Forskningsrådet

# Midway Evaluation of eight Centres for Environment-friendly Energy Research

Evaluation
Department for Energy Research

The Research Council of Norway

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Visiting address: Drammensveien 288
P.O.Box 564
NO-1327 Lysaker

Telephone: +47 22 03 70 00
Telefax: +47 22 03 70 01
post@rcn.no
www.rcn.no

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# Preface

This evaluation report presents the midway evaluation of the eight Centres for Environment-friendly Energy Research, FME, which started in 2016/2017. This is the second group of FMEs with main focus on technological research. The FME scheme was launched in 2010 and is one of the Research Council's most important instruments for research on environment-friendly energy research. The overall objective of the scheme is to help to solve key challenges in the energy sector, generate solutions for the low-emission society and enhance the innovation capacity of the business sector. The scheme is also expected to strengthen technology transfer, internationalisation and researcher training.

The centres are co-financed by the Research Council, host institutions and the centre partners. User partners from industry and public sector participate actively in governance and research.

When the centres were established, they were given a contract for five years. Based on a successful midway evaluation the contract may be extended for another three years.

In this midway evaluation, each centre has been evaluated by a panel of four international experts; two scientific experts with expertise to evaluate the research activities of the centre, and two generalist experts with experience to evaluate organisation, management and innovation activities. The two generalists participated in the evaluation of all eight centres, while the two scientific experts were specific for each centre.

Because of the pandemic, the evaluation interviews with the eight centres were held by videoconferences. Thanks to very good preparations both from the evaluation panels and the FMEs, the virtual process worked very well, however compared to physical meetings, some aspects were missing. This is reflected on in the first chapter of the report.

The report from the evaluation panel has two main purposes:

1. It will form the basis for a decision about whether to continue the individual centre for the remainder of the overall eight-year term, or to close it down after five years.
2. The evaluation will give advice to the centres on aspects of their activity that should be improved.

It is the Council’s decisions whether to prolong individual centres or not.

The Research Council of Norway wants to express a great appreciation to the international evaluators. Particular thanks go to Professor Mary O'Kane for her impressing leadership of the panel and the process of writing the report. Thank goes also to Dr. Mattias Lundberg who participated in all eight centre evaluations and contributed with invaluable experience from similar evaluations and also helpful advice on how to conduct the virtual meetings. The evaluation teams have produced a report which will be of great value both for the further activities of the centres and for the Research Council in administration of this and similar schemes.

Rune Volla
Department director

# Content

# 1 Overarching comments from the generalist evaluators

## 1.1 Introduction

The midway evaluation of eight centres funded under RCN's Centres for Environment-Friendly Energy Research (FME) scheme took place in February-March 2021. This report covers the evaluation including recommendations to RCN and recommendations for the individual centres. It comprises this introductory chapter covering the FME scheme and its organisation and the process of the evaluation and then eight chapters that are the evaluation reports of the eight centres.

## 1.2 The helicopter view - what this evaluation says about the success of the FME scheme

As noted in the background and terms of reference document for this evaluation, "the overall objective of the FME scheme is to help to solve key challenges in the energy sector, generate solutions for the low-emission society and enhance the innovation capacity of the business sector."

From the perspective of this evaluation, the FME scheme's overall objective is being met. The eight centres evaluated are each focused on different but major key challenges in the energy, CCS and low-emissions sector, generating and laying the groundwork to generate solutions for the low-emission society, reducing energy intensity, and enhancing innovation capacity across the energy and energy-related business sector as well as in public utilities and the research sector.

Taken together, the centres provide a remarkably capable and internationally high-profile national facility to help address the spectrum of energy and emissions reduction transformation challenges required to deal with climate change and the consequent decarbonisation agenda.

While the FME scheme has led to the formation of centres with strong research capacity to tackle real-world problems, possibly the most important longer-term impact of the scheme will be the production of a cohort of people trained through the centres in Masters, PhD and postdoc programs who will contribute significantly to the transforming energy industry. While this is done well, more could be done to support this group especially during the COVID pandemic and to equip this group with the further skills. We address this issue below.

Another major achievement has been the boosting of innovation capacity in energy and related firms and the public utilities. It was clear from the contributions of representatives of these firms and utilities at the evaluation interviews that this capacity had been strengthened but understanding the mechanisms by which it happens was harder to discern. Again, we discuss this further below.

One of the unusual and most impressive aspects of the scheme is the emphasis it places on involving a large number of partners and on the centres acting as a catalyst for subsets of the partners bidding for projects funded by other means (RCN, EU, etc.) building a portfolio of associated (sometimes called affiliated) projects. The Centres and their constellations of associated projects provide a powerful network of activities both increasing the influence of the centres and bringing new influences and ideas into the centres.

The FME scheme is a mature scheme, the purpose and mechanics of which are clearly well understood by the participants interviewed. But there are some aspects that maybe should be adjusted.

## 1.3 The evaluation process

### The process

RCN established eight evaluation panels, one for each centre. Each panel comprised two international experts, specialists in the scientific field of the Centre, who had prime responsibility for the research and research training aspects of the evaluation and two international generalist experts with experience in similar schemes. The generalists, one of whom was the Chief Evaluator, were common to all eight panels. They took prime responsibility for commenting on organisation, innovation and value creation.

Panel members were drawn from the following countries: Sweden, Denmark, United Kingdom, Germany, Italy, South Africa, Belgium, Spain and Australia.

RCN provided the evaluation panels a portfolio of material prepared by each centre according to a template. Crucially this portfolio included a self-evaluation (including a SWOT analysis), budget details, details of plans for the next funding period, reports from advisory bodies such as International Scientific Advisory Boards, annual reports, and assessments from the partners and the host institution. RCN also provided clear instructions on what was expected of the panels.

Because of the pandemic, the evaluation interviews were held by videoconference using Microsoft Teams. Each centre interview ran from 9am to 3pm with the relevant evaluation panel meeting with the centre Chair and members of the Board, the Director, project leaders, industry representatives, postdocs, PhD students, and representatives of the host institution. RCN representatives also attended. In the morning the discussions focused on the research at the centre followed by a meeting with PhD students and postdocs. In the afternoon, discussions focused on industrial and organisational matters and the future of the centre. The evaluation reports in the following chapters are based on these interviews and on the self-evaluation report and other written material supplied beforehand. The interviews were held over two weeks from 22 February to 4 March. They were preceded by a pre-interview meeting held a few days before for each evaluation panel with RCN to discuss process and the issues arising from the material supplied by each centre.

At the end of each interview day, the panel involved debriefed and decided on its main findings and recommendations. Different panel members then wrote the parts of the report they had been allocated by the Chief Evaluator who compiled the report before circulating it to the whole panel for discussion/agreement. When all panel members had signed off, the report was forwarded to RCN which in turn forwarded it to the centre for fact checking.

### Reflections on the virtual interview process

Overall, the interviews worked well in that the centres, as requested, prepared good presentations to start the morning and afternoon sessions; both ‘sides’ were well prepared; and the discussions were professional, courteous, open and frank.

What was missing compared to face-to-face interviews was the following:

- the chance to see the centre 'in action' and inspect laboratories and test rigs. These visits and inspections generally also provide a chance for informal but often in-depth scientific discussions
- the liveliness of a multi-part discussion/debate that can occur when contentious issues are discussed at evaluation interviews. It is harder to read body language over videoconference and contributions have to be made seriatim. It is also more difficult to pick up important but spontaneous posts and comments via digital media and incorporate them in the ongoing discussion
- in-depth discussion among members of the evaluation panels most of whom were fitting the evaluation into the normal working day, the functioning of which was already exacerbated by the pressures of various COVID lockdowns. The issue here is that tricky aspects of the evaluations possibly did not get worked through enough either before or after the interviews. There is great benefit in an evaluation panel being able to bounce impressions and observations around before finally settling on questions, findings and recommendations.

But there are also advantages in the fully virtual approach – it's cheaper to run with less environmental footprint, and is less time disruptive, meaning that some international experts could participate who cannot travel to fit nominated dates.

Reflecting on the pros and cons of the virtual process, we make two recommendations, one to use this opportunity to evaluate the process with a view to improving process for 'normal' times, maybe moving to a hybrid model, and the other to boost the expertise available to the evaluation panel by international peer reviews (we suggest four) of the material supplied for the evaluation in advance of the interview. Having such peer reviews would have been of special value during the COVID pandemic situation.

**Recommendation 1:** that RCN formally evaluate the virtual evaluation process/meetings to identify pros and cons that can provide guidance on how future evaluation processes should be designed. RCN might draw on other national research funding bodies within the EU which can contribute their experience on this matter.

**Recommendation 2:** that RCN consider increasing scientific quality of the research assessment available to the evaluation by seeking peer reviews of the centre material and making them available to the evaluation panels before the interviews.

## Observations on the material provided

Evaluation panel members noted that, in general, the material provided for each centre was comprehensive, detailed, and provided in a timely manner along with appropriate instructions from RCN.

However, categorising and tagging some of the material provided could add significantly to the usefulness of the information available to the panels on how a centre works and how different parts of it have an impact.

The end user assessment was useful in giving a general sense of whether end users were generally happy or not with their involvement in the centre. But the scoring given to some of the answers was often hard to interpret. When this was discussed at interviews, it seemed that different user partners were interpreting the questions somewhat differently. The assessment could be profitably re-visited to clarify what is required. Also, some simple questions could be added at the start.

**Recommendation 3:** that RCN consider reviewing the material provided with a view to increasing the value of the information without significantly increasing the administrative burden on the centres. Particular issues that could be considered are the following:

- tagging publications according to workpackage and according to whether or not any of the authors came from user partners in the centre and whether any came from outside the centre
- tagging associated/affiliated projects as to whether they were 'spin out' (arising from Centre's research), 'spin in'
- (projects contributing ideas or equipment to the centre), or other
- for the end user assessment, clarifying the instructions, and adding some top-level questions such as "What is the most useful aspect of the Centre to your organisation?" and "If you could improve the centre in just one way, what would it be?"

## 1.4 Performance of the centres as a whole against the success criteria

Overall, the centres are addressing the success criteria for the scheme fairly well. The following table summarises the performance of the centres taken as a whole against individual success criteria. The sections following the table address some of the problems highlighted.

| Success Criteria | Performance |
|---|---|
| **Research activity** | |
| - The centre conducts long-term, thematically relevant research of high international standard in the field specified in the project description, and demonstrates this through its production of doctorates, scientific publications, papers for presentation at recognised international conferences and other measures of scientific excellence. | √ |
| - The centre has a distinct research profile and has been successful in achieving recognition at the international level | √ |
| - There is genuine cooperation between the research partners at the centre and the centre has helped to improve the national structure of research carried out within its thematic area. | √ |
| - The centre's user partners have increased their research commitments both through participation in the centre's activities and their own R&D activities on topics of relevance to the centre. | Largely true |
| **Innovation and value creation** | |
| - The centre's research activity has generated or is expected to generate the potential for innovation and enhanced competitiveness among user partners from the business sector and strengthen the knowledge base for user partners from public sector organisations | √ |
| - The centre's research activity has ramifications for society beyond that of the partners directly participating in the centre's activities. | √ |
| - The centre has achieved reciprocal mobility of staff between the centre and user partners. Researchers from partners work at the centre, and research fellows and researchers from the host institution are seconded to the user partners for periods of time. | Largely not happening |
| - The centre uses work processes that ensure that the research activity is relevant for the user partners and that the expertise and results achieved by the research activity are effectively transferred to and utilised by the partners. | Research activity is relevant for user partners; transfer of expertise & results not quite as strong |

| | |
|---|---|
| - The centre has a framework for enabling results that fall outside the user partners' core areas to be commercialised by other means, e.g. through establishing new research-based enterprises. | Not uniformly good across all centres |
| **Internationalisation** | |
| - The centre has a distinct profile and clearly articulated objectives for international cooperation. | √ |
| - The centre is successful in international research cooperation. | √ |
| - The centre engages in active collaboration with international research groups and has contributed in other ways to the internationalisation of Norwegian research and business and industry. | √ |
| - The centre attracts outstanding international researchers, including research fellows and senior staff, as visiting researchers. Researchers and research fellows at the centre have conducted stays at research institutions abroad. | √ though this has been adversely affected by COVID |
| **Researcher training and recruitment** | |
| - The centre has an effective framework in place for researcher training and helps to train highly skilled personnel in the centre's areas of specialisation. | √ though more support and training in generic skills are needed |
| - The centre is actively engaged in education, especially at the master's degree level, and promotes recruitment to the centre's subject areas with special focus on increased recruitment of women. | √ though more women should be recruited |
| **Partners and funding** | |
| - The centre receives long-term funding from the host institution and partners, and these have increased their funding beyond the minimum requirements. | √ |
| - Active efforts are made to attract new user partners, and the user partners include large companies as well as small and medium-sized companies with a high technology and innovation profile. | √ |
| - The centre has been successful in securing other external funding. | √ |
| **Organisation** | |
| - The centre has a visible profile, a strong identity and has established successful collaboration between its partners. | √ |
| - The centre is organised in a manner that is well adapted to the host institution's organisation. | √ |
| - The centre has a board and management which ensure that the intentions and plans on which the centre is based are followed up. | √ but see comments on board chair and scientific advisory board below |
| - The centre has a common administration with a high degree of scientific and administrative autonomy. | √ |
| - The centre has achieved a satisfactory gender balance among the management staff and research fellows. | True for some centres; not for all |

## 1.5 Innovation and Technology Transfer

Noting that enhancing the innovation capacity of the energy business sector is a core part of the objective of the FME scheme, the evaluation has paid particular attention to the mechanisms the centres use to do this and how effective these mechanisms are.

One of the centre directors made the sage comment that user partners that are very engaged in the centre tend to be the ones that get the most out of it. We noted the truth of this statement with many of the centres. Industry representatives at interviews spoke of good things they had achieved

through their involvement in the centres ranging from help with changing culture in their firm/industry through knowledge updating for technical workers, through to involvement in big associated projects and successful contracts for new work and exports. And of course, user pull (through active participation) is one of the best innovation/technology transfer mechanisms possible.

Nevertheless, even the most engaged users did not seem to be maximising their opportunities for technology transfer. For example, the evaluation panels did not encounter many examples of user partners using RCN's or their own Industrial PhD and the Public Sector PhD schemes in conjunction with these centres. Also, as noted above, reciprocal mobility of staff between the centre and user partners was largely not apparent. While the centres should be encouraging this, so should the user partners. A further oddity in this respect was that practically none of the PhD students interviewed, when asked what they would be doing in 5 years' time, said they saw themselves working in industry.

Within the centres the innovation achievements are mixed. The awareness of knowledge and technology transfer is good in general. There is also a reasonable awareness of innovation strategies and innovation tools such as technology roadmaps, the Technology Readiness Level scale, and life cycle analysis. And there were some very good innovation initiatives such as the following:

- the "FME Innovation Task Force" where all FMEs met and highlighted different strategies to enhance innovation in the centres
- "open calls" initiatives in several centres whereby funds have been set aside to accelerate promising and innovative developments arising from centre research and to identify potential affiliated projects.

On the other hand, the centres did not seem to be promoting reciprocal mobility of staff between the centre and user partners very actively and the evaluation panels heard little about patents arising from the centres' work. While some of the PhD students interviewed had attended courses on intellectual property protection and research commercialisation, they did not seem to be getting any active experience with these matters.

It is hard to interpret exactly what is going on, i.e. get a clear picture of the centres' strategy and activities in this respect. But it would seem that more emphasis on innovation and commercialisation should be a feature of the second funding phase of the centres, acknowledging and building on the good things happening already with a view to achieving and measuring innovation and commercialisation outcomes especially aimed at boosting innovation capacity of the energy business sector.

**Recommendation 4:** that, for the second funding period, RCN encourage all the FMEs to increase their innovation and commercialisation outcomes and impact, particularly with a view to boosting the innovation capacity of the energy business sector.

To support Recommendation 4, all centres could be encouraged to

- improve their knowledge of innovation, technology transfer, and IP strategies, e.g. developing roadmaps and using TRL categorisation including time frames
- increase the intensity of reciprocal mobility of staff between the centre and user partners especially for PhDs
- set aside part of the annual budget for open calls mechanisms to support innovation initiatives.

## 1.6 Early career researchers - greater support and training needed

An important part of boosting innovation in the centres is ensuring innovation, commercialisation and intellectual property protection courses are taken by all early career researchers in a centre (Masters students, PhD students and postdocs) and that their work is organised so they get practical experience with these matters in their projects if possible.

Also, these early career researchers are the future of what will be an expanding and high-value industry sector. Accordingly, equipping them to take an active part in it is vital. Part of this is education e.g. courses in establishing a business in the environmentally friendly energy sector. Another part of it is experience, particularly through spending a significant portion of time working for/with a user partner. Encouraging user partners to use the industrial PhD scheme goes a long way to achieving this.

**Recommendation 5:** that RCN expands the requirements on the centres with regard to training early career researchers in innovation and commercialisation and providing them with industry experience. This should include requirements that they all take courses in innovation, commercialisation, intellectual property protection, and establishing an energy business and are given as much practical experience as possible in these matters. They should also have the opportunity to work for/with user partners for a period. End user partners should be encouraged to make greater use of the of the Industrial PhD and the Public Sector PhD schemes.

Many of the PhD students interviewed said that what they particularly value from being in the centres was the networking with other students and researchers (e.g. at centre days) and the insight they got especially from end users on energy industry value chains. With COVID much of this networking appears to have fallen away, possibly just when it is most needed. Also, some students have had their experimental work disrupted by COVID and are now likely to miss their PhD completion deadlines and consequently lose financial support as well. They need help.

**Recommendation 6:** that RCN seeks assurance from all FMEs that they have appropriate networking for all their PhD students (and other early career researchers) over the COVID period and that all PhD students are receiving support in the form of financial support and altered programs of study to allow for disrupted experimental work in order to be able to complete their degrees in minimum or close-to-minimum time.

## 1.7 Organisational issues

The evaluation panels were impressed in general by the governance and management of the centres and the support from the host institutions. The enthusiasm and commitment of the centre boards and senior management was a notable feature of the interviews, with all board chairs and directors taking an active part.

We note, however, that two of the board chairs are from SINTEF. Perhaps, given the focus of the FME scheme on strengthening innovation in the energy business sector, all centres should have board chairs drawn from user partners and, preferably, industry user partners.

**Recommendation 7:** that RCN require all FMEs to have board chairs drawn from industry user partners.

Most of the centres, but not all, have scientific advisory boards with international expert members. Such boards are highly valuable to centres such as the FMEs which strive for excellent and relevant research with a high international impact. They play the role of critical friends, providing challenging comments and advice and they are an important reference source for the centres when applying for funding in the international domain.

Currently, even for those centres that have scientific advisory boards, some centres do not have them meeting often and, sometimes, not meeting at all, rather just seeking advice from members of the boards on a one-by-one basis. Some have a mixed membership of internal and external members of the centre and several are not gender balanced – not an ideal situation for the prime external advisory structure to a centre.

Also, several centres did not organise meetings of their scientific advisory boards during the COVID period, which is a pity because this is a time when international advice and networking is particularly necessary.

**Recommendation 8:** that RCN require all FMEs to have International Scientific Advisory Boards (ISAB) comprising leading international peers in the centres' fields. These ISABs should be gender balanced. They should meet once or twice a year including virtually as appropriate and should provide a report to the board and management that all members sign off on.

## 1.8 Gender issues

The energy and related industry and research sectors are traditionally male dominated so achieving gender balance in the FMEs is a challenge. Some of the centres have risen to this challenge very well. But others are not doing so well though some acknowledge the problem and are clearly trying to address the matter.

As pointed out in several of the centre reports in the following chapters, one area where the centres can achieve gender balance is in their boards (through appropriate appointment processes) and in the ISABs where the centre has complete control over who they appoint. These are important matters to get right as they signal the centre's commitment to gender balance which makes recruitment of female researchers and PhD students easier.

**Recommendation 9:** that RCN require FMEs that are weak on gender balance to rectify this in the second funding period.

## 1.9 Possibilities

At the start of this chapter we noted that, taken collectively, the centres reviewed were a formidable national asset. We have wondered if RCN could not make more of them considered as a group and the even bigger group when taken with their impressive array of associated projects?

We have already commended the centres for establishing FME Innovation Task Force as a collective approach to good practice in innovation. In the centre reports we also note, with approval, joint initiatives between particular centres. But more could be done. Some possibilities are the following:

- survey the several firms and public utilities that are in more than one centre to investigate what practices in the centres work best for end user partners

- encourage (especially during COVID lockdowns) networking of the PhD students from all centres and offer common courseware on generic subjects such as scientific writing, innovation, commercialisation, intellectual property protection, and establishing an energy business
- formalise a mobility scheme for the centres considered as a group.

## 1.10 Acknowledgements

We thank the centres for the quality of the material supplied and their helpful and frank discussions on the interview days. And we particularly thank Tone Ibenholt and her colleagues at RCN for their support and guidance throughout this evaluation.

Mary O'Kane

Mattias Lundberg

# 2 Norwegian Research Centre for Hydropower Technology - HydroCen

## 2.1 Introduction

**The evaluation**
On 22 February 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, workpackage leaders, industry representatives, researchers, postdocs, PhD students, and representatives of the host institution, NTNU. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students and postdocs. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation report, "HydroCen will enable the Norwegian hydropower sector to overcome complex challenges and exploit new opportunities through innovative technological solutions. The ambition is to double the value creation in the Norwegian hydropower sector by 2050."

The Centre focuses on delivering value for Norway in the hydropower and related sectors and especially for its large number of end-user partners but, as well as doing this, it has built up an impressive set of strong international connections.

## 2.2 Research activities

**Summary of aim and scope**
Norwegian hydropower stands for an installed power capacity of 33 GW, an annual production of 136 TWh/y and a major share of the storage capacity for hydropower in Europe, capacities that are of utmost importance for the future renewable energy system in Norway and Europe. HydroCen includes research in hydropower technology, power markets, operation and maintenance, regulatory frameworks and environmental impacts. The total budget comprises 405,358,000 NOK for the 8-year period and from the start in 2016 it has involved 17 staff members with an engagement of more than 10%.

Research activities have been focused on tunnels, dampening of surges, reservoir and intake design, power houses, reconstruction of dams, dam safety and sediment handling. Other research activities have addressed minimisation of risk and maximisation of profits, exploitation of market opportunities and adaptation to climate change, market design and price structure and relation to climate development. One interesting area is the development of methods and models for calculation of value potential for hydropower in a future with changing markets, new environmental restrictions, rapid technology development and increasing need for renewal. The workpackage dedicated to environmental design has involved governance of hydropower operations and public perception of environmental design concepts, as well as cleaning systems for intakes and bypass structures.

**Overall outcome**
The Centre has one completed and 21 ongoing research projects that have led to results on a developed Francis runner design for variable speed operation, a new design using serrated edges in turbines, guide vanes and drums improving turbine efficiency, development of fish downstream migration solutions, including innovative guiding structures, novel environmental design solutions for inland trout rivers, and novel monitoring tools for biodiversity and fish abundance.

According to the self-evaluation, the project has produced 97 peer-reviewed papers, 20 reports and more than 50 conference contributions. There is an established policy both among senior researchers and PhD students to publish in international peer-reviewed journals with high impact factor. The dissemination activities include 11 publications that are co-authored with user partners and 47 with international partners from 2016 to 2020. HydroCen has two ongoing patent projects.

**Comments and criticism**
The number of publications is good but not excellent considering the size of the budget, the number of senior and young researchers involved in the Centre, and the number of relevant, ongoing projects. Generally, however, the Evaluation Panel considers that the productivity is extensive both within research teams as well as in collaboration with the industry and international partners. It is clear from the partner assessments that the involvement with and interaction of several of the industrial partners is limited. This is something which should be considered in the planning of future research activities and implementation activities.

**Recommendation 1:** That in order to increase the quality of its research output especially in a manner that is focused on industry needs, the Centre set clear goals for numbers of high impact publications in the second funding period and that a significant proportion of these publications be co-publications between research and industry partners in the Centre.

The interaction between WPs, which are strongly interconnected, can be improved. This would enhance the cross-disciplinarity and, for example, enable a stronger focus on sustainability issues, such as adaptation of the hydropower system to climate events (e.g. energy droughts) and anticipated developments of the renewable energy system. Work focused on the general importance of rapid variations in power production, such as efficiency curves for turbines, production management models, dam safety and environmental flow design should become subsidiary to this. To some extent, a sustainable adaptation of the hydropower system to specific climate challenges requires consideration of a broad range of aspects, which could lead to interesting technical developments and identification of market opportunities.

**Recommendation 2:** That in order to align with shifts in public sentiment and with the acceleration of the global decarbonisation agenda, the Centre significantly increase its focus on sustainability, environmental impact and climate change adaptation for the second funding period (as identified by the Board). To achieve this, the Centre should tilt its prioritisation between workpackages towards market, services and environment and somewhat away from structures and turbines making use make use of its Open Calls mechanism to speed up this re-focusing.

**Recommendation 3:** That in order to increase the impact of its research and to help build the sustainability focus, the Centre increase its emphasis on cross-disciplinarity and build stronger links between the workpackages.

The project activities have been characterised by some delays and/or changes but they are still in line with the original plans. However, to make the contribution of the Scientific Committee more

effective in following the progress of the Centre activities, it is advisable to improve the communication activities and to increase its involvement through updated and frequent reports.

There are no major delays in deliverables. We note, however, that workplans are updated once per year and sent for approval to the Research Council, which can be seen as a good procedure.

## 2.3 Internationalisation

**Summary**

HydroCen is focused on long-term initiatives targeted towards solving climate and energy challenges and promoting industrial development, challenges that to a large extent depend on international technical solutions. Hence, research activities should be conducted in close cooperation between Norwegian and international research groups, companies and public-sector bodies. According to the self-evaluation report, HydroCen has developed contacts with 50 different institutions in Europe, 8 in Asia, 6 in America and 1 in Australia. Collaborations are conducted with Uppsala University, Chalmers University, Luleå Technical University, KTH, Stockholm Environment Institute (SEI), and Svensk Vattenkraftcentrum (SVC). HydroCen collaborates with TU Berlin and TU München in Germany, University of Natural Resources and Life Sciences and TU Graz in Austria, Lucerne University of Applied Sciences and Art in Switzerland, University of Sussex in England, and University of Bologna in Italy. Furthermore, there are some collaborations in South America (Brazil), e.g. CEPEL, on the role of reservoirs and their environmental impacts. Sandia's contribution is more generic - in the field of non-linear optimisation. In North America, HydroCen has a MoU with the US DoE, and several ongoing research activities.

More than 50 peer-reviewed papers have been produced in international collaboration organised in the form of 5 R&D projects with international partners and 47 publications with international partners. There are 9 named researchers with whom international collaborations have been conducted. Further, there have been more than 8 visiting researchers and at least 8 exchanges to international partners and more than 15 exchange Masters students in 2019-2020.

Norwegian investors and consultants involved in HydroCen have been active in Asia.

**Comments and criticism**

There is an impressive set of international collaborations and a good co-publication record. This includes involvement in several large European projects and in the European hydropower community. Research on hydropower is conducted on many different aspects in an international context. However, there is a lack of international research themes such as implications of large, international electric power systems, which might be important for a sustainable future electric power system.

The Centre does not explicitly support international collaborations through mobility schemes, though these are mentioned by R&D partners in each WP and further collaborations are expected from the new Joint Program Hydropower within the European Energy Research Alliance (EERA).

## 2.4 Researcher training and engagement in education

**Summary**
Recruitments of postdoc and PhDs are prioritised activities in HydroCen, especially at four departments at NTNU with support from external (industry and authority) partners. According to the self-evaluation, 26 PhD students have so far been recruited with financial support through the Centre budget, 4 of these completed their theses before the end of 2020. There are also several "associated" PhD students in similar subject fields. Further, 27 PhD students are working in Centre projects with financial support from other sources. All except 3 of these, had completed before 2020. Industry has provided short-term internship positions for PhD students and postdocs. SINTEF and NINA have had an excellent experience in supervising PhD candidates. The distribution of PhD students and postdocs across workpackages is as follows:

WP1: Hydropower structures – 10 PhD candidates and postdocs
WP 2: Turbines and generators – 11 PhD candidates and 5 postdocs
WP 3: Market and services – 2 PhD candidates
WP 4: Environmental design – 1 PhD candidate.

There have been 31 Masters degree projects conducted within the Centre in 2020. For the period 2016-2020 there have been 184 Masters degree projects within the Centre.

**Comments and criticism**
The distribution of PhD students gives low priority to market and services as well as environmental issues. It is suggested that higher focus be given to these important subject fields.

There is a decent number of ongoing PhD candidates, but only 4 have completed.

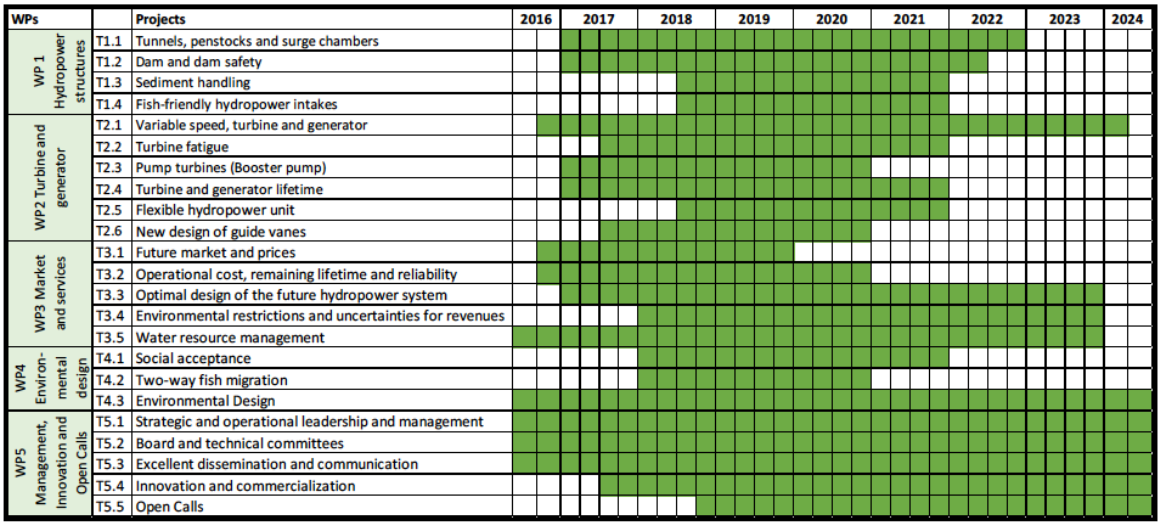
There is a clear awareness about publication policy among the PhD students, including publication and citations in international literature.

Opportunities for PhD students to do part of their training abroad have been limited recently by the pandemic emergency but it would be wise to promote them again as soon as possible.

## 2.5 Plans for final three-year period

**Summary**
From the interview it became clear that there is a well-structured annual assessment and updating of the project plans. From the self-evaluation (Section 2.E), the Centre leadership indicates that the objectives applied for the period 2016 to 2020 are still valid for the coming 4 years. The relatively limited changes of the plans call for attention, as there is no analysis that this relative steadiness in progress is right, especially given the increased global emphasis on decarbonisation, though the board chair noted at interview that the board believed changes were needed (see Recommendation 2 above).

**Comments and criticism**
Future plans are nearly the same as the original centre description (document 3.2). It is not so easy to see exactly what the activities in the last four years will be. However, there is the time chart below that gives a rough overview of the project status and future plans. We suggest that the so-called Open Calls mechanism be used to prioritise certain aspects like gender balance, energy sustainability and closing "gaps" between research results and implementation in practice. See Recommendations 2, 3, 5, 6 and 7.




## 2.6 Organisation and Management of the Centre

The Centre has an actively engaged board with its chair, Ivar Arne Børset, bringing a strong strategic focus. The management under the leadership of Liv Randi Hultgreen is effective and the support from partners and thehost institution is very good. A strong test of the overall leadership of Centre will be maximising the impact of the Centre for the second funding period given the opportunities afforded by the accelerating decarbonisation, clean energy and environmental protection agendas referred to in Recommendation 2 above.

The Centre has good national and international visibility. Communication and collaboration processes across the Centre are appropriate.

The Panel was pleased to note that the Centre has a Scientific Committee which is happy to be a critical friend on technical matters and scientific networking, but the Panel was surprised to note in the most recent report from the Scientific Committee that it has for some time been requesting more information on which to base conclusions and this has not been forthcoming or was supplied too late to be of use. We suggest this situation be rectified as soon as possible as it will allow the Committee to produce higher quality reports which should be of even greater use to the Board and management in making strategic decisions.

**Recommendation 4:** That in order to support good governance and management, the Centre ensure that all needed data are provided in a timely manner to entities connected to the Centre.

## 2.7 Innovation and value creation

The Centre's has a relatively large number of partners which together span major parts of the value chain for hydropower. The Centre also connects in different ways to other parts of the innovation system in Norway, e.g. to the FME centre CINELDI and a lot of associated projects.

The number of associated projects is commendable. This is one way to secure knowledge transfer both to the Centre and from the Centre's research. However, the Evaluation Panel suggests that the Centre clarify its own impact and the positive impact on it from outside. We also encourage the Centre to identify potential future associated projects originating from the Centre's 22 ongoing projects before the start of the final period. This can be included in the Open Calls as one of the criteria for attracting support to establish an associated project. The associated project mechanism is also an important "assurance of impact" for the potential life after the 8 years of FME funding.

Associated projects are an important component of the process of demonstrating the total potential impact from the Centre in the final period.

There is also good evidence of knowledge transfer in the form of co-publications with some partners. The Evaluation Panel encourages the Centre to use this to a greater extent in the final period to secure more knowledge transfer.

There is a commendable dialogue between the research partners and the industry/public partners to identify potential innovations and implementations including knowledge transfer and technology transfer from the Centre's research. The Technical Committee seems to play an important role in this respect.

As noted above, the Centre has a relatively large number of partners covering different parts of the value chain in the hydropower sector. With four main areas of interest including 22 sup-projects, the Centre is in a good starting position to secure new, mutual knowledge transfer to and from these partners. However, there are several indications in the material supplied that there is an insufficient critical mass of technology and knowledge transfer to all partners:

1. the self-evaluation gives a very differentiated picture of the potential transfer. There are normally big partners that have absorption capacity, both in short- and long-term transfer. This large company absorption does not seem to be happening

2. to date, there seems to be relatively little evidence of innovations that have been implemented, e.g. pilots, patents, guidebooks etc. There are good, proposed examples of potential innovations proposed for the final period, e.g. scaling up the fish fence, but the Evaluation Panel suggests that innovations and implementation can be utilised in a more coherent and structured way

3. some of the research partners are well aware of the importance of knowledge and technology transfer, but some do not see this as an important driving force in the Centre (according to the self-evaluation). We suggest that this situation can improve

4. there also seem to be obstacles to getting access to data to execute research projects and potential conflicts of interest in the partner group. These could cause a diminution of the Centre's ability to use its full research capacity and lower the potential impact on industry, both short and long term.

Another risk factor for this Centre, is that the majority of its 38 partners contribute relatively little cash and/or human capital to the Centre and, hence, several of the partners might end up not getting the chance to absorb a critical mass of knowledge or get access to new technology for their future business in the final period. In addition, there is a high risk that the partners will not get the opportunity to articulate their specific needs from the Centre, e.g. influence the direction of research. To some extent this risk can be mitigated by the role of SINTEF as a transforming intermediate institution. Our view is that SINTEF needs to increase its efforts in this direction in a structured way, especially for the small partners. We strongly encourage the Centre to develop KPIs for knowledge and technology transfer in the final period. One possible KPI is the mutual mobility of people. We also think that TRL classification of all projects should be used more to help the Centre to identify appropriate technology and knowledge transfer to all partners in the final period.

**Recommendation 5:** That in order to increase the usefulness of the Centre to its end-user partners, the Centre put a strong focus in the second funding period on implementation of research results. To achieve this, it should give serious consideration to determining potential exploitable results for each

of its projects; instituting annual TRL analyses for its research portfolio; and establishing and then communicating a clear set of tech-transfer KPIs. The Open Calls mechanism could be used to boost funding support for this implementation emphasis.

The Centre needs to work with industry and SINTEF to find a more coherent picture of what each partner can get from research in HydroCen in the final period, and also to influence the research agenda. This will probably lead to further changes to the research program, both in focus and in organisation. The Open Calls mechanism could probably play an important role in implementing this change. The Evaluation Panel suggests the Centre might need to consider an increased budget for Open Calls to meet this challenge. It is also important to identify common output from research which is of use to groups of industries, both short and long term. This must be done both on an individual basis but also by bringing the researchers and partners (at least groups of partners) together in the beginning of the final phase of the Centre.

**Recommendation 6:** That in order to build more involvement in the Centre by two inherently competitive groups (consulting firms and equipment manufacturers), the Centre work with them to find projects that are truly pre-competitive but have real value for all of the firms involved.

The Evaluation Panel suggests that the board must play a key role in those matters supported at a strategic level by the Scientific Committee.

## 2.8 Funding and financial aspects

In total 38 partners contribute cash and in-kind. However, it turned out that approximately 11 partners did not contribute any in-kind for 2020. The balance between cash and in-kind is important to secure mutual real engagement in the Centre. The Evaluation Panel suggests the Centre strive for a more balanced cash and in-kind contribution from all partners in the final period to maximise potential impact to and from all partners.

## 2.9 Gender aspects

The Centre has adopted its Host Institution's gender target of at least 40% women in all roles and structures within the Centre's organisation. At the moment the Centre is falling short in meeting this target. The Panel acknowledges that hydropower is traditionally a male-dominated discipline and it notes the work the Centre is doing in improving the number of female project leaders appointed and the wider communication strategies to encourage young women to think about studying in this field. However, the Centre could do much more to send strong signals that it is committed to gender balance notably setting up the processes for Board and Scientific Committee composition so that least the 40% target is achieved in those leading bodies of the Centre.

**Recommendation 7:** That the Centre give more attention to achieving gender balance throughout its operations. This should start with ensuring the board and the International Scientific Advisory Board are gender balanced in order to signal that the Centre at its top level is serious about this issue. This will involve modifications to selection and appointments processes.

## 2.10 Future activities

The Centre is clear that there is a need for research coordination in the Norwegian hydropower sector beyond the FME funding period. It points to the success of the NTNU's organisation of hydropower industry cooperation in Norsk Vannkraftsenter in the period before HydroCen was created and suggests something like this is needed at the very least. And it has been somewhat informally considering even more than this in board and management discussions. This is

commendable and it would be wise to settle on a proposal for the post-FME-funding period sooner rather than later as the plans for the second funding period can be integrated with and support this longer-term vison.

**Recommendation 8:** That in order to provide certainty of some ongoing, long-term research and innovation support structure for Hydropower in Norway, the Centre move quickly to determine its vision for post-FME funding, using mechanisms such as Open Calls to support this.

## 2.11 Conclusion and recommendations to the centre

HydroCen is a leading hydropower, industry-focused research centre in international terms. The Evaluation Panel notes however that there are several aspects of the Centre that could be improved to make its impact even greater and to take advantage of the increasing global focus on decarbonisation and clean energy agendas. Accordingly, the Panel makes eight recommendations which are listed below.

**Recommendation 1:** That in order to increase the quality of its research output especially in a manner that is focused on industry needs, the Centre set clear goals for numbers of high impact publications in the second funding period and that a significant proportion of these publications be co-publications between research and industry partners in the Centre.

**Recommendation 2:** That in order to align with shifts in public sentiment and with the acceleration of the global decarbonisation agenda, the Centre significantly increase its focus on sustainability, environmental impact and climate change adaptation for the second funding period (as identified by the Board). To achieve this, the Centre should tilt its prioritisation between workpackages towards market, services and environment and somewhat away from structures and turbines making use make use of its Open Calls mechanism to speed up this re-focusing.

**Recommendation 3:** That in order to increase the impact of its research and to help build the sustainability focus, the Centre increase its emphasis on cross-disciplinarity and build stronger links between the workpackages.

**Recommendation 4:** That in order to support good governance and management, the Centre ensure that all needed data are provided in a timely manner to entities connected to the Centre.

**Recommendation 5:** That in order to increase the usefulness of the Centre to its end-user partners, the Centre put a strong focus in the second funding period on implementation of research results. To achieve this, it should give serious consideration to determining potential exploitable results for each of its projects; instituting annual TRL analyses for its research portfolio; and establishing and then communicating a clear set of tech-transfer KPIs. The Open Calls mechanism could be used to boost funding support for this implementation emphasis.

**Recommendation 6:** That in order to build more involvement in the Centre by two inherently competitive groups (consulting firms and equipment manufacturers), the Centre work with them to find projects that are truly pre-competitive but have real value for all of the firms involved.

**Recommendation 7:** That the Centre give more attention to achieving gender balance throughout its operations. This should start with ensuring the board and the International Scientific Advisory Board are gender balanced in order to signal that the Centre at its top level is serious about this issue. This will involve modifications to selection and appointments processes.

**Recommendation 8:** That in order to provide certainty of some ongoing, long-term research and innovation support structure for Hydropower in Norway, the Centre move quickly to determine its vision for post-FME funding, using mechanisms such as Open Calls to support this.

**Evaluation Panel**
Mary O'Kane (Chief Evaluator)
Giovanna Cavazzini
Mattias Lundberg
Anders Wörman

# 3 Norwegian Centre for Sustainable Bio-based Fuels and Energy - Bio4Fuels

## 3.1 Introduction

**The evaluation**
On 23 February 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, Sub-Project leaders, industry representatives, postdocs, PhD students, and representatives of the host institution, NMBU. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students and postdocs. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation "The centre has the ambition to improve the technologies and economics of processes for converting low-grade woody biomass and agricultural waste to advanced biofuels, while investigating the sustainability, economics and design of process concepts and testing fuel quality in today's engines".

The Evaluation Panel commends the Centre Management and the Centre Board for their strong commitment to the Bio4Fuels Centre and for the critical role they have played in coordinating a very broad spectrum of biofuel-related research activities in Norway and for developing the Bio4Fuels Centre into a genuine competence centre that is recognised by the stakeholders.

Nevertheless, the Evaluation Panel provides a number of recommendations to assist the Centre improve performance and impact in relation to its mission and ambition statements.

## 3.2 Research activities

**General observations**
According to the self-evaluation and its ambition statement (above) the Centre covers most - if not all - generic pathways/value chains to convert biomass feedstocks to biofuels. That is, according to the Project Description, it "provides a common research platform across the individual value chains, which is unconstrained in terms of the scientific approaches and conversion technologies (biochemical, thermochemical) and products (biofuels, valorisation of side streams) to foster interdisciplinary research and rapid innovation". Furthermore, over time, the product slate now also includes aspects of bio-products as a complement to biofuels, and at more or less equal value, which the Evaluation Panel finds relevant and timely.

The above approach is technologically and quite scientifically broad, which has advantages but can lead to a certain level of fragmentation. This broader science-technology approach is to a considerable extent offset by forming a national (and beyond) stakeholder platform through which the industrial and public partners can get an overview of the full range of research in the biomass-to-biofuel/bioproducts research field in Norway.

While the focus on feedstocks is on biomass materials that can be sourced in Norway, there are many conversion pathways to biofuels addressed in the program while the research activities only cover one or a few links between the specific full value chains. In line with the overarching ambition to "investigate the sustainability, economics and design of process concepts", more visible cost-efficiency comparisons, clearer sustainability criteria targets (i.e. alignment with UN SDGs), and potential effects of the technological processes on $CO_2$ emissions are aspects that should be considered more across the value chains and in communicating the Centre's activities. This also implies that the Centre could become an efficient channel for dissemination and science-based communication of the sustainability of biomass use and new processes for biofuels and, with time, for selected biomass refining value chains - in this way providing broader, societally relevant insights to industry and the public.

Regarding technical maturity, the R&D can generally be judged to be in the range TRL3-5, i.e. from experimental proof-of-concept to validation in relevant (industrial) environment and where just a few of the activities reach the highest level of TRL in this span.

One striking thing about the Centre is the synergy with the NorBioLab infrastructure project. In many of the workpackages there are refences to new, state-of-the-art research infrastructure which in turn has been instrumental in enabling the Centre to reach research targets.

On the research partners' side, the Centre brings together various research groups in Norway in the biomass processing and biofuels area. The groups appear to already have been established and active in their respective fields before the start of the Centre in 2017 and have since continued their activities according to the Project Description. In parallel, these groups are also engaging in research on similar topics in other organisational settings, these associated activities having been intensified during the Centre's lifetime. The result is that interactions between the research groups are generally not very visible outside of the frame of their Centre research topics.

The initial organisation of the SPs was structured on conversion stages (primary conversion, secondary conversion etc.) with several technical pathways in the same SP to promote contacts and interactions between research groups at the same stage. However, this was found not to be very efficient, and the organisation was changed in 2019 to organise SPs based more on a value chain approach. The Evaluation Panel commends the Centre on taking steps to reorganise in order to create better research paths that align with technological focus area value chains. However, whether this new organisation is more efficient and successful is probably too early to tell as the new structure of the Centre now carries a risk that there is no cross-fertilisation across the different technological approaches and research environments, e.g. bio-related approaches (SP3) may not be sufficiently integrated with the bioresource supply chain (SP1) and/or it may be difficult to compare technologies across, for example, catalytic pyrolysis developments (SP2) versus bioconversion (SP3) etc. From the annual reporting in 2019 and 2020, there is little evidence that the reorganisation has made any significant difference in the interactions between research groups, except where some have more natural contacts (sequential processes such as fractionation-hydrolysis-fermentation or pyrolysis and HTL, respectively and upgrading of the intermediate bio-oil) than others and some have the full value chain within one SP (e.g. SP4 on gasification).

Apart from the research on the generic value chains, SP2, SP3, and SP4, there are also two cross-cutting SPs to support technical activities – one on biomass feedstock and sustainability (SP1) and one on the scale-up and use of the biofuels (SP5). However, at this stage it appears that the interaction between these two SPs and the generic research SPs has been quite limited.

Overall, the research activities in the SPs/WPs have followed the outline in the Project Description and it is proposed that this arrangement continue in the second funding period, an issue discussed more below.

A shortcoming is that in both the Project Description and in the annual reports, the SPs and the project-workpackages do not generally have associated KPIs by which to assess and benchmark the progress in both the outputs (publications, etc.), in the core research results (improvements in conversions, inhibitor levels, scale-up and similar process characteristics that can be envisaged to be accomplished by the research), and in the development of, for example, tighter or new industry-academic collaboration. The use of KPIs is strongly recommended as this also allows non-academic focus points and accomplishments such as targeting specific UN SDGs, achieving new transverse collaborations and/or new partnerships to be assessed more clearly.

As for the dissemination and outreach activities, in addition to the Bio4Fuels days and larger scale workshops, there have also been some cross-cutting activities related to the research activities, e.g. a summer school in 2018. The 2019 reorganisation had as one of its objectives to improve contacts across the Centre. And this type of activity does seem to have been intensified despite the limitations imposed by the pandemic; for example, there were four Centre Status Meetings in 2020. However, the cross-cutting meetings appear to mainly target the management level(s) and may not sufficiently target e.g. postdocs and PhDs as the partner evaluations in 2020 indicate a moderate satisfaction only with the Centre's communication (average slightly above 4 on a 1-6 scale).

Despite the restrictions imposed by the pandemic, crosscutting activities at the researcher and PhD levels should be increased, not least so these early career researchers can create networks and improve their employability in the industry. Accordingly, the Evaluation Panel suggests the Centre organise additional summer schools, topical workshops within the R&D area and also workshops covering generic subjects (e.g. entrepreneurship, standards for biomass and fuels, regulatory and policy aspects on biomass usage, biofuels and the use of waste, etc.). There was a clear request from the PhD students for such activities at the interview.

On the positive side, the formation of the Centre has assisted in maintaining and maybe also in forming new long-term research activities and associated capacity building for most of the research partners. In conjunction with the other research activities pursued outside the Centre this capacity building will ensure high research quality and potentially critical mass in the respective research fields. Here, the Bio4Fuels activity can serve as a platform for a research group but also be a basis for continued formation of strategic alliances to engage in other research cooperation. However, from the self-evaluation, it is clear that at least two research partners (IFE and NIBIO) indicate they only have a small role and have difficulties in forming a stable platform for research.

Given how the Centre has progressed to date, the objectives should at this point be reconsidered. The improvements of technologies and economics of processes and rapid innovation it had aimed for has not happened for all value chains (the $m^3$ pilot scale demonstration of $H_2O_2$ driven LPMO boosted biomass conversion being a notable exception). In some of the value chains, aiming for strategic competence/technology consultancy expertise on a broad basis in direct collaboration with relevant stakeholders would be more realistic.

When reconsidering its objectives, the Centre should formally acknowledge the inclusion of bioproducts in the scope, not only valorisation of by-products and biomass to biofuels.
The Centre should also take into account the increased global emphasis on decarbonisation (see Recommendation 2).

The Centre should revise its research program to include clearer sustainability criteria, in particular regarding GHG emissions, in the technology development decisions. The Centre should also include predictive assessments of how any new technology developments or products may contribute to reducing $CO_2$ emissions.

**Sub-Projects**

**SP1 Bioresources, Environment and Climate**

Considering the overall scope of the Centre and the need to focus on sustainability this SP is both a logical and an essential part of the Centre's activities.

More outreach should be planned from this WP. The use of forestry biomass and its sustainability is debated in many fora and even questioned in campaigns orchestrated by certain groups. It is very important to counteract this by communicating science-based arguments on the benefits and limitations of bioenergy and biofuels as well as providing concrete and accessible data on the potential of bioenergy in society, for Norway, and elsewhere. Furthermore, joint communication activities with other platforms and groups such as IEA Bioenergy should be considered when suitable (see Recommendation 11 below.)

**SP2 Liquefaction Processes**

This SP has four WPs commented one by one below.

- WP2.1 Pyrolysis - Overall a relevant topic which is addressed in a good way.
- WP2.2 Hydrothermal Liquefaction - Overall, good industrial connections and equipment that could bring SINTEF to the forefront of R&D on this topic. It is likely to become a productive WP in the coming period.
- WP2.3 Thermochemical upgrading of bio-oils - Overall, this is a very relevant research theme as this is a main alternative upgrading pathway for bio-oils both from pyrolysis and HTL liquefaction and the missing link to get to biofuels. Therefore, it has and continues to be the subject of numerous studies. In particular, the upgrading of HTL bio-oils is a fairly novel topic with fewer results available in the literature.
- WP2.4 Chemo-catalytic conversion - The project description discusses the conversion of separated cellulose, hemicellulose and lignin by hydrogenolysis as a first phase activity, and one-pot conversion of lignocellulosic biomass as a second phase activity. However, the reported activity is a kind of one-off; it does not relate to biofuels as such but more to the valorisation of a by-product. The project description appears significantly broader than the work reported which actually only consists of the final step in the valorisation of glycerol, a by-product from FAME biodiesel production, via hydroacetone to 1,2-PDO (1,2-propane diol, *aka* MPG, monopropane glycol), a pathway already in commercial use.

**SP3: Biochemical Processes**

The overall goal in the four WPs in this SP is related to the valorisation of softwoods, being of both highest potential for Norway but also being more difficult to process than for example the types of agricultural residues used internationally in pioneering industrial scale lignocellulosic ethanol plants (corn stover, bagasse).

WP3.1 Pre-treatment and Fractionation - The WP mainly follows the methodology described in the Project Description, which has a two-fold approach, initially using established fractionation technologies to produce substrates for WPs 3.2 and 3.3 followed by development of an organosolv fractionation method. The work is of good quality but organosolv processes have until now had limited industrial impact, and the potential processing advantages and end products need to be addressed to ensure the value of the approach. Cross-WP activities between activities in SP2 and SP3 are encouraged.

WP3.2 Enzymatic saccharification - The activity in the Project Description mainly relates to the optimisation of the use the lytic polysaccharide monooxygenases (LPMOs) in saccharification, a recently discovered type of enzymes, currently attracting a lot of attention. Overall, successful, pathbreaking work on an interesting topic. Feed-in of $H_2O_2$ appears to invite to new equipment considerations for large scale saccharifications and hence the potential involvement of a new type of technology partner to complete the value chain with equipment design.

WP3.3 Fermentation - The focus is on fungi-based lipid production and optimised SSF ethanol production with consolidated bioprocessing (CBP) being added. Overall, the sugar to lipids concept using oleaginous fungi is an approach that can fit well into an expansion of the Centre focus from biomass-to-biofuels to other bioproducts. Yeast improvements for SSF ethanol production and thermophiles for CBP have been studied globally for at least a decade, so breakthrough progress may be difficult to achieve in these areas, but research on these topics nevertheless fits well into the overall efforts of the Centre.

WP3.5 Anaerobic digestion and gas upgrading
The project description for this WP has seven themes – the main two of these have been addressed (hydrogen addition to the AD process, both *ex situ* as well as *in situ* to digesters to convert the $CO_2$ to additional bio-methane and sorbent enhanced reforming of the biogas to generate hydrogen).

Overall, although this is an area attracting interest at present, the research seems to follow the established approaches.

**SP4: Gasification**
This subproject has three WPs, Gasification, Gas Conditioning and Preparing for piloting and up-scale, respectively. This is a new SP since 2019, these WPs were previously part of SP2, 3 and 4, respectively, in 2017-2019. Generally, the reporting is fairly vague on the details of the work carried out. In the 2020 report, it describes two associated projects rather than the work performed in the Bio4Fuels program.

Overall, for this WP, the experimental equipment has limited the generation of results. It is also worth noting that there seems to be no industrial partner engaged nor any reference to cooperation on catalysts and sorbents. The Evaluation Panel suggests the Centre lower its ambitions to a level where the competence is maintained to await any emerging industrial interest.

**SP5 Process design and End Use**
This SP has three WPs:

- WP5.1 Modelling Tool for Biorefineries
- WP5.2 Techno-Economic Evaluation/Scale of Economy
- WP5.3 Product quality and End Use.

From the reporting it appears that this SP has had a long induction period with not much said in the 2017 and 2018 annual reporting. The situation was discussed in the interview. The present situation is, on one hand, related to the relatively slow development of the modelling tools, and on the other hand, to the fact that the WPs in other SPs have not developed as planned and therefore the input to the modelling was not generally available.

**Publications**
The Centre seems on track to meet its original publications target of 80 peer-reviewed publications throughout the life of the Centre. In addition to the peer-reviewed publications, there are also a number of articles for the general public and numerous presentations for conferences etc. Overall,

the publications output is in line with what could be expected from a Centre of this nature but in order to be able to assess the dissemination and impact of the Centre scientifically, bibliographic/bibliometric analyses with impact factors should be included in annual and final reporting from the Centre. The Evaluation Panel suggests that the Centre carry out such a bibliographic/bibliometric analysis

From sampling the publications, it was noted, however, that quite a number of these did not acknowledge the Bio4Fuels funding. Should these publications be on the publication list or is there no acknowledgment policy, something that is important for the visibility and identity of the Centre?

## 3.3 Internationalisation

The Centre has an extensive international network. Also, it has an International Advisory Board which interacts with the Centre via participation in workshops where developments in each WP are presented during the Bio4Fuels days followed by a meeting with the management group, supplemented occasionally by written recommendations.

The material submitted for the evaluation refers to networks such as f3 and Supergen as well as collaboration with other research groups in various universities and institutes. The Centre is also in other activities, such as IEA Bioenergy TCP tasks (32 Biomass Combustion, 33 Gasification of Biomass and Waste, 34 Direct Thermochemical Liquefaction (ambiguously stated in the reporting), 37 Energy from Biogas, 39 Commercialising Conventional and Advanced Transport Biofuels from Biomass and Other Renewable Feedstocks and 45 Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy but not in 40 Deployment of biobased value chains, 42 Biorefining in a Circular Economy, 43 Sustainable biomass supply integration for bioenergy within the broader bioeconomy, 44 Flexible Bioenergy and System Integration).

Furthermore, the research partners participate in various EU projects, notably in Horizon 2020. In the 2020 annual report, 24 such EU projects were noted.

The goal for research cooperation in the original Project Description was to achieve a portfolio of projects 2-3 times the size of the Centre's operations by the end of its lifetime. However, even with its large number of associated projects, it was concluded at the interview that it would be difficult to reach this from projects associated with Bio4Fuels alone, but nevertheless, the Centre has had an impact in this area. There are also significant examples of bilateral cooperation with various academic institutions and research institutes. In the interview the Centre stated that the capacity of the research organisation was sufficient to avoid associated projects straining infrastructural and human resources to the detriment of the operation of the Centre. However, the Evaluation Panel notes that the senior managers in the Centre have time-consuming commitments in associated projects, on top of their Centre obligations which is of concern.

On the researcher level there is a high degree of internationalisation, all 5 postdocs and 8 of the 11 (9 of 14 when other funding is factored in) PhD students listed in the 2020 report are non-Norwegian.

## 3.4 Researcher training and engagement in education

The target set in the project description was a total of 14 PhDs and up to 60 MSc candidates. At present 11 PhDs are engaged, and the Centre’s plans indicate there are more to come, such that it seems realistic to assume the Centre will reach this target. There is no census of MSc students, so this target cannot be assessed.

In the Annual Report draft for 2020, there is a list of some 30 courses at undergraduate and Masters levels involving Bio4Fuels research staff and topics.

With regard to training for the Centre's early career researchers, the Bio4Fuels meetings and workshops could be seen as informal researcher training (although not giving academic credit). And a Summer School was arranged in 2019.

In the interview, the PhD students and a postdoc were positive about the common activities that have been arranged, nevertheless, they clearly indicated that they desired additional activities over and above the interactions they have in the Sub-Projects and workpackages to underpin the sense of being part of a centre with a common mission and focus.

So, as already noted above, it is recommended that the Centre have more and dedicated events for PhD and postdoc researchers such as Summer Schools, self-organised PhD meetings or workshops as well as workshops on generic topics.

## 3.5 Plans for final three-year period

The research plans for the final three-year period are mainly a continuation of the activities along the lines established in the Project Description and as a result of the previous work in 2017-2020. There is no information on any planned major changes in the Centre's management or organisation.

The plans include the recruitment of at least three more PhDs (thereby fulfilling the target of 14 PhDs). One postdoc is planned as well. Furthermore, additional outreach activities are planned.

As noted above, the Evaluation Panel suggests the Centre use this interregnum as an opportunity to review the work program and adapt it to the results obtained and to changed circumstances, both internally and externally, and increase the Centre's communication to the external world, notably via its website and via a more broad, societal, communication strategy.

In some WPs, there are activities that have not yet been initiated (e.g. 2.4, 5.1). For such activities, it is suggested that the Centre consider whether or not they should be started in view of their relevance and the possibilities of making significant progress in the remaining years and, if that is unlikely, it should focus resources elsewhere where more progress could result. Also, there are other, new, activities identified of interest to the stakeholders that could be initiated. The Centre plans to implement open funding calls in the final period, discussed further in Section 7 below.

In SP1, there will be a focus on regional biomass availability, including studies on the details of supply chains for planned full scale projects. Going to a more local level in the biomass assessment is good from the point of view of preparation of the supply chains, and for certain stakeholders, and it is also presumably of high interest, even value, for the public bodies and forest associations that are also partners in the Centre. Communication activities on this do not seem to have been planned but they will be important.

SP2 and 3 are planned to more or less to continue the research along the lines already established, addressing the issues already identified. Generally, and considering industrial activities by Silva Green Fuels and the newly established research infrastructure in many of the WPs, this approach is reasonable and will give progress beyond the state of the art, with some question marks already noted.

In SP4 there are plans for generating more data from gasification experiments and work on gas cleaning. Here, the ambitions to develop process data for a scale-up to a larger plant seems

overambitious. For the coming years, an ambition to build the knowledge basis and competence, while trying to increase the industrial interest by an increased focus on wastes and residues, seems to be a more realistic approach.

In SP5, apart from continuing the work already initiated, and a research line on electrochemical production of biofuels is planned. The ambition stated in the interview was also to work more closely with the other SPs. However, this ambition needs to be substantiated by a real plan on how to achieve such interactions and what results will be obtained.

## 3.6 Organisation and Management of the Centre

The Centre has a committed board with its chair, Ingo Machenbach, bringing a clear focus on strategy to keep the Centre relevant in the face of rapidly evolving economic and policy changes.

As noted above, the Centre also has International Advisory Board which is well-constituted and provides good advice to the Centre. Its advice on the plans for the next period should be sought in the light of this evaluation.

The Centre has good visibility with the relevant industries in Norway.

There are some major challenges for management most notably in enhancing the experience for the PhD cohort and in communication especially given how contentious the biofuels topic is at present. The Director and other senior leaders in the Centre have several important roles outside the Centre and this doubtless leads to difficulties in managing all the commitments involved. The Panel suggests that management would be more effective if more Centre resources were allocated to provide support to the Director (e.g. in administration, communication, stakeholder engagement and other areas as required).

As noted, several times already, communication is a challenge for this Centre given the external environment. And it is also an internal challenge as illustrated by the low level of interaction between Sub-Projects and the PhD students' request for more networking and cross-disciplinary activities. While some communications activities have clearly worked well (e.g. the Bio4Fuels Days), other communication mechanisms need attention. For example, the website does not seem to be used as an active tool for communication and dissemination as much as it could be. At present the actual results of the research and associated publications are not made available on it.

## 3.7 Innovation and value creation

The Centre comprises 27 industrial partners interested in 3 different main value chains together with 8 public partners/NGOs and 7 research partners. The Centre has produced a significant amount of research output in various different forms. Some of this has been of benefit to some of its industrial partners, e.g. Borregaard and Novozymes. Other companies which have also been able to benefit directly include Cambi, Biokraft and ZEG Power, all using anaerobic digestion.

While a small number of partners has had tangible benefits from the Centre's activities to date, the partner assessments give a somewhat different view for a majority of the industrial partners. On the positive side, the partner evaluation scores are high for the perception of the competence of the research staff (average above 5) and generally high on access to new knowledge and a larger network (averages 4 and above 4, respectively).

The overall impression is that the Centre so far has had limited success translating science into knowledge and technology that meets the majority of industry and end-user partner needs. Even if 2019 reorganisation can improve this to a certain extent, the Evaluation Panel suggests there is a need for several extra actions to improve the knowledge translation activities in the second funding period. One explanation offered at the interview for the delay in technology and knowledge transfer was that there have been several delays in securing different test facilities to be used in the different research Sub-Projects in the first funding period. Most of those technical issues seems to have now been solved but it is unclear to what extent this actually caused delays in the overall science output.

Another missed opportunity is not using mobility to and from industry and end-user partners to secure mutual knowledge and technology transfer. The Panel encourages the Centre to facilitate this in structured way in the next funding period and track it using a "new internal" KPI.

The involvement of public authorities and NGOs in a centre in this field is laudable and can potentially result in a broader and necessary societal impact. However, it was not possible to identify any clear impact on those organisations so far for example in terms of policy guidance from the Centre's activities. The Panel encourages the Centre to work more with those partners in the final period to increase the impact and to meet those partners' needs.

The Centre plans to implement open funding calls in the final period. This is good and has the potential to secure knowledge transfer and technology transfer to a higher extent for all partners. The Panel suggests that the Centre consider increasing the annual budget for this purpose. The open calls can also hopefully be used to close the missing links between Sub-Projects to a certain degree.

The Centre informed the Panel that TRL rating of projects had been used in the beginning of the first funding period of the Centre, but it is unclear why the Centre stopped using this for helping it with short- and long-term knowledge and technology transfer. We suggest that this be resumed in order to keep track of all projects' potential to deliver knowledge, IP/innovations and technology to all partners, and also to find interconnections between different Sub-Projects.

The Centre has a commendably large number of associated projects more or less directly connected to the Centre. This gives some idea of the total capacity of and total impact from the Centre. However, it is unclear how many of those projects actually originate from Centre research results (spin-out projects), and how many of the projects actually feed into the Centre's research (spin-in projects). It was also unclear how many of the reported associated projects do not fall into either of these two categories, i.e. have no connection to the Centre's projects at all. We encourage the Centre to keep track of the new innovations coming out from the associated projects, especially those that originate from the Centre's research.

## 3.8 Funding and financial aspects

The Centre has a good balance of total in-kind and cash contributions. However, half of the partners do not contribute any cash. This might be a fair situation, but it raises the question if these partners have any real involvement in the Centre. The same is true when a partner only contributes cash. The overall impression is that the Centre might be missing an opportunity to get real engagement from its partners and thereby achieving mutual real impact on both the industry and the research agenda. We urge the Centre to improve this situation in the final period.

## 3.9 Gender aspects

The Panel was pleased with the overall good gender distribution in the Centre particularly noting good gender balance in the Board and International Advisory Committee. Improvement is needed however in the gender balance at science leader level. This is something the Centre acknowledges.

## 3.10 Future activities

The Panel notes the Centre's idea of aiming for a "Virtual Bio4Fuels Centre" after the eight-year FME funding period. A virtual research centre needs a quite focused and coherent research mission to function well, to ensure sufficient contact between the partners. While the Centre currently has a broad approach with many pathways being addressed, the Panel suggests that, if the Centre decides to transition to a virtual centre, that it aims to continue a prioritised few value chains and develop a new funding scheme (e.g. industrial membership) to maintain the role of being a competence centre for industrial stakeholders that offers, for example, web-based short courses and science-based information within the prioritised value chains.

Alternatively, there might be an opportunity to have the best of both worlds and continue the Centre as a type of Concerted Action, using the H2020 terminology, while still seeking to support industrial and end-user partners. The focus for this alternative type of centre would then to be as a Competence Centre (for industrial stakeholders) and focal point for information exchange and contacts with stakeholders and with a mission to report on on-going associated research projects and to summarise the state-of-the-art in different fields, rather than carrying out frontline research within the centre itself.

## 3.11 Conclusion and recommendations to the centre

This Centre has several good aspects where it is world class but, overall, it could be much better than it is at present as an industry-focused research centre. Where it does do well, however, is as a biofuels/bioproducts competence centre, acting as a coordination point for the highly diverse set of industry and research players with interests and needs in biofuels/bioproducts in Norway. It also serves as a producer of highly qualified graduates to work in this sector and shape its future.

To improve its performance and impact, the Panel makes the following 13 recommendations:

**Recommendation 1:** That in order to increase its impact and maximise the advantages for its partners, the Centre go beyond biofuels and include other bioproducts.

**Recommendation 2:** That the Centre relate biofuel-technology research decisions to $CO_2$ mitigation policies; and establish sustainability assessment criteria for assessing projects.

**Recommendation 3:** That the Centre build on its research strengths, using clear KPIs covering outputs and deliverables as well as technical performance targets for all WPs to steer performance.

**Recommendation 4:** That the Centre particularly engage partners, but also other stakeholders, to speed up exploitation of research and innovation results.

**Recommendation 5:** That the Centre develop better integration across its five Sub Projects; and integrate modelling tool(s) development directly into technology research projects.

**Recommendation 6:** That the Centre be more specific about research progress in its annual reporting.

**Recommendation 7:** That the Centre develop bibliometric analysis to benchmark its performance in international terms and disseminate these results on its website and in the final report.

**Recommendation 8:** That in order improve the PhD students' employability, the Centre significantly improve its PhD training by additional activities and elements at the Centre level for this important group (networking, interdisciplinarity, transferable skills, industrial exposure)

**Recommendation 9:** That the Centre seek to initiate more industrial PhD student projects.

**Recommendation 10:** That the Centre ensure its management and administration are effective and have adequate resources to support the core business of the Centre.

**Recommendation 11:** That in order to increase its visibility in the public eye, and its impact on policy and on the public debates about biofuels, the Centre improve its communication capabilities. This should include a major upgrade and ongoing attention to the Centre website and social media channels.

**Recommendation 12:** That in order to meet the needs of its industry and end-user partners better, the Centre upgrade its technology transfer capabilities significantly. This should include a more extensive TRL analysis of all projects which should be repeated on an annual basis and a clear mapping of the connections between all Centre projects and the relevant Centre partners.

**Recommendation 13:** That in order to understand its wider impact and innovation commitment, the Centre report on its associated projects as 'spin out' and 'spin in' to show the impact both from the Centre and to the Centre of these projects.

**Evaluation Panel**
Mary O'Kane (Chief Evaluator)
Mattias Lundberg
Anne Meyer
Lars Waldheim

# 4 Research Centre for Sustainable Solar Cell Technology - SuSolTech

## 4.1 Introduction

**The evaluation**
On 24 February 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, project leaders, industry representatives, a postdoc, PhD students, and representatives of the host institution, Institute for Energy Technology (IFE). In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students and the postdoc. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation report, "The primary objective of FME SUSOLTECH, as stated in the contract, is to increase the size and number of jobs in the domestic solar cell industry". There are various secondary objectives.

The Centre follows on from a related centre – FME Solar United.

## 4.2 Research activities

The Centre covers a broad part of the Si-PV value chain from Si-feedstock to Si-based PV-systems with emphasis on Building-Integrated PV for the latter. It builds on the unique position of Norway in terms of having access to Green Electricity for the energy-intensive parts of the PV value chain (Si-feedstock and ingot/wafer making) allowing manufacture of products with extremely low $CO_2$-footprint. In addition, it builds on the large public awareness of PV as the most promising way to realise Near-Zero-Energy-Buildings (NZEB), which is giving rise to a new industrial ecosystem of PV-system companies active in the domain of Integrated PV. In terms of the Norwegian industrial ecosystem, there is, however, a gap between the Si-wafer level and the PV-system level which reflects also on the relative strengths of the different workpackages. This being said, the scientific and technological contribution of the Centre is overall of excellent quality as is the Return-on-Investment. The remarks below should be read as advice to make the Centre even stronger,

**WP1: Sustainable feedstock production**
In WP1 the Centre starts from an ecosystem which is unique in Europe as described above. This means that the groups of the Centre involved in this activity have also a pretty unique position at least on the European level. This can also be seen in their participation in International Workshops and Conferences where the main contributions in this part of the value chain come from the Centre. This said, it was difficult to pinpoint exactly what bilateral projects were rooted in the insights gained in the Centre. In addition, there is a concern that some of the developments are rather ad hoc and not based on a clear Roadmap on where to head to serve the rest of the value chain with improved products over the next decade. Even more importantly, the lack of such a roadmap based on the links with WP2 and 3 bears an inherent risk for overspecification (it has to be Just-Good-Enough not The-Best-Possible).

**WP2: High performance Si-ingots and wafers**
This WP can also build on a rather unique position in Europe with major manufacturers of high-quality Si wafers being part of the Norwegian industrial ecosystem. The focus is on fundamental understanding of the degradation mechanism of the minority carrier lifetime in ingots and wafers as a function of thermal and irradiation history. For this type of activity, the Centre is in a strong position, albeit at the same level as institutes like University Konstanz and ISFH in Germany. This knowledge is highly valuable but should be linked to the specific cell architecture which is the subject of WP3. This link is however quite weak partly because the cell processing capabilities of the Centre are rather limited in terms of efficiencies reported. But, given its experience in wafer making, the Centre is in a good position to predict the specifications in terms of wafer thickness.

Special attention is given to kerfless wafers as the "Holy Grail" in terms of reduction of specific Si-consumption ($gSi/W_p$) and $CO_2$-content. The Centre reduces its activity portfolio in this context by removing the controlled cracking of Cz-Si wafers - in all probability a good decision. However, for the remaining activity on kerfless wafers, the focus of the activities is on e-beam deposition of the Si for the active Si-wafer. Although the arguments to do so are clear (potentially low-cost, high growth rate, etc.), it is still a problem to reach sufficiently low defect densities as compared to Chemical Vapour Deposition. It would be good risk mitigation to look for partners with a strong background in Si epitaxial growth by means of Chemical Vapour Deposition.

**WP3: High-efficiency silicon-based solar cells and modules**
This workpackage is clearly linked with the previous one as it deals with the impact of the different process steps and field operation on the wafer quality. However, there are two remarks to be made here: first, the cell process used to manufacture the Si solar cell will depend on the architecture used (PERC, PERT, Integrated Back Contact cells, heterojunction cells). Hence, the impact will have to be differentiated according to the cell type as the processes and thermal impact will be different. It is also necessary to be able to make State-of-the Art devices in the high-quality wafers which at the moment is not guaranteed within the context of the Centre. This requires special attention and could be a fundamental driver to seek international contacts (ad hoc or even more structural) to ensure access to these capabilities. In parallel, there are several activities on novel materials for photon conversion or as a high-bandgap partner in a tandem configuration. These activities have a very pre-competitive character.

For PV-modules the emphasis is on BIPV-modules. The Centre is doing good work on coloured cells for this application, but it might be advisable to deepen the link with applications here by taking into consideration the specific environment of BIPV as compared to traditional PV power plants (higher temperatures, different thermal evacuation, higher diffuse radiation, etc.).

**WP4: End use and impact**
This part of the activities deals with assessing and preparing the (Norwegian) Solar Industry for the TeraWatt-era with specific attention towards sustainability and the performance of Si-based modules in real-life conditions which is obviously a key input for the life-cycle analysis. The Centre is collaborating in this context with well-known groups in Europe, although there is room for enlarging these collaborations in order to come up with solid advice on initiatives like Eco-Design, PV Cycle, etc.

**Publications and international visibility/collaborations**
In terms of publications and visibility, it is clear that the activities of WP2 contribute most strongly to the international visibility followed by WP3 and 1. For WP2 the Centre is present in the relevant fora like CSSC. A stronger presence at material conferences like MRS and Silicon PV might help to further build up the impact of the Centre.

A specific remark must be made in relation to WP3 however. The publications are often very far from showing any impact on Si-related PV-devices. These publications and presentations concern mostly the material properties of materials, their modification, and their potential use on top of the Si-cell (as photon convertor or as a tandem) without attempts to realise such proofs-of-concept. For WP4 the number of publications is lower, but this is understandable as this domain does not lend itself so easily to impactful publications. In order to achieve higher visibility there, it is probably necessary to increasingly cover in a systematic way more of the system aspects like energy yield modelling and link it with technology developments in WP3.

As far as one can judge, this is also reflected in the international collaborations which are particularly strong for WP1 and WP2 thanks to the uniqueness of the R&D ecosystem in Norway. That uniqueness is less the case for WP3 and 4. There are ad hoc collaborations in Horizon 2020 projects, but there seems to be no systematic approach towards international collaboration based on a detailed analysis of the missing competences in Norway in terms of cell and module development for the different cell and module architectures.

## 4.3 Internationalisation

Internationalisation is made on several levels in SUSOLTECH. Bilateral collaborations described are mainly with Jülich and also involve research stays. The University of Tokyo and Xiamen in China were mentioned as important international partners. From the publication list, it is not clear if these collaborations are leading to joint publications. If that is the case, it could be worth pointing it out! Joint papers with international collaborators and with industry could be used in the final report from the Centre as a measure of collaboration success.

There is a great interest in the Centre in taking part in European projects. One perceived problem here is the strong focus on silicon feedstock and wafering, which does not harmonise well with the rest of the European silicon industry and research, which is focussing more on higher levels in the value chain. There is also a lot of focus on tandem solar cells in European research and it is not clear how SUSOLTECH will be placed there, since many European groups and projects deal with perovskite tandems. Partners from SUSOLTECH are active in the European Energy Research Alliance as well as the Eco-design directive. The Centre could pursue opportunities to join projects covering more of the silicon value chain.

If entering into European projects is less of an opportunity at present, there are also possibilities to increase involvement in bilateral projects, especially to evaluate the silicon feedstock and wafers to make high efficiency solar cells, where there may be different requirements on silicon purity depending on cell architecture for example. One excellent example of this is the collaboration with Sunpower and the sustainability labelling.
As the Norwegian silicon is to a large extent exported to France, due to its legislation on sustainability maybe there are also opportunities for bilateral collaborations there?

In the PhD and postdoc programs, the internationalisation is extensive. Most PhD students are from outside Norway. Recruitment of PhD and especially of postdocs provides excellent opportunities to extend the Centre's network and initiate collaborations. If the Centre decides to recruit new members (PhD or postdoc) for the remaining period, using international networks for high quality, more targeted recruitment should be considered.

We also discussed the possibility of having a scientific advisory board as a means to extend the scientific scope and network and get suggestions for near future research ideas and focus. This board should preferably comprise members from outside Norway.

**Recommendation 1:** That in order to increase its overall scientific quality and benchmarking, the Centre establish an International Scientific Advisory Board ensuring that it meets regularly and provides written advice to the Centre Board and management.

**Recommendation 2:** That in order to increase its scientific quality, the Centre build strong international collaborative projects especially for Workpackage 3.

## 4.4 Researcher training and engagement in education

The Centre has an important role in educating the future workforce in Norway. Having a good recruitment base is also mentioned by the industrial partners as an important role of the Centre. The Centre is involved at three main levels, Masters student thesis work, PhD thesis work and postdoctoral fellow research. The capacity for Masters students' supervision is about 10 per year, most of them at NTNU.

In the revised plan, the number of PhD students per workpackage with direct funding from the Centre is as shown in the table.

| | WP1 | WP2 | WP3 | WP4 |
|---|---|---|---|---|
| PhD students | 3 | 4 | 4 | 0 |
| Postdocs | 2 | 4 | 3 | 3 |

Most of the funding for PhD students seems to be allocated to NTNU; we note that UiA has only self-financed PhD students.

