Evaluation of the New Energy Programme 2015-2020

5 October 2021

ACADEMY OF FINLAND

Contents

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Foreword

The current energy transition is a systemic change that affects all people. Car buyers are starting to favour all-electric or hybrid vehicles, local neighbourhoods are asked to approve wind farms, LED lights and refrigerators at summer cottages are becoming solar-powered, and individual consumers can start selling energy to energy companies.

The drivers of this energy transition include climate change, the network-based advancement of science and the introduction of novel applications. Energy transitions are ever-evolving processes where a broad range of actors create and modify connections with each other using new technologies and practices. As activities and technology change, they give rise to competition, and there will be a huge need for scientific exploration, since changes require research.

The New Energy Academy Programme, which ran from 2015 through to 2020, was launched to give energy research a boost. The field of energy research is extensive, and its focus is changing rapidly. Thus, the bioenergy projects of the older Sustainable Energy Programme, were transformed under the New Energy Academy Programme to study energy systems and consumer behaviour.

The main objective of this evaluation report is to examine the results produced within the New Energy Academy Programme. The evaluation also includes recommendations for the future as well as ideas on a possible new programme. The evaluation was limited primarily to projects funded in the main call of the programme in 2014. The aim was to benchmark the New Energy Academy Programme against energy research programmes in other countries.

The objectives of the evaluation were defined by the programme's steering group, and the evaluation was carried out by an international group of experts in energy research. The evaluation has been carried out as part of the development of the programme activities of the Academy of Finland, and its objective is to provide information to researchers, the Academy and the Academy's stakeholders.

In the future, perhaps with a small modular nuclear reactor, we may be able to produce not only electricity but also district heating, hydrogen and process heat for industry as well as remove salt from sea water and produce drinking water. Hydrogen can be used to store wind energy and produce fuels. Electric-vehicle batteries can be charged with wireless technology. All around the world researchers are exploring and finding new solutions and applications. Science is advancing and developing rapidly. We hope that this evaluation report will give readers a picture of the benefits that energy research has already brought to society.

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Executive Summary

The Academy of Finland tasked a seven-member international panel to evaluate the recently completed New Energy Programme, highlighting success stories and possible areas for improvement. Based on the evaluation the panel has made several recommendations for a Future Energy Programme.

The panel unanimously agreed that the New Energy Programme was value for money, had some very strong scientific outputs, was impactful on industry, society, and training of Early Career Researchers.

With the energy transition starting to gain momentum globally the panel believes a Future Energy Programme is highly desirable and can build on the success of the New Energy Programme.

The panel makes several recommendations for a Future Energy Programme related to funding, objectives, reporting, transparency, impact, scale, engagement, adaptation, relevance and equality, diversity, and inclusion.

1. Introduction

1.1. Background

This report is the culmination of a review of the New Energy Programme (NEP) 2015-2020. The programme was funded and coordinated by The Academy of Finland, the major research funding agency in Finland, and consisted of 13 research projects funded in the Main call plus several others funded in four international calls, as summarised in Table 1. In common with other focussed research programmes at the Academy of Finland, the NEP was funded for a fixed period. This evaluation therefore assesses the success of the completed NEP and uses the findings to make recommendations for The Academy of Finland to consider in a Future Energy Programme.

Table 1 – Calls in the New Energy Programme (NEP) 2015-2020, their timeframes, budgets and number of funded projects

Call	Timeframe of projects	Budget	Number of funded projects
Main call 2014	2015 to 2018	10.2 M€	13
Joint project call with Indian DST	2015 to 2017	1.4 M€	3
New Indigo ERA-NET Energy 2014 call	2014 to 2017	1.1 M€	4
ERA-Net LAC Energy 2016 call	2017 to 2019	0.77 M€	4
Inno Indigo ERA-Net Energy 2016 call	2017 to 2020	1.62 M€	5

The key research objective for the NEP was to use scientific methods and identify solutions to resolve complex issues related to the ongoing energy transition. The Main NEP call was designed around three key themes, and proposals were only required to align with one of them, but many were aligned with more (3 aligned with three themes and 4 with two themes).

- *Consumers' energy choices*, which sought to investigate the economic and social driving forces behind energy choices and public authority ability, and routes to influence such choices.
- *Adaptation of energy production and consumption*, with the aim to create systemic models for managing the balance between production and consumption, and for the dynamics of new energy markets.
- *Integrated energy solutions*, with the aim to study processes and management methods associated with integrated energy solutions, as well as their compatibility with local production and their connectivity to the power grid.

The four international calls had different themes, described in Appendix A.

The other objectives of the programme were identified as:

- The creation of new national and international research collaboration networks for the programme and the establishment of multidisciplinary research groups
- Increasing the mobility of research students and researchers
- Improving international research and industrial competitiveness
- Taking Finnish energy research to the international leading edge in some research areas
- Social impact

The Academy of Finland began preparing materials for evaluation in Spring 2020 and initiated the review process in Spring 2021. An independent panel of six international experts and a scientific secretary was established to provide a critical evaluation of the performance of the programme and to provide conclusions and recommendations to the Academy of Finland for consideration in a Future Energy Programme.

1.2. Terms of Reference

Membership of the evaluation panel is provided in Table 2 and all members are acting as individual experts and are not representing their employers. The report covers the NEP as a whole and is not a review of each project individually. The principal focus of the evaluation is on programme performance with respect to projects in the Main NEP call. The four international calls are considered separately in Appendix A and they did not form the basis of the evaluation and/or recommendations.

Table 2 – The NEP Evaluation panel and their affiliations

Member	Affiliation
Dr Heli Antila	Vice President of Finnish energy company Fortum Oyj
Professor Russell McKenna	Chair in Energy Transition at the University of Aberdeen, Great Britain
Professor Mark O'Malley (Chair)	Professor and Chair of Electrical Engineering, University College Dublin, Ireland; Chief Scientist, Energy Systems Integration Group, USA; Chair Research Agenda Group, Global Power System Transformation Consortium
Professor Arthur J. Ragauskas	UT-ORNL Governor's Chair for Biorefining, Department of Chemical and Biomolecular Engineering, University of Tennessee, Knoxville, USA
Professor Roman Sidortsov	Associate Professor of Energy Policy, Department of Social Sciences, Michigan Technological University, USA Senior Research Fellow In Energy Justice And Transitions, Science Policy Research Unit University of Sussex, UK
Professor Arno Smets	Professor in Solar Energy in the Photovoltaic Materials and Devices, TU Delft, Netherlands
Dr Kathryn Wills (scientific secretary)	Programme Manager, Integrated Development of Low-carbon Energy Systems, Imperial College London, UK

The panel was asked to evaluate how successful the NEP had been against the following criteria:

- scientific quality of the programme
- the establishment of multidisciplinary research groups
- the creation of new national and international research collaboration networks
- increasing the mobility of researchers
- scientific and societal impacts of the research
- added value for working as a part of the programme
- need for future research/research programmes in the field
- projects' future

The panel was also asked to highlight strengths and weaknesses of the NEP, to draw clear conclusions and make specific recommendations, to provide a fair and honest evaluation and to include success stories in their report.

This report will be made public and circulated directly to the relevant stakeholders of the programme: staff at the Academy of Finland, the research teams, Business Finland, Ministry of Education, Science and Culture and Ministry of Economic Affairs and Employment.

1.3. Evaluation Process

The Academy of Finland provided the panel with background programme information and an extensive range of data sources and analyses for the Main call projects, including final project reports, project presentation slides, researcher survey responses, background statistics and bibliometric analysis. These materials fixed the boundaries for the panel's review.

The panel grouped the criteria listed in Section 1.2 into five areas as follows:

1. Quality: scientific quality of the programme
2. Impact: scientific and societal impacts of the research; added value for working as a part of the programme
3. Collaboration and mobility: the creation of new national and international research collaboration networks; increasing the mobility of researchers
4. Disciplinarity aspects: distinctive properties of the programme with respect to disciplines, including multidisciplinary collaboration on research and outreach.
5. Future: need for future research/research programmes in the field; projects' future

These five areas formed the basis of the aggregate evaluation of the 13 individual projects in the Main call (Table 1). Short public abstracts for all these 13 projects are included in Appendix B.

The panel conducted all business remotely. A review pre-meeting was held on June 2nd, 2021, to agree the evaluation process. Each panellist was assigned two areas (out of the five above) against which to evaluate in aggregate all Main call projects and a few projects to read and evaluate in detail. This resulted in every area and project having two panellists assigned. All panellists were paired with as many other panellists as possible to ensure a robust and self-calibrating evaluation. These contributions formed the starting point for discussions at the review meeting held on June 16th, 2021, where the panel discussed their evaluations across the areas, with individual projects only used for justification and for cross-referencing.

A foundational recommendation of the panel on June 16th was that a Future Energy Programme should be supported within the portfolio of the Academy of Finland or elsewhere within Finland's research support mechanisms. On that basis, the panel drafted a report with specific recommendations, in advance of a final panel meeting on July 6th, 2021. The panel unanimously agreed the report content, its conclusions, and all the recommendations.

The remainder of the report is structured as follows. Section 2 is the detailed evaluation and corresponding recommendations. It has three subsections, the first is a summary of the Aggregate Strengths and Weaknesses followed by Specific Findings and lastly a subsection on Equality, Diversity and Inclusion (ED&I). Section 3 provides a brief conclusion and lists for convenience all of the specific recommendations. Two Appendices are included. Appendix A is a very brief description of the international calls within the NEP and Appendix B lists the project titles, lead investigators and short public abstracts of the 13 research projects in the Main NEP call.

2. Evaluation & Recommendations

Having reviewed all the material provided, the panel unanimously concluded that the NEP was successful. The panel established that there were many credible outputs that had an impact ranging from publications, people trained, collaborations to some commercial activity (detailed below). This formed the basis of the foundational recommendation of the panel.

Foundational Recommendation: As soon as practical, a Future Energy Programme should be supported in Finland and should consider the specific recommendations in this report for its implementation.

The evaluation detailed below establishes the basis for this foundational recommendation and presents the more specific recommendations[1].

The panel noted that the objectives of the NEP and the criteria the panel was asked to consider are indicative of an ambition for a high impact research programme across multiple dimensions and technology readiness levels (TRL). However, the modest funding, multitude of projects and the short period of performance (four years) will naturally lead to a limited ability to cover all programme objectives to a high standard.

A good descriptor therefore of the NEP from the outputs is that it was a very heterogenous programme with a very wide range of Principal Investigators (PIs) from many different disciplines and different types of “impacts”. When the panel went deeper into some specific areas (see Section 2.2) the evaluation not surprisingly was less clear with a wide range of performances across an extremely diverse group of projects. Weaknesses can be found by focussing on individual projects but in aggregate

[1] Recommendations are placed appropriately throughout the report, but the reader should note that they are holistic and they do not necessarily apply only to that part of the report.

the programme was regarded to be successful by the panel. This report does point out some weaknesses and makes recommendations to how these may be overcome but it is understood that improvements in one dimension may come at the cost of performance in others, and this is a trade-off that the Academy of Finland needs to make.

Funding and Objectives Recommendation: A Future Energy Programme based on the same objectives and level of funding as NEP needs to clearly indicate that performance across all objectives, while desirable, is not expected; it is better to do well at a smaller number of objectives. Other possibilities are that funding levels are substantially increased and/or the number of projects awarded is reduced. Additionally, objectives can be reduced and/or prioritised, on an individual project basis at the call, proposal, or award stage.

2.1. Aggregate Strengths and Weaknesses

With only 13 projects funded (Table 1), across a wide range of topics, generalisations of aggregate strengths and weaknesses are very difficult to make. However, with that caveat in mind what follows is a summary that the panel felt were noteworthy and indicative of issues that may need to be considered in a Future Energy Programme. Some indicative examples of these strengths and weaknesses are given and full details can be found in Section 2.2 on specific findings. Specific recommendations that address the weaknesses are also indicated and details of these can be found in other parts of the report.

2.1.1. Strengths

Value for money

Considering the very modest scale of funding the panel are convinced that the NEP was certainly good value for the investment. This strength is the cornerstone of the foundational recommendation.

Strong research in specific areas

The NEP fostered several examples of world-leading excellent research, with some "lighthouse" projects producing outstanding high-impact publications and some potential for revolutionary results/outputs. The three Success Stories detailed below are indicative of this.

Some industrial R&D and cross-fertilisation

Underscoring the applied nature of energy research and the current energy transition, several of the projects funded under the NEP resulted in spinoffs, patents and/or research to business projects (for example, the patent filed from the AQUA-CAT project, *Method and apparatus for treating a side water fraction*; ongoing interactions with the Finnish biorefinery industry of the SusBioRef team via Business Finland projects). These activities demonstrate the relevance of the research to the energy industry and the wider society. They also prove that specific projects and academic teams can commercialise their research outputs.

High impact on Early Career Researchers

The programme generally resulted in a high level of support in nurturing Early Career Researchers (ECRs) into their careers and involving them in the projects. For example, the DEMEC project supported 2 PhD degrees, 1 Licentiate degree and several Master students.

Multi, inter & trans – disciplinarity

The programme positioned itself on the forefront of the emerging multi-, inter-, and transdisciplinary trend in whole system energy research with several research teams effectively used interdisciplinary high-impact journals to disseminate their research.

Programme structure

The panel recognised the benefits of encapsulating the range of projects in such a programme structure as this and the ability of general programme-wide activities to help fulfil programme objectives such as creating new networks and increasing opportunities for researchers and students. Researcher-wide training opportunities in topics such as social media and selling your research idea, plus the annual seminars to bring project teams together, are particularly valuable elements.

Success Story – VaGe

Improving the value of variable and uncertain power generation in energy systems

This project has revolutionised energy system modelling by developing an open-source, modular and highly versatile modelling framework called Backbone. The Project has

1. improved uncertainty estimates of weather-related power generation on short- and medium-term time scales,
2. enhanced the way these uncertainties are considered in energy models and
3. improved the way in which system analyses exploit flexibility from dispatchable renewables and on the demand side to integrate variable renewable energies.

The project has supported 5 PhD students, produced high-impact excellent publications (e.g., Nature Energy) and demonstrated the widespread application of the model with 30 users in 5 countries. Research collaboration and visits have been crucial in broadening the understanding and success of the Backbone model. The open-source approach has also enabled the model to be further improved by other parties. The Backbone model continues to be developed and applied in many European research projects and offers huge opportunities for future research.

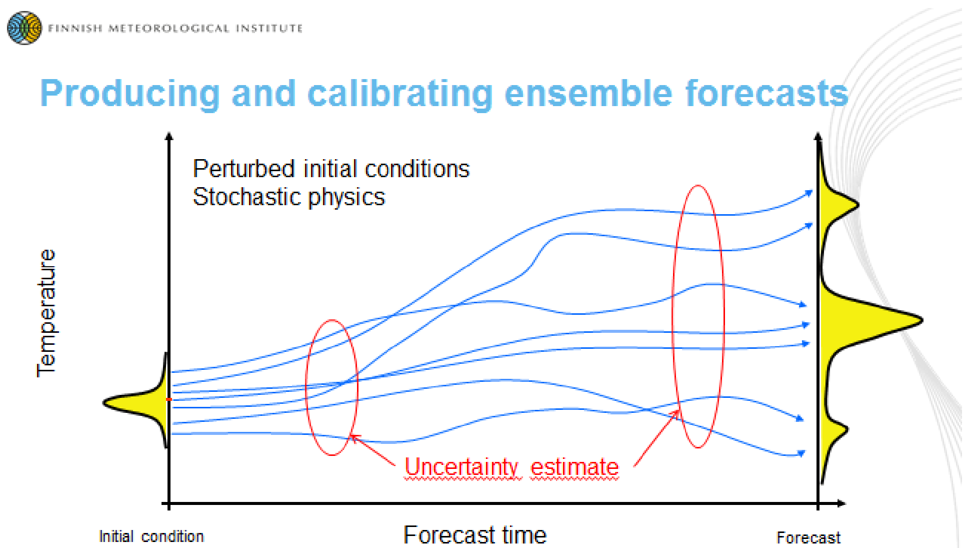

Figure 1 – an output from the VaGe project, which improved the uncertainty estimates of weather-related power generation on medium- and short-term time scales. The diagram shows a complete description of weather prediction in terms of a Probability Density Function

Some sample outputs from the project:

1. Uploading the code for Backbone to a public repository was an important channel of dissemination: https://gitlab.vtt.fi/backbone/backbone
2. Research featured in Nature Energy, *Effects of turbine technology and land use on wind power resource potential*. Nature Energy, 3 (6), 494-500.

2.1.2. Weaknesses

Some project-specific weaknesses are not reported here. Some weaknesses are evident of the aggregate of the programme itself and are reported here, and some are outside the scope of the programme but should be addressed or at least acknowledged.

Funding & Objectives
The funding for the programme is very small compared to the range of objectives and the number of research projects. (**Funding and Objectives Recommendation**)

Scale, Diversity, and Timeline
The programme is too small in scale, diverse in objectives and on a timeline that is challenging to really have a significant impact in the Finnish energy industry. (**Impact and Scale Recommendation)**

Relevance
Considering the applied nature of energy and the rapidly occurring transition, the programme could do with more industry engagement and be more adaptable and nimbler. (**Relevance and Adaptation Recommendation)**

Communication, Engagement, Impact and Reporting
There was some poor/lacking communication of results, which partly obscures the impact category, and limited evidence of wider non-expert/public engagement activities. **(Engagement and Impact Recommendation)**

Equality, Diversity and Inclusion
While not in scope, the panel did recognise some possible weaknesses associated with equality, diversity, and inclusion. (**Equality, Diversity and Inclusion Recommendation**)

2.2. Specific Findings

2.2.1. Quality

The research carried out in the NEP had an overall high standard of internationally recognised work. In some research areas the work was excellent. The research that has been carried out in the programme addresses a large variety of scientific questions and challenges along the sustainable energy value chain, with a focus on challenges relevant for Finland's energy infrastructure. The research in the 13 projects in the Main call is well balanced across the different sciences and covers various technical readiness levels, going from highly fundamental concepts for optical, physical and chemical properties of functional energy materials and devices; up to system research & design of components for energy generation, energy conversion, energy transport, and energy storage; up to techno-economic and social studies of the entire future energy value chain. The fact that the programme is spread across so many disciplines makes the evaluation of the programme challenging, as the various scientific disciplines have different types of metrics to determine quality.

The quality of research is obviously not just about the number of papers and citations; however, they are the only quantitative measure we have within our scope. The programme resulted in a good quantitative and qualitative publication record with 132 publications having an average of 19 citations per publication. The appreciation of international peers is demonstrated by the 20% fraction of publications that is in the top 10% most cited work in the corresponding field. The Category Normalised Citation Impact (CNCI) of the programme is 1.57, showing that the citation impact of the program is above world average (CNCI=1). A fraction of 50% of the publications has at least one co-author with an international affiliation, highlighting the excellent international outreach of the researchers and consortia in the programme.

In one case, the number of publications listed is not consistent with the size of the project. The evaluation panel suspects that in this case the reported publication list presented to the programme administration might be diluted by results obtained in other programmes[2].

Reporting and Outputs Recommendation: Reporting should include a basic assignment of the relative contribution to outputs from programme funding and from other sources. This is not intended to be an onerous task, rather a simple assignment of low, medium, or high level of contribution.

All the projects except for two, address at least one of the three key themes described in Section 1.1. These two projects cover fundamental research related to energy material sciences at a TRL 1. They do not directly address one of the key themes, however, their scientific quality is excellent and focuses on the innovation potential of the fundamental scientific concepts. This is noteworthy considering the overly ambitious objectives and the low level of funding and has prompted a recommendation on transparency.

Transparency Recommendation: Post award, the Academy of Finland should specifically state how each project addresses the themes and objectives of the programme and include these in the public abstracts of funded projects (Appendix B).

A final observation from the panel is that while individual research projects did show an appreciation for a whole energy system approach, the aggregate of the NEP appeared not to take this on at a programme level to the extent that it could have. The yearly meetings between all the various researchers would have been an opportunity

[2] This project's publication list was excluded from reported bibliometric analysis above.

to pursue whole system opportunities and could be utilized as such in a future energy programme.

2.2.2. Impact

Overall, the scientific impact of the NEP was found to be very good, or excellent in some cases, with a large number of high-impact publications as discussed above in the Quality subsection, 2.2.1.

There is evidence of some pioneer or “lighthouse” projects in specific areas, for example in energy system modelling (VaGe) and semiconductor materials (DEMEC). These projects have produced very high-impact journal publications, and/or patents (e.g., AQUACAT), and/or there is evidence of a widespread adoption of their work within the wider research community (e.g., the Backbone model from VaGe). Some of the projects appear to enjoy a high level of visibility within the wider scientific and political community.

In addition, there are examples of cross-fertilisation between industry and academia, with some patents, spin-offs and research to business activities. Whilst these activities are the exception rather than the rule, they are an example of excellence in terms of research impact. In terms of the fraction of industrial co-authors on publications, this reached 12.5% and 20% in Electrical and Electronic Engineering and Materials respectively, whereas it was much lower in other fields. The level of industrial involvement in most of the projects was relatively low. Industry advancement was not explicitly an objective of the programme and therefore impact in this area may be more relevant for follow-on work and potentially requiring significant additional funding. Impacts from this programme will be, and are, more broadly based around academic publications, training of personnel and general outreach and education. However, as energy research is a very applied area, and the current energy system is undergoing an enormous transition, industry involvement should be seen not as a *nice to have* but should be encouraged for real impact.

Impact and Scale Recommendation: With relatively small funding routes, it is recommended that a Future Energy Programme works in tandem with some of the larger Finnish funding mechanisms. This would allow the projects to be more impactful, relate to real problems and be part of a bigger and more diverse set of stakeholders, in particular industry where appropriate.

The impact on ECRs is generally very good, with many PhD and Master students supervised through the programme. The integration of these students into ongoing research programmes is an example of best practice in supporting ECRs.

There are some instances of poor or lacking documentation and communication of activities and results. This means that some of the actual impacts of the projects are unclear to the panel, and therefore by extension to other researchers and wider society. There is little evidence of wider non-expert or public engagement activities carried out as part of the projects – the exception here seems to be the engagement of primary schools in the INDO-NORDEN project, which is from an international call (Inno Indigo ERA-Net Energy 2016) of NEP rather than the Main call.

2.2.3. Collaboration and Mobility

The panel judged that overall, the collaboration and mobility aspects of the programme were good and satisfied the relevant objectives described in Section 1.1. Many examples of exchanges and visits both nationally and internationally were noted, with 6 projects reporting 0-4 visits and 7 projects reporting 5-13 visits. The number of short visits (days) outweighed the number of longer visits (months) and almost all projects undertook both types of visit.

In the majority of projects, the mobility plan was either realised as planned or changed for particular reasons but still reported to be effective overall. In DEFEND the team quote “The realized mobility differs from the planned one. However, the realized mobility has exceeded the academic and intellectual expectations.” The panel is sensitive to the practicalities of mobility and recognise that personal circumstances can change, and sometimes limit, mobility ambitions of a project.

The panel recognised the impressive extent of international visits across the programme, but noted it was not always clear what the mobility activities did to advance the research projects and their goals. However, there are also the broader benefits of such mobility opportunities to consider, for example as career enhancement and personal development opportunities for ECRs, which can be more difficult to quantify.

International collaboration was strong overall (e.g., VaGe collaborated across five countries; DEFEND had collaboration with 10 international institutions) and the number of new (26) and existing (28) collaborators was balanced at a programme level, although variation was greater between projects. An example of a positive outcome from such activities is noted from the AQUACAT project, where a four-month visit by a researcher to VTT as part of a new collaboration with the University of Basque Country, Spain, resulted in the subsequent recruitment of the researcher to Aalto University. The AQUACAT project is featured in more detail in the Success Story below.

A final observation from the panel is that there is an opportunity for collaboration between PIs in a Future Energy Programme and PIs with experience from the NEP that may be valuable. This could be achieved by encouraging networking between these two sets of PIs to share best practices and for some informal mentoring.

Success Story - AQUACAT

The value of mobility opportunities and collaboration in research

The AQUACAT project investigated and developed catalysts to convert organic residues in waste waters from biorefineries to valuable gases, such as hydrogen, to be used as energy carriers. In addition to the primary research teams at Aalto University and VTT the project had a strong set of supporting collaborators at the University of Twente, Netherlands, and Imperial College London, UK. In this project the planned mobility and collaboration plan was realised and directly contributed to the achievements of the research goals, illustrating the importance of building in meaningful collaborations at project conception stage with genuine routes of engagement mapped out. Catalysts that were developed at the home institution were then tested and analysed during visits to collaborator sites, as well as working together to develop the reactor setup experimental work. The collaborations identified were a mix of new and existing, and researcher visits included short trips to gain learnings on reactor use which were implemented in follow-on work at the home institution, through to placements of several months to conduct reactor builds and catalyst analysis.

A Scientific Advisory Board was described as very active. The Board included the collaborators and the group met annually to present and analyse results and decide on next steps. As well as instructing and guiding the project, the Scientific Advisory Board also acted as an enabler for researcher visits.

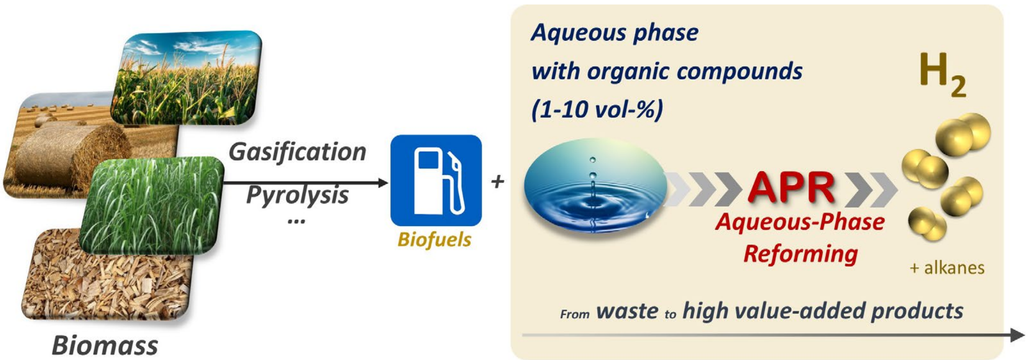

Figure 2 – overarching process from the AQUACAT project

Some sample outputs from the project:
1. A patent application was made: P-FI108520T / PC17027FI: Method and apparatus for treating a side water fraction. Filing date: 11/12/2017
2. Six journal papers were published, including one co-authored with the project’s collaborator from the University of Twente

2.2.4. Disciplinarity Aspects

The affirmation of the ongoing energy transition and the importance of Finland's role and strengths in the transition, as well as the recognition that such a complex and multi-faceted challenge cannot be solved by a single discipline, positioned the programme to be an innovative funding initiative at the time of its inception.

The origins of the programme's focus on multidisciplinarity lie in the December 2012 and September 2013 seminars organised in preparation for the programme that included a wide variety of researchers and representatives of stakeholders and end users. It is not surprising that the programme's work covered high-impact topics such as electricity storage and demand side response. The first expectation listed in the programme memorandum (PM) is to make multidisciplinary inroads into the three theme areas (consumer behaviour, new energy-based business opportunities and energy sector innovation). The PM also lists applied and contextual approaches, as well as the systemic approach, as methodological themes of the programme. The term multidisciplinarity is often used interchangeably with inter- and transdisciplinarity despite significant conceptual differences. The former usually refers to the cross-use of methodologies and literature by multiple disciplines whereas the latter adds to incorporating non-academic researchers and approaches into research design and activities. This suggests that perhaps in addition to multidisciplinarity, interdisciplinarity and transdisciplinarity could have been used in the programme's description.

There is plentiful evidence suggesting that the programme succeeded in fostering multidisciplinary collaboration. With a few exceptions, projects were staffed by researchers representing a wide range of disciplines resulting in well-rounded research outputs. For example, EVIDENCE featured collaboration across several engineering fields including software, computer, and systems engineering and TPXENERGY included collaboration of physicists, material scientists, and engineers. The commitment to multidisciplinarity did not appear to come at the expense of producing solid science within the boundaries of individual disciplines. There is also evidence of interdisciplinary collaboration. Unfortunately, many final reports do not specifically highlight the utilisation of methodologies and concepts across multiple disciplines, although when noted (see the Success Story highlighting the USE project) the quality of interdisciplinary collaboration is clearly visible. Most of the evidence of interdisciplinary research comes from the publications noted in their final reports. Many outputs were published in high-impact interdisciplinary journals under titles implying interdisciplinary nature of the published work.

Transdisciplinarity is an area in which the programme can improve going forward. As noted in the Impact subsection, 2.2.2, the participation of industrial partners could have been more extensive, as well as the utilisation of workshops, focus groups and other co-production and co-design activities. Yet there are a few examples of excellent transdisciplinary work described in project reports. For instance, USE researchers involved a wide range of stakeholders in various facets of the project including the steering committee, industry workshops, project seminars, and outreach to a parliamentary group. Their work was summarised in policy briefs accessible to a broader audience.

Engagement and Impact Recommendation: Projects should be more focussed on impact and engagement with the wider community and adopt a more whole system approach with roles for multiple disciplines. The projects should also consider the formation of a broadly based advisory/steering committee, leveraging the yearly programme meetings and interactions with previous principal investigators to enhance whole system impact. Report templates should reflect these aspects and principal investigators should identify and explain shortcomings in project implementation and outputs.

Success Story - USE

The results of building a multidisciplinary and diverse research team

Inter, multi-, and trans-disciplinarity have been among key indicators of research and scholarship innovation for over a decade. However, putting multidisciplinary teams together and producing high quality research and scholarship that transcend disciplinary silos remains difficult.

The Change in Business Ecosystems for Local Renewable Energy and Energy Efficiency -- Better Energy Services for Consumer (USE) project serves as an example of such effort. One of the key deliverables of USE was the adoption of the ecosystem concept from natural sciences to envisage integrated renewable energy and energy efficiency solutions for the ongoing energy transition. This novel approach garnered significant attention among energy scholars as evidenced by 227 citations that one of the papers reporting the study findings received. The USE's team success is not surprising considering its disciplinary diversity.

The project was carried out by a well-balanced mix of social and environmental scientists, engineers, industrial management and automation and systems technology researchers. In addition to the disciplinary diversity, the USE team was well-balanced in terms of age and gender. USE featured a stellar co-production and stakeholder effort both of which can be at least partially assigned to the richness of perspectives, skills, and talents of the project team.

