-up the technology for to produce therapeutic proteins, proteins for diagnostics and a natural zero calorie replacement for sugar that tastes like sugar.

By further improving our understanding of the mechanisms of action of the enzymes involved in disulfide bond formation in the cell our technology should dramatically reduce the cost of production of protein based drugs, as well as give important insights into disease progression.

Principal Investigator: Jussi Taipale
Project: MirrorBio, Establishment of a fully synthetic, mirror-image biological system

The project is part of the ERASynBio project entitled 'Establishment of a fully synthetic, mirror-image biological system' (MirrorBio), which aims to create a mirror-image synthetic biology to mimic parts of a biological system entirely independent of nature using artificial component parts. These mirror molecules could prove beneficial in therapeutic use as they are more stable biologically and less immunogenic than their natural counterparts. In this part of the project, minimal fragments of transcription factors were selected for chemical protein synthesis based on molecular modeling and their DNA-binding capacity, which was evaluated by systematic evolution of ligands by exponential enrichment (SELEX) experiments. Altogether, 28 of 39 the tested minimal constructs (72 %) showed binding specific DNA sequence, indicating that these minimal fragments have retained DNA binding activity.

Principal Investigator: Arto Urtti
Project: Bio-active protein synthesis in vitro with cell free platform

In this project, cell free methods were developed to facilitate rapid production and initial testing of proteins at high numbers, but small quantities. Proteins may be developed using this methodology for biomedical and industrial purposes.

Principal Investigator: Pia Vuorela
Project: Fabricating bacterial biofilms via artificial nano(bio)components (ArtFilm)

ArtFilm has focused on artificial bacterial biofilms, including the investigation of biofilm properties, development of engineered and natural protein components to functionalize biofilms, development of new materials with biofilms involving printing technologies, as well as the explicit

considerations of research ethics in synthetic biology and in the development of methods and procedures to interview multidisciplinary teams - with applications to health care and other disciplines, and for timely and accurate research communication about synthetic biology to the public. The project resulted in a wide array of results (characterisation of biofilms and biofilm bacteria, novel materials, engineered proteins, 3D structures, diagnostic reagents, novel methods and procedures for experimentation and research ethics etc), which have been published in international journals and in masters and doctoral theses, as well as deposited with international data repositories

Appendix 4: Interactions reported in the FinSynBio projects

Principal Investigator: Eva-Maria Aro
Project: Design and engineering of synthetic hybrid photo-electro organisms

Luonnontieteilijä (Luonnontieteiden Akateemisten Liiton jäsenlehti):
9/2015 Pauli Kallio popularized article: "Tulevaisuuden biopolttoaine saadaan syanobakteereilta"
9/2015 Yagut Allahverdiyeva interview "Tulevaisuuden biopolttoaine saadaan syanobakteereilta (Future fuels from cyanobacteria)" (journalist: Hannu Aaltonen)

Aurora:
9/2015 Pauli Kallio popularized article: "About bioenergy research at UTU" (Edit. Jenni Valta)
9/2015 Yagut Allahverdiyeva in Aurora: Interview about bioenergy research at UTU (journalist: Jenni Valta)

Radio interviews:
Yle Radio 1/Tiedeykkönen, 12.8.2016 "Biopolttoaineita synteettisen biologian avulla" Interviewed: Penttilä, Rautio, Lienemann, Jäntti (VTT), Kallio (UTU) (Ed. Teija Peltoniemi)
Radio interview of Merja Penttilä (VTT) in YLEn Tiedeykkösessä on Synthetic biology on 22.4.2016 (YLEn Areena: http//:areena.yle.fi/1-3331847?autoplay=true)

TV:
27.3.2016 Eva-Mari Aro and Pauli Kallio Suomen Tulevaisuus science documentary for Mtv3 http://www.suomentulevaisuus.com
Merja Penttilä, Joosu Kuivanen and Jussi Jäntti interviewed in Yle Tiede/Prisma Studio TV program 21.9.2015 (Toim. Milla Kontkanen)

Tieteen päivät 15.1.2017:
Jussi Jäntti (VTT) Talk "Synteettisen biologian avaamat mahdollisuudet öljyn korvaajana teollisessa tuotannossa" Tieteen päivät 15.1.2017
Merja Penttilä (VTT) Chair and talk "Synteettinen biologia - mistä on kyse?" in a thematic session on synthetic biology Tieteen päivät 15.1.2017

23.4.2016 Eva-Mari Aro presentation "Photosynthesis for sustainable bioeconomy - living factories (LIF)" in Turun Biotieteilijätapaamisessa
Jussi Jäntti (VTT) participated in the public "Tiedekulma" panel discussion on Synthetic biology (25.11.2014, co-organized by University of Helsinki and the Academy of Finland)

Principal Investigator: Tarja Knuuttila
Project: Biological Knowledge through Modeling and Engineering: Epistemological and Social Aspects of Synthetic Biology (SynBioMode)

Yleisradio, YLE Tiede 1, tiedetoimittaja Teija Peltoniemi
-Radiohaastattelu, ja Internet-podcast-sarja, 2015/2016

Principal Investigator: Minna Poranen
Project: Prokaryotic virus as a tool for synthetic biology

- Interview for Tiedelehti on the production of dsRNA-based vaccines for plant production (published in May 2018 "Voiko kasvin todella rokottaa tauteja vastaan?)
- Interview for Yliopistolehti on the production of dsRNA-based vaccines for plant production (published in May 2018 "Eroon tuholaismyrkyistä")
- Press release with the University of Helsinki on the publication "Niehl A, Soininen M, Poranen MM, Heinlein M (2018). Synthetic biology approach for plant protection using dsRNA. Plant Biotechnol J". This has resulted over 50 global media hits, with over 21 miljon potential readers.
- Interview for Kemia journal. Article based on the interview entitled "Virustutkija on paljon vartia" published in Kemia 5/2016.
- Interview for radio on synthetic viruses. YLE Tiedeykkönen: Miten komennetaan virus töihin?, broadcast on radio, 26.2.2016. Available also through YLE Areena (http://areena.yle.fi/1-3234780).
- Interview for Tekniikka ja Talous. Article based on the interview entitled "Biologiasta tulee insinööritiede" published on 19.2.2016.
- Interview for radio on synthetic biology, 2015.
- Interview for Kemia journal on synthetic biology. Article based on the interview entitled "DNA-palikoista rakennetaan biokoneita" published in Kemia 3/2015.
- Interview for Kemia journal on plant vaccination. Article based on the interview entitled "Rokotus pitää kasvin terveenä" published in Kemia, 8/2016.
- Presenter in a press conference (Tiedeaamiainen; Virusten toiminnan tuntemus avaa mahdollisuuksia niiden hyödyntämiselle: Virukset synteettisen biologian työkaluina) organized by the Academy of Finland, 26.1.2016.
- Presenter in a press conference on topic Sattuma tieteessä (University of Helsinki main building, Helsinki, Finland), 2015

Appendix 5: Synthetic Biology Foresight Workshop

Synthetic Biology Workshop Process and Results

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