From a gender perspective, the number of female Masters students is high, while the number of female PhD students is low. The table below lists the associated PhD students so far as well as the postdocs who were active during 2020. One woman (Guro Marie Wyller) appears twice in the table, since she defended her thesis in 2020 and then was offered a postdoc position at the same institution.

| | Number of PhD students in 2020, (F/M) | Finalized theses, (F/M) | Number of postdocs during 2020 (F/M) |
|---|---|---|---|
| NTNU | 6 (1/5) | | |
| UiO | 2 (0/2) | | 2 (1/1) |
| NMBU | 2 (2/0) | 1 (0/1) | |
| UiA | 2 (0/2) | | 1 (0/1) |
| IFE | 1 (0/1) | 1 (1/0) | 1 (1/0) |

The low involvement of women was noted in the self-evaluation. This can in part be explained by the lower number of women in the recruitment base, which to a large extent has been from outside Norway. A considerable number of Masters theses with better gender balance would be an interesting recruitment base in the near future and these Masters students should be encouraged to apply for upcoming PhD student positions in competition with the international applicants.

While internationalisation is important, a good mix in the PhD student pool between Norwegian and international students should be encouraged, since one objective is to keep the PhD graduates in Norway as a recruitment base for the industry.

Over time, the number of PhD students affiliated with the Centre has varied with an (expected) ramp-up during 2017-2018 and an expected large number of dissertations planned during 2021 (in parenthesis in the table below for 2021).

| | 2017 PhD | 2018 PhD | 2019 PhD | 2020 PhD | 2021 PhD (diss 2021) |
|---|---|---|---|---|---|
| NTNU | 3 | 4 | 5 | 6 | 6 (4) |
| UiO | 1 | 1 | 2 | 2 | 2 (1) |
| NMBU | 1 | 3 | 3 | 2 | 2 (2) |
| UiA | | 1 | 2 | 2 | 2 (1) |
| IFE | 1 | 1 | 2 | 1 | 1 (0) |

The table Includes PhD students with funding from partners

As is clear from the table, the number of PhD students will reduce significantly during 2021, with only five remaining. Since the next period of funding is three years, it will be important to fill the empty PhD student positions as soon as possible, or to take a strategic decision to go for postdocs instead of PhD students. This was mentioned in the revised application.

However, in order to have a meaningful interaction between the PhD students, the Centre is strongly encouraged to keep at least a critical number of PhD students associated with the Centre during the next period.

During the interview session with 2 PhD students, one Norwegian and one from outside Norway, and one postdoc recruited from outside Norway, the benefits of belonging to a Centre, such as FME SUSOLTECH, were discussed. Advantages mentioned were possibilities to network and get to know other students, postdocs and researchers, especially important for those coming from abroad. The Norwegian solar cell conference is mentioned as an important venue to meet. However, networking could be made more efficient during the next period as noted in the recommendation below. The students would also benefit from some PhD-only meetings to build mutual support.

Another advantage of belonging to the Centre is having access to more specialised equipment and knowledge, especially among the academic partners. This increases the quality of the thesis work. The Centre encourages collaboration, including student-initiated collaboration.

It is also possible to stay in the Centre (in academic or industry roles) after the PhD. At least two students seem to be staying on. Thus, one of the objectives - to build a knowledge base for Norway - is at least partially fulfilled. However, it is not clear how many PhD graduates will go to industry.

The awareness of and involvement of PhD students in patenting appears to be low. The industrial partners did not mention PhD students in their evaluations of the Centre. The PhD students that we interviewed are not involved in the innovation process and not aware of technology readiness level concepts for example. However, we interviewed only two students and one postdoc, so this statement may not be true generally. At the pre-competitive stage, the focus has been on publishing the results in peer-reviewed journals and this could also be reflected in the PhD students' topics.

The best connection to industry we heard about was workpackage meetings, with industry representatives present. We got the impression however that industry up till now has not sought to initiate collaboration with the PhD students or academic postdoc projects, but rather is following the research from the outside.

Regarding training in generic research skills, apart from what is offered by the individual partners to their candidates, we were offered no example of courseware in generic skills offered by the Centre e.g. intellectual property, leadership skills or other cross-cutting topics. However, the students did highlight a specialist course (on silicon waste and recycling) offered in 2020. Courseware offerings would not only be valuable in themselves but would provide a chance for student networking. Ideally this would also be complemented by effective student induction into the Centre.

The Evaluation Panel notes that there were specific courses developed under FME Solar United but the students did not mention any of these.

Of course, with the proposed lower numbers of PhD students going forward and the changing PhD/postdoc mix, there may be different needs for training. However, the following recommendation may be beneficial also for new postdocs.

**Recommendation 3:** That in order to increase the effectiveness of its graduate training, the Centre 1) develop an induction package for new PhD students, 2) develop a formal network for all PhD students in the Centre for mutual support and development, 3) provide courses and seminars for all PhD students so they learn relevant generic and specific knowledge and skills as a group thereby increasing the bonds between them.

## 4.5 Plans for final three-year period

The plans for the next 3 years are quite clear in terms of activities (and reduction of some activities). However, it would be good to give sufficient attention to the following issues:

- Optimising the unique potential to extend over the full Si-PV value chain by capitalising on stronger links between the workpackages. These links could be based on a clearer roadmap based on quantitative KPIs whenever useful and possible

- To see in WP2 to what extent e-beam deposition is in a position to deliver high-quality Si-layers and compare it to CVD-approaches. There might be opportunities to build a stronger link between WP1 and WP2 on the subject of Si-layer deposition. At present the e-beam deposition is quite isolated from the expertise in WP1

- Choose carefully the fundamental approaches towards beating the Shockley-Queisser limit in WP3. There is a certain risk of subcriticality there as a result of the many options possible. In order to deal with the broad variety of material and cell architecture options, international collaboration is a potential approach to mitigate these risks

- In WP4 it would be good to further build up the international network as a lot of LCA-related activities in Europe are popping up.

- In WP4, consider strengthening the link with international actors to get access to time-series of data of PV-systems so as to develop and validate the models developed within the Centre.

- In WP4, it would be wise to build a stronger link with WP3 so as to have a better view of the energy yield of different cell and module architectures. This might help to detect which technologies are better suited for which climate, for instance.

## 4.6 Organisation and Management of the Centre

The Centre has a clear identity within the Norwegian PV industry and is known internationally especially given the Centre's strong position with regard to sustainable feedstock production. The Centre's board is engaged, and it has enthusiastic and committed management under the able leadership of Erik Stensrud Marstein. The partners generally seem content with progress although many of them do not contribute large amounts either in cash or in kind, something that could be addressed in the second funding period.
The Centre generally communicates well with its broader range of stakeholders. What is less clear is just how effective internal communication is especially given COVID restrictions. The PhD students and postdoc we met seemed somewhat disengaged from the Centre. The workpackages are not optimally interconnected, as noted above. Also, it was not clear that adequate resources were available to engage end user partners more fully with a view to them contributing more resources and to recruit new partners.

**Recommendation 4:** That in order to make management more effective, the Centre allocate more resources to provide increased administrative support for the Director. This in turn will enable such things as a better experience for PhDs and postdocs, better connected research workpackages, and stronger networking between researchers and industry.

The Centre and the Norwegian Solar Energy Cluster recently developed a roadmap for the PV industry. This is laudable but it would be stronger if the Centre had a stronger sense of what it wants to achieve in terms of research and industry impact both by 2025 and in a lasting sense.

**Recommendation 5:** That in order to provide a framework for planning the next phase and beyond, the Centre work out a well-articulated KPI for the impact it wants to achieve by the end of the funding period and by 2030. This could feed into the next iteration of the industry roadmap.

## 4.7 Innovation and value creation

The Centre is an important entity in the Norwegian innovation arena contributing to building up a new emerging industrial value chain. The global value chain(s) can currently be seen as quite immature and dynamic, even if it is maturing relatively quickly. Still, there are many new industrial challenges and a great need for successful research breakthroughs to make this market grow and contribute even more significantly to renewable energy supply. The international competition is fierce both industrially and in research. The Evaluation Panel commends the Centre and its partners for its significant contribution to this new emerging value chain in Norway.

The Centre organises its research into four workpackages (each comprising several 'Tasks') that follow the value chain. The partners naturally are more closely connected to one or another of these four workpackages.

The Centre has several associated projects. It is unclear exactly how those projects are connected to the Centre. The Evaluation Panel urges the Centre to report associated projects both as originating from research results of the Centre and associated projects that feed into the Centre's research in a mutually beneficial way. Also reporting on the total budget, including the budget for these associated projects, will be important to show the total capacity and potential impact from the Centre. We suggest this information should also be reported on the website.

The Evaluation Panel has the impression that the partners seem satisfied with the Centre's performance so far. However, it seems that most of the partners have higher expectations for the

final period rather than expecting any substantial innovations or technology transfer from the first period. This is not surprising. So far, the bulk of the research is in the precompetitive domain with some tasks aimed at fundamental understanding while other tasks have a more applied focus, and some have both. This is probably a good strategy. However, the Panel suggests the match between the research tasks and industrial needs need to grow, from both a short- and a long-term perspective.

In order to increase the usefulness of the Centre's research output to its end-user partners, the Centre must put a stronger focus in the second funding period on implementation of research results. To achieve this, it should give serious consideration to determining potential exploitable results for each of its projects; instituting annual TRL and LCA analyses for its research portfolio; and establishing and then communicating a clear set of tech-transfer KPIs. Setting aside funding would enable an 'open calls' mechanism to be used to boost funding support for this implementation emphasis. There is good awareness of the need for this knowledge in the Centre, but it does not seem to be used in a systematic way. The TRL and LCA analyses used together will help identify weak links or new challenges throughout the value chain in the Centre's different tasks. We strongly suggest the Centre use this knowledge more systematically in the final period. In addition, the Centre could consider increasing the number of Masters projects focused on industry needs.

**Recommendation 6:** That in order to increase the usefulness of the Centre to its end-user partners, the Centre put a strong focus in the second funding period on implementation of research results. To achieve this, it should give serious consideration to determining potential exploitable results for each of its projects; instituting annual TRL and LCA analyses for its research portfolio; and establishing and then communicating a clear set of tech-transfer KPIs. The Open Calls mechanism could be used to boost funding support for this implementation emphasis.

## 4.8 Funding and financial aspects

There is a reasonable number of partners in the Centre. Nevertheless, the Evaluation Panel supports the initiative to bring in new partners. The Centre could even consider having two categories of partners (partners that are closely involved with Centre projects and others with a more watching brief) to better meet its needs – more cash and more connected/involved partners. At present, the Centre has rather unbalanced in-kind and cash contribution from partners. The Centre indicated its goal is to keep the cash contribution at least at the same level during the final period. We encourage the Centre to go for higher amounts of cash, especially if recruiting new partners.

## 4.9 Gender aspects

The Centre's gender balance record is mixed at best. Only one of the eight board members is female, and the majority of the research and technical staff is male. As noted above, the number of female PhD students is low. However, the number of female Masters students is high and there are several women in the management team.

At present the Centre does not have a policy on gender and diversity, on the principle that its partners are likely to have such policies. However, with no policy and targets, achieving systematic improvement in gender balance across all categories in the Centre is unlikely to happen as the recruitment pool in this field is overwhelmingly male especially at senior levels.

In order to show its commitment to this issue, it is important that the Centre set an example and start 'at the top' by making sure its Board is gender balanced as soon as possible

**Recommendation 7:** That the Centre give more attention to achieving gender balance throughout its operations. This should start with formally adopting a gender balance policy for the Centre and ensuring the board is gender balanced in order to signal that the Centre at its top level is serious about this issue. This will involve modifications to selection and appointments processes.

## 4.10 Future activities

The Centre notes that there will be a need for research in this field well beyond 2025 and that there will also be a continuing need for strong collaboration between industry and research institutions. Given the span of its current research, the Centre suggests that seeking to establish two follow-on centres might be advisable. In this regard, the Evaluation Panel particularly commends the Centre's role in developing the PV industry roadmap. Updated regularly, this roadmap will provide important guidance to the post-2025 developments.

## 4.11 Conclusion and recommendations to the centre

Overall, SUSOLTECH is progressing well as an industry-focused research centre with an international presence. Several aspects of its operation could be improved however in order to achieve greater impact for its partners and the PV industry more generally in the second funding period. Accordingly, the Panel makes seven recommendations which are listed below.

**Recommendation 1:** That in order to increase its overall scientific quality and benchmarking, the Centre establish an International Scientific Advisory Board ensuring that it meets regularly and provides written advice to the Centre Board and management.

**Recommendation 2:** That in order to increase its scientific quality, the Centre build strong international collaborative projects especially for Workpackage 3.

**Recommendation 3:** That in order to increase the effectiveness of its graduate training, the Centre 1) develop an induction package for new PhD students, 2) develop a formal network for all PhD students in the Centre for mutual support and development, 3) provide courses and seminars for all PhD students so they learn relevant generic and specific knowledge and skills as a group thereby increasing the bonds between them.