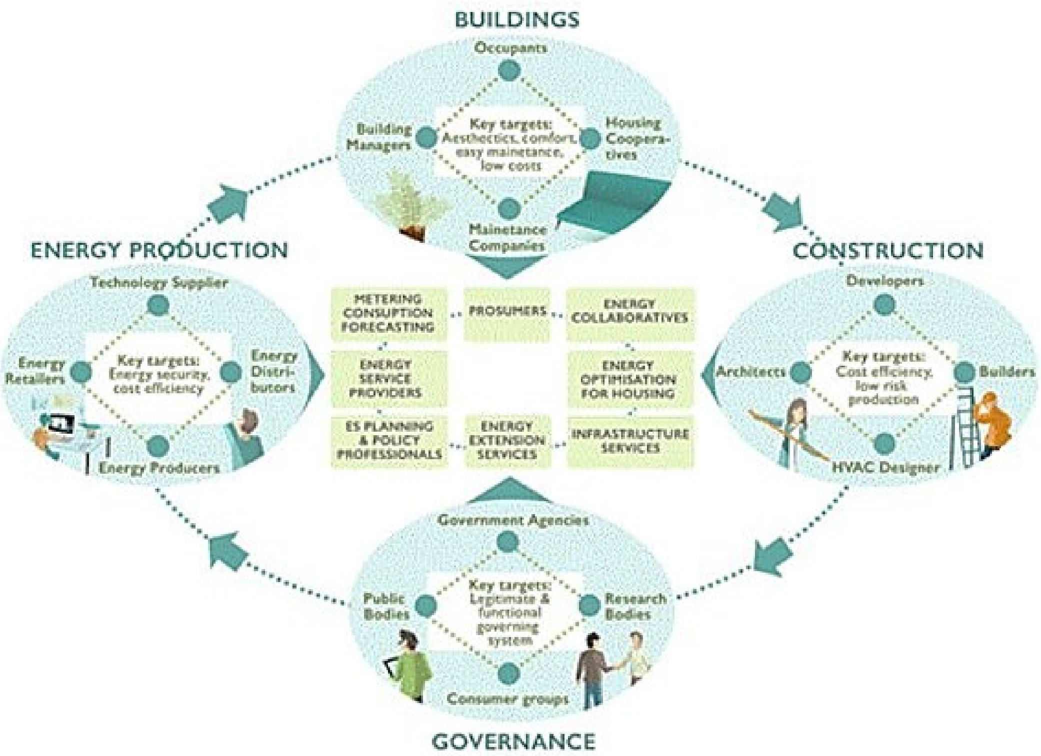

Figure 3 – from the USE project, which co-developed ideas on how the generation, implementation and scaling up of new innovative service solutions and the acceleration of business ecosystems could be enhanced in the sector

Some sample outputs and outcomes from the project:

1. Four academic publications in the high-ranking, interdisciplinary, journal *Energy Research & Social Science*
2. The USE project provided background papers for Finland's medium-term climate policy plan in 2017 and to inform government discussions on improving building energy efficiency in 2019.

2.2.5. Future

The energy transition is gathering pace and change is rapid. The NEP was established over 7 years ago and the process that led up to its formation is almost a decade old. Therefore, some of the research projects look outdated because the area they were in has evolved rapidly in the past few years.

Relevance and Adaptation Recommendation: A Future Energy Programme needs to be much nimbler and more responsive to a rapidly changing energy industry and policy environment. It needs to adapt to a situation where even basic research needs to be applied and adopted in a short period of time to maintain relevance. A specific example of this would be to have a check in (not a review) with the Academy and some relevant external experts at the midpoint of the project to accommodate any changes in direction and enable the project to adapt to shifts in the energy environment.

As mentioned earlier, this programme consists of a variety of different types of projects. Some projects would have benefited from closer connection to industry: both to receive industry insight but also to enable progress from basic research to Business Finland financed applied research projects. Projects focusing on consumer behaviour would have benefited from both stronger industry involvement to bring in industry learnings and an understanding of market impacts into projects, and from larger society involvement and dissemination (e.g., advisory/steering committee).

More general comments for the future relate to supporting more movement from industry to academia and vice versa. Another angle is the diversity of PIs, discussed in more detail in Section 2.3. If these topics are considered important to advance, perhaps they should be brought into the project funding criteria or otherwise acknowledged in a Future Energy Programme agenda.

2.3. Equality, Diversity and Inclusion

The panel notes that there was no requirement for an ED&I statement in the project proposals. Therefore ED&I is not a criterion of the review and is out of scope. Nevertheless, the panel made the following observations on some limited aspects of ED&I, based on the available data, which they felt were pertinent to bring to the attention of the Academy of Finland and which may be useful in developing a Future Energy Programme.

The panel noted the profile of PIs was very similar across the projects. The profile of a PI was typically older, male and of Finnish nationality. In the Main call, 39% of PIs were 56+ years old when the research commenced in 2015 and 68% of PIs were aged 46+. The nature of this programme funding means that the call is open to all academics, whereas in some funding streams there are limitations. This may have swayed the success rate in favour of older, typically more experienced, PIs.

Gender diversity was generally well below an equal 50/50 split, with 23% female PIs in the Main call. The panel noted that, in half of the Main call projects, gender is reasonably balanced across the wider team, with two projects (DEFEND and USE) comprising more female than male personnel. The other half of the projects showed low female representation, with five projects comprising at least 80% male staff. Overall, across project teams the split was 69% male and 31% female.

The panel also observed that PIs were predominantly Finnish, with only 6.5% of PIs being foreign citizens in the Main call. However, around half of projects reported a reasonably balanced international research team and a similar number reported at least 80% Finnish nationality staff.

Therefore, it is noted that within the research projects the age/gender/international profile appears to be more balanced in some cases and is a sign of change, which may indicate there is no need to be proactive. This is a complex area and equality of opportunity rather than outcome is possibly more important and the panel does not have the expertise and/or the data to advise in-depth on this matter.

However, it is noted that any activities to expand the talent pool in the energy sector are valuable. Also recognising that the energy transition is a multi-decade event, it is important that research talent is engaged in it on a continuous basis. This indicates that some sort of preference may need to be given to younger PIs. This includes encouragement and enablement of ECRs to take on leadership roles to safeguard the talent pipeline and build capacity within Finnish energy research for the future.
Based on the information provided and recognising its importance in ensuring the best human talent is available, the panel has made the following recommendation.

Equality, Diversity and Inclusion Recommendation: The Academy of Finland, after further investigation, may want to consider how best to improve Equality, Diversity and Inclusion in a Future Energy Programme.

3. Conclusions and Recommendations

In conclusion, the New Energy Programme was successful, and the Foundational Recommendation of this evaluation is that a Future Energy Programme for Finland should be established that considers the specific recommendations here for its implementation. The recommendations are based on the Programme the panel were tasked with evaluating and should be understood within this context, and not interpreted as a blueprint for a new programme.

Funding and Objectives Recommendation: A Future Energy Programme based on the same objectives and level of funding as NEP needs to clearly indicate that performance across all objectives, while desirable, is not expected; it is better to do well at a smaller number of objectives. Other possibilities are that funding levels are substantially increased and/or the number of projects awarded is reduced. Additionally, objectives can be reduced and/or prioritised, on an individual project basis at the call, proposal, or award stage.

Reporting and Outputs Recommendation: Reporting should include a basic assignment of the relative contribution to outputs from programme funding and from other sources. This is not intended to be an onerous task, rather a simple assignment of low, medium, or high level of contribution.

Transparency Recommendation: Post award, the Academy of Finland should specifically state how each project addresses the themes and objectives of the programme and include these in the public abstracts of funded projects (Appendix B).

Impact and Scale Recommendation: With relatively small funding routes, it is recommended that a Future Energy Programme works in tandem with some of the larger Finnish funding mechanisms. This would allow the projects to be more impactful, relate to real problems and be part of a bigger and more diverse set of stakeholders, in particular industry where appropriate.

Engagement and Impact Recommendation: Projects should be more focussed on impact and engagement with the wider community and adopt a more whole system approach with roles for multiple disciplines. The projects should also consider the formation of a broadly based advisory/steering committee, leveraging the yearly programme meetings and interactions with previous principal investigators to enhance whole system impact. Report templates should reflect these aspects and principal investigators should identify and explain shortcomings in project implementation and outputs.

Relevance and Adaptation Recommendation: A Future Energy Programme needs to be much nimbler and more responsive to a rapidly changing energy industry and policy environment. It needs to adapt to a situation where even basic research needs to be applied and adopted in a short period of time to maintain relevance. A specific example of this would be to have a check in (not a review) with the Academy and some relevant external experts at the midpoint of the project to accommodate any changes in direction and enable the project to adapt to shifts in the energy environment.

Equality, Diversity and Inclusion Recommendation: The Academy of Finland, after further investigation, may want to consider how best to improve Equality, Diversity and Inclusion in a Future Energy Programme.

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Appendix A: International Calls

For the International call projects, the information supplied was not as extensive as the Main call projects and had different themes. Three of the four are ERA-NET – "networks of public research organisations that coordinate joint research activities in research areas which are of significant strategic value and relevance to the EU" and one is specifically with India. Therefore, they all had strong collaboration and mobility. Their themes are outlined below:

- Bilateral DST call in 2014 themes: 1. Offgrids services and concepts in electricity and heating production for example in solar energy and photovoltaic technologies, 2. Combined heat and power technologies and waste management especially Industrial CHP concepts and urban city energy concepts, 3. Energy efficient information nets
- New Indigo ERA-NET call in 2014 themes: Smart Energy Grids, New Energy Materials
- ERA-NET LAC call in 2016 themes: Biorefinery and Wind energy
- Inno Indigo ERA-NET call in 2016 themes: Biofuels, From waste to energy

The funding level per project in these programmes was significantly below that of the Main call (roughly half or less on average) and the projects were funded via the EU programmes noted rather than the Academy of Finland directly. The panel did not evaluate these to the same degree as the Main call. The panel observed that these international programmes if fully evaluated would share many of the same characteristics as the Main call.

The panel concluded that these international programmes are complementary to the Main call, can also enhance the objectives of the Main call, and therefore should be retained in any future energy research programme.

Appendix B: Main call funded projects public abstracts

USE

Change in Business Ecosystems for Local Renewable Energy and Energy Efficiency – Better Energy Services for Customers

Laura Sokka, VTT, *consortium leader*
Paula Kivimaa, Finnish Environment Institute

Application's public abstract

It is increasingly stressed that production technologies alone will not meet sustainability challenges, and attention must turn to the factors influencing and transforming consumption at individual, household and community level. A part of the solution is systemic innovations encompassing production-consumption chains in a new way. The aim of this consortium is to create an understanding of transition in the integration of renewable energy and energy efficiency solutions for consumers at the level of buildings and districts. Particular attention is paid to the emergence and diffusion of service-based innovations for integrated energy services, their role in system transition, and drivers and barriers to the above providing knowledge on how these could be better promoted. The project will also support piloting new innovative energy services and will analyse governance frameworks and instruments from the perspective of new service-based ecosystems and sustainable energy transitions.

VaGe

Improving the value of variable and uncertain power generation in energy systems

Hannele Holttinen, VTT, *consortium leader*
Sami Niemelä, Finnish Meteorological Institute

Application's public abstract

The project will seek ways to improve the value of wind power and PV. Wind and PV are more variable and uncertain than conventional power generation and therefore not as readily accommodated in the energy system. Better forecasts can reduce the uncertainty of wind power and PV generation, but weather forecasts have not been fully optimized to output data for energy system models before this project. Weather models generate detailed forecasts that extend up to two weeks. Existing energy models do not use all this data, although it will become more important as energy generation will be increasingly driven by weather. The project will build a model layer to utilize the two week forecast data. Another layer will be added to model household energy use. Finally, the improved models will evaluate future energy systems: how to best balance large amounts of variable and uncertain power generation, increasing consumer participation, building integrated energy solutions, and the role of biomass.

DEFEND
<u>Decentralizing Finland's energy regime: The triggers and dynamics of transition</u>

Janne Hukkinen, University of Helsinki, *consortium leader*
Mika Järvinen, Aalto University
Peter Lund, Aalto University

Application’s public abstract

The objectives of DEFEND are: (1) To analyze the institutional, behavioral, economic, political and technological dynamics that drive the centralization of the Finnish energy regime. We synthesize lessons from Europe and the United States with successful decentralization policies, and experiences in ongoing projects in Finland that would require regulatory support. (2) To develop behaviorally grounded policy tools that enable changing the institutional framework and enable transitioning into a locally-oriented, more self-sufficient and greener decentralized energy system. We conduct experiments with science-policy interventions to nudge the energy regime toward resilience and adaptation. We synthesize the results into energy policy tools with which to trigger and facilitate energy transition in Finland from a centralized and vulnerable energy regime based on non-renewable resources toward a locally oriented and resilient regime based on renewable resources.

EVIDENCE
<u>Evaluating Smart Incentives in Social Formation of Energy Choices</u>

Giulio Jacucci, University of Helsinki, *consortium leader*
Tarja Häkkinen, VTT
Marko Turpeinen, Aalto University

Application’s public abstract

The project EVIDENCE objective is to understand and provide tools for the social formation of energy choices. Current measures (dynamic pricing, consumption feedback, campaigns on social norms, and conventional social media) are only partially effective in changing habits or energy choices. Also current models based on rationality choice and social norms are limited in considering the active role of networks of people and technologies. Based on constructivist approaches and field work the project will develop models of social formation of choice accounting for different social levels influence (household, neighborhood, community, society) and layers of technology (building, energy systems, equipment, devices). In the unique GreenCampus Test bed the project will develop services that combine active demand and eco-feedback, encompassing choice support systems and dynamic pricing addressing different layers of the technological environment and different levels of social organization.

RESPONSE
Improved Modelling of Electric Loads for Enabling Demand Response by Applying Physical and Data-Driven Models

Pertti Järventausta, Tampere University, *consortium leader*
Seppo Hänninen, VTT
Mikko Kolehmainen, University of Eastern Finland

Application's public abstract

The aim of research is to develop enhanced models for load and control response forecasting required by dynamic optimisation of demand response (DR) actions and network operation in a future sustainable energy system. DR is one of Mainkey issues in adaptation of energy production and consumption and in creating flexibility to integrated energy.

The project is carried out in the multi-disciplinary research consortium with wide scientific expertise including units from Tampere University of Technology, University of Eastern Finland and VTT. They have also established international collaboration with several universities in Europe.