**Recommendation 4:** That in order to make management more effective, the Centre allocate more resources to provide increased administrative support for the Director. This in turn will enable such things as a better experience for PhDs and postdocs, better connected research workpackages, and stronger networking between researchers and industry.

**Recommendation 5:** That in order to provide a framework for planning the next phase and beyond, the Centre work out a well-articulated KPI for the impact it wants to achieve by the end of the funding period and by 2030. This could feed into the next iteration of the industry roadmap.

**Recommendation 6:** That in order to increase the usefulness of the Centre to its end-user partners, the Centre put a strong focus in the second funding period on implementation of research results. To achieve this, it should give serious consideration to determining potential exploitable results for each of its projects; instituting annual TRL and LCA analyses for its research portfolio; and establishing and then communicating a clear set of tech-transfer KPIs. The Open Calls mechanism could be used to boost funding support for this implementation emphasis.

**Recommendation 7:** That the Centre give more attention to achieving gender balance throughout its operations. This should start with formally adopting a gender balance policy for the Centre and

ensuring the board is gender balanced in order to signal that the Centre at its top level is serious about this issue. This will involve modifications to selection and appointments processes.

**Evaluation Team**
Mary O'Kane (Chief Evaluator)
Marika Edoff
Mattias Lundberg
Jef Poortmans

# 5 Mobility Zero Emission Energy Systems - MoZEES

## 5.1 Introduction

**The evaluation**
On 25 February 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, project leaders, industry representatives, a postdoc, PhD students, and representatives of the host institution, IFE. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students and a postdoc. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation, "The main objective with MoZEES is to be a Center for environment-friendly energy research with focus on new battery and hydrogen materials, components, technologies, and systems for existing and future transport applications on road, rail, and sea. The overall goal of MoZEES is to contribute to the design and operation of safe, reliable, and cost competitive zero-emission transport solutions."

## 5.2 Research activities

**Summary of aim and scope**
The overarching aim of the Centre is to conduct research, build knowledge and advance technologies within zero-emission transport, with battery technologies and hydrogen technologies as the two focus areas. For both research areas, there are efforts along all parts of the value chain comprising materials – components – systems. The research activities are organised in four research activities, with RA1 covering fundamental research within battery materials and components, RA2 fundamental research within hydrogen fuel cell and electrolyser materials and components, whereas RA3 covers applied research within battery and hydrogen systems for application areas of heavy-duty transport, i.e. road, rail and sea. RA4 covers new transport solutions and services, with focus on techo-economic feasible pathways towards zero-emission systems.

These research areas are of high importance and receive a lot of attention globally, since they are some of the technology prerequisites for the energy transition to lower GHG emissions and zero-emissions technologies and fuels for transportation. These research areas are also of high strategic importance for Norway due to the need to transition from oil exploration to lower-carbon and zero-carbon fuels and technologies.

MoZEES operates with a total budget of 260 million NOK for the period 2017-2024 and from the start in 2017 it has involved more than 100 active people from the host institution IFE, 4 research institutes, 3 universities, 6 public partners, 21 commercial & industrial partners and 2 private interest organisations.

**Overall outcome**
New and innovative results and scientific advancements have been achieved in all four research areas. In RA1, new anode materials and electrolyte formulations with improved properties have been developed and characterised. In RA2, progress on both electrocatalysts for PEM fuel and electrolysis cells as well as on bipolar plates both for PEM and alkaline electrolysis has been made. In RA3, modelling tools for PEM fuel cell and electrolysis systems have been developed for design and operation, and models for battery lifetime, durability and safety as well as hydrogen safety have been developed. In RA4, cost estimates and technoeconomic studies for battery electric and hydrogen trucks and buses have been developed, and models for battery and hydrogen vessels are under development. The level of scientific research in overall is impressive.

According to the self-evaluation, the Centre has so far produced 37 peer reviewed publications and one invention disclosure for possible new IP. This is a very good outcome, given that in the initial years of operation many of the fundamental developments have been made, that will in the coming years lead to application. Furthermore, several PhD students are close to finishing and this is expected to lead to an increase in publications.

**Comments and suggestions**
The Centre has created an excellent foundation, and in the coming years the focus will be to apply the developed model as well as test developed battery materials in actual cells. This will be important to actually capitalise on the fundamental advancements of the first period. Furthermore, during 2017-2021, there has been a fundamental paradigm shift in the battery industry from a technology push to an industry pull. This will require a careful balance of the Centre to, on the one hand, capitalise on and respond to the industry push and, on the other hand, continue to build knowledge and explore low TRL topics. While hydrogen technologies are not as commercially ready as battery technologies yet, a similar development could be expected with a lag of several years. Therefore, it is important that the Centre evolves its priorities to stay relevant, and this is the underlying consideration for Recommendations 1 and 2.

**Recommendation 1:** That in order to maximise impact, the Centre continue ensuring critical mass in activities, de-selecting less relevant topics where necessary. The Centre should also continue to explore low TRL topics as well as contributing to near-implementation research.

**Recommendation 2:** That in order to assist the effective prioritisation of research topics in light of the paradigm shift especially in the battery industry from technology push to industry pull, the Centre restructure its budget so that there is sufficient “free money” to respond quickly and stay relevant. Implementing an “open calls” mechanism with this funding to start small feasibility studies is one way to do this. Such feasibility studies can then be the basis for seeking funding for new associated projects.

In the self-evaluation and the partner evaluations, only a few innovations and associated projects were identified. However, in the interview and in discussions with the researchers, several more innovations and associated projects where identified that had not been reported. The Centre’s work is excellent and therefore it is important to capitalise on it and also get recognition for it in an optimal way, hence Recommendation 3.

**Recommendation 3:** That in order that its significant achievements be recognised, the Centre improve its reporting by at least:

- better reporting of affiliated and associated projects, categorising them as 'spin in', 'spin out' or both
- better reporting of innovations, especially "soft" and "hidden" innovations
- focus on capturing innovations in the research work (see also Section 7)
- reporting publications that are joint between research and industry partners
- reporting field-weighted citation indices (FWCI) where possible for Centre publications. Many research institutions use FWCI as it gives an indication of how well an institution's publications are cited compared with other publications within that field allowing benchmarking to other research institutions and researchers in the field
- reporting new courses at undergraduate and Masters levels in addition to PhD courses which were initiated by the Centre or are based on Centre research.

## 5.3 Internationalisation

The Centre has an international profile, which is a key aspect of its success because both battery and hydrogen research need to be conducted in a global context. To this end, the Centre has established formal collaboration agreements with four international universities and collaborates with other international partners as well. Furthermore, several of the industrial partners are from outside Norway, e.g. Johnson Matthey, and/or have a global presence such as Lloyd's Register, ABB, and DNV GL. The Centre has also established a Scientific Advisory Committee with strong international representation.

The international profile is also reflected in the Centre postdocs and PhD students and in staff exchange. The international PhD students reflected positively on their experience in the Centre during the evaluation. Also, all postdocs and PhD students enjoy events with international exchange such as summer schools and conferences.

## 5.4 Researcher training and engagement in education

The researcher training program of the Centre is strong. Apart from the engagement in PhD and Master theses as such, there are a number of young researcher education and training activities that are valued highly by the students.

During the evaluation, several PhD students raised concerns about delays in their PhDs caused by COVID, leaving them with an incomplete PhD and no further funding to finish it. This gives raise to Recommendation 4.

**Recommendation 4:** That the Centre introduce mechanisms to support PhD students whose research programs have been significantly disrupted by COVID so they can secure research support & funded extensions to finish their PhDs.

## 5.5 Plans for final three-year period

The research plans for the final three-year period are of high quality, with the main goal to apply the fundamental work completed by the Centre and get as much value out of the results as possible.

The evaluation of the research plans for the final period also resulted in Recommendations 1-3, see Section 2 for a detailed discussion of those.

## 5.6 Organisation and Management of the Centre

The Centre is well run with a competent Assembly and Board and a well-functioning management team under the leadership of the Director, Øystein Ulleberg. As noted above, there is also a Scientific Advisory Board that offers high quality advice on the research program and connections (though see Section 9 for a comment on its gender (im)balance). The Director maintains close links with the host institution, IFE.

The Centre has prioritised communications and building its visibility in Norway and internationally although it could do more to highlight its achievements (see Recommendation 3 above).
While the partner evaluations submitted as part of the evaluation were not uniformly strong, the partners who attended the interview were satisfied with their engagement with the Centre and the plans for the next phase.

## 5.7 Innovation and value creation

The Centre has 36 partners as well as the host institution, IFE. The partners' involvement as described during the interview was vibrant and commendable in the two interlinked, emerging new industrial areas that the Centre focuses on. Recent developments in these fields throw up significant challenges for all involved – industry suppliers, end-users, the research community and the public sector. The value chains for both battery and hydrogen technology are at the moment extremely exposed to fast-moving international competition. The Centre convinced the Evaluation Panel that it makes a substantial contribution within Norway to building up new competitive competences across the value chains within those two areas.

Many of the partners are naturally primarily interested in applications, but the Centre commendably continues to cover from research to innovation in both fuel cells and batteries.

The Centre has identified some weaknesses in its self-evaluation, and taking account of these together with the overall impression from the partners' evaluations and the interview, the Evaluation Panel makes the following suggestions for the Centre to consider in order to increase its broader impacts and outreach in the second funding period:

1. Increase the number of associated projects directly originating from the Centre's research such as MSc projects that are more connected to industry or have other funding
2. Invite the industry partners to identify their most wanted feasibility study on an annual basis
3. Increase the mutual mobility as a tool to enhance knowledge transfer
4. Target specific impacts on public partners like standards (e.g. safeguards and LCA standards), public discussions, regulatory inputs, etc.
5. Report media outputs such as interviews, public engagement, op-eds, podcast, as another way to broaden its societal impacts.

## 5.8 Funding and financial aspects

The Centre has commendably recruited new partners and there seems to be potential for more to come in those two emerging value chains in the final period.

The in-kind contribution from the partners is good and seems to be increasing. The cash contribution seems to be somewhat low (even though there has been an increase from the industry partners), but maybe this is fair considering the mix of small and large partners involved. It also seems that the Centre is rather dependent on the cash contribution from public partners. In the interview we were

told that some of those partners might be unable to contribute during the final period due to internal organisational decisions. It was unclear if there is a back-up plan to deal with this. The Evaluation Panel suggests that the board secure a back-up plan if this cash contribution is withdrawn. The Panel also encourages the partners to grow their in-kind contributions in the final period to secure knowledge transfer even more.

## 5.9 Gender aspects

The Centre has paid careful attention to gender and diversity issues from student recruitment through to encouraging more women to apply for board positions. Half the management team is female as is about a third of the cohort of key researchers. While there is some way to go to achieve optimal gender and diversity balance, as the Centre acknowledges, the trends are in the right direction. One area where the Centre could be more proactive is in the membership of the Science Advisory Committee – all the current appointees are male. This is something that could be easily rectified, maybe by enlarging the Committee slightly with the addition of two new (female) appointees.

## 5.10 Future activities

The Centre notes that there will be a continuing need for considerable research and innovation in both battery technology and hydrogen technologies after the end of the funding period and it suggests the possibility of applying for two new FMEs, one in each of the fields, if the scheme continues. This makes sense.

## 5.11 Conclusion and recommendations to the Centre

MoZEES is a high-performing FME but, like all organisations, improvements are possible. The Evaluation Panel makes four recommendations to assist with this.

**Recommendation 1:** That in order to maximise impact, the Centre continue ensuring critical mass in activities, de-selecting less relevant topics where necessary. The Centre should also continue to explore low TRL topics as well as contributing to near-implementation research.

**Recommendation 2:** That in order to assist the effective prioritisation of research topics in light of the paradigm shift especially in the battery industry from technology push to industry pull, the Centre restructure its budget so that there is sufficient "free money" to respond quickly and stay relevant. Implementing an "open calls" mechanism with this funding to start small feasibility studies is one way to do this. Such feasibility studies can then be the basis for seeking funding for new associated projects.

**Recommendation 3:** That in order that its significant achievements be recognised, the Centre improve its reporting by at least:

- better reporting of affiliated and associated projects, categorising them as 'spin in', 'spin out' or both
- better reporting of innovations, especially "soft" and "hidden" innovations
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- reporting new courses at undergraduate and Masters levels in addition to PhD courses which were initiated by the Centre or are based on Centre research.

**Recommendation 4:** That the Centre introduce mechanisms to support PhD students whose research programs have been significantly disrupted by COVID so they can secure research support & funded extensions to finish their PhDs.

**Evaluation Team**
Mary O'Kane (Chief Evaluator)
Berit Hinnemann
Mattias Lundberg
Sonia Yeh

# 6 Centre for an Energy Efficient and Competitive Industry for the Future - HighEFF

## 6.1 Introduction

**The evaluation**
On 1 March 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, project leaders, industry representatives, postdocs, PhD students, and representatives of the host institution, SINTEF Energi AS. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation report, HighEFF has "four cornerstones of the Centre; energy efficient