The research methods include various mathematical and statistical methods (e.g. artificial neural networks, support vector machines, Bayesian methods, Kalman filtering, modern control and optimization methods). Large smart metering data sets and field tests are used together with open data (i.e. weather, building and socioeconomic grid data) in modelling.

DEMEC
Rational design of non-noble metal (electro)catalyst materials for energy conversion applications

Kari Laasonen, Aalto University, *consortium leader*
Tanja Kallio, Aalto University
Esko Kauppinen, Aalto University

Application's public abstract

New (electro)catalyst materials enabling storing of electrical energy into chemical compounds, e.g. hydrogen, and regeneration of electricity are designed, synthesized and investigated in a rational manner. The aim is to design and develop new low cost (electro)catalysts free of critical raw materials, i.e. noble metals, for readily scalable and integrable hydrogen energy conversion technology. Oxygen reduction (ORR) and hydrogen evolution reactions (HER) are the fundamentally important reaction for electrochemical energy conversion and storage. Recently we have shown that metal free nitrogen doped carbon nanotubes (N-CNT) are good catalyst for HER. To our knowledge this is the first time as N-CNT material is used for HER. We have also very promising results from metal capsulated systems as catalyst: Fe-CNT materials developed by us for HER are at least as good catalyst as Pt/C.

Flexible Customer
<u>Harnessing consumer for a flexible energy system architecture</u>

Matti Lehtonen, Aalto University, *consortium leader*
Matti Liski, Aalto Universty

Application's public abstract

Increasing the intermittent energy, like wind and solar will pose a challenge to the balance of the power system. This situation requires new energy system architectures to increase the flexibility both at the generation side and at the consumption side. The objective of this research project is to harness the customer flexibility and to bring the consumer to the center of the new power system designs. The project combines a rich set of register data on consumer technologies and characteristics with the traditional power system analysis. Socio-economic databases for consumer behavior are utilized in a power system context to experiment with architectures for market interactions, incentive schemes, power balancing, and drastic changes in the capacity portfolios. The research consortium combines customer behavioral studies to electricity markets and to the control architectures of future sustainable energy systems.

TPXENERGY
<u>Thermophotonic energy conversion for efficient heating and cooling in buildings</u>

Harri Lipsanen, Aalto University, *consortium leader*
Mircea Dorel Guina, Tampere University
Jukka Tulkki, Aalto University

Application's public abstract

TPXENERGY combines the expertise of the consortium partners to demonstrate EL cooling and thermophotonic (TPX) heat transfer in simplified structures where LEDs and photovoltaic cells are enclosed within a single semiconductor cavity. This eliminates the conventional light extraction challenges and dramatically enhances the optical interaction strengths and emission efficiency. The multidisciplinary research is expected to provide the first step in revolutionizing the present heating and cooling applications by the developed optical technologies.

SusBioRef
<u>Sustainable production concepts on integrated biorefining industry</u>

Ari Pappinen, University of Eastern Finland, *consortium leader*
Juha Tanskanen, University of Oulu

Application's public abstract

Decentralized production of energy and biochemicals in the SME companies operating as a member of industrial ecosystem would present one opportunity and model for integrated forest biorefinery in the future.

In this project, the target is to increase the feasibility of effective process schemes and industrial ecosystems for sustainable, distributed production of biochemicals and biofuels by developing new hybrid separation systems, improving new value chains and industrial ecosystems for biorefining processes, and evaluating sustainability of biorefining processes utilizing hybrid separation techniques.

coRENE
<u>Converting the surplus of intermittent renewable energy to carbon-negative advanced biofuel</u>

Ville Santala, Tampere University

Application's public abstract

Due to the strong dependence of renewable electricity production to environmental conditions (wind, sunshine), strong fluctuations occur in production output. As storing electricity is expensive and inefficient, consistent supply of renewable electricity is very challenging. In this project a new system is developed to exploit the surplus intermittent electricity in production of advanced traffic biofuel in a carbon negative manner.

Aquacat
<u>Catalytic aqueous phase reforming of biorefinery water fractions</u>

Reetta Karinen, Aalto University, *consortium leader*
Pekka Simell, VTT

Application's public abstract

The aim of the project is to investigate and develop catalytic aquoues phase reforming technology. Aqueous phase reforming is suitable for the conversion of organic matter to valuable energy carrier gases in diluted aqueous biorefinery side streams. In this project, aqueous phase reforming technology is studied by a multidisciplinary approach combining development of novel heterogeneous catalysts and modelling based reactor and process concept development and intensification. Finally an improved and intensified concept of aqueous phase reforming of biorefinery side streams is proposed and published.

SCCC
<u>Tackling the Challenges of a Solar Community Concept in High Latitudes</u>

Kai Siren, Aalto University, *consortium leader*

Jaakko Aspara, Svenska Handelshögskolan
Md. Munjur E. Moula, University of Helsinki

Application's public abstract

The Mainobjective of this three year project is to find scientifically based methodologies and solutions for the major challenges and obstacles in the implementation of a solar community concept in the Finnish environment. The work is divided into four Work Packages: i) WP1 Concept development and adaptation to local conditions; ii) WP2 Solutions for long-term energy storage; iii) WP3 Business models for new type construction projects; iv) WP4 Customers' economic and environmental demands and preferences. The research partners are: Partner 1: Aalto University, School of Engineering, Department of Energy Technology and Department of Civil and Environmental Engineering; Partner 2: Hanken Swedish School of Economics, Department of Marketing; Partner 3: University of Helsinki, Faculty of Social Sciences, Department of Social Research.

OPTOBIO

Conversion of light to transport fuels through integrated optoelectronic cell factories

Ilkka Tittonen, Aalto University, *consortium leader*
Merja Penttilä, VTT

Application's public abstract

Certain organic compounds are highly effective in energy transport and enable high energy storage density. However, the efficiency of current industrial methods to reduce CO_2 into fuels and chemicals is only a fraction of the theoretical maximum. Our aim in the OptoBio project is to increase the efficiency of light and CO_2 conversion to a specific fuel component by development and integration of non-biological and biological systems. Synthetic light harvesting systems based on optoelectronics possess the potential to increase the overall light-harvesting efficiency by converting light to electricity or hydrogen, by using nanoscale structures as electron guides and for enhancing microbial immobilization, and by photoelectrochemical reduction of CO_2 to an auxiliary carbon source. The major benefit is the possibility to combine all the above innovations into one system. As a result we will design new types of bioreactors that take use of light energy in conversion of transport fuels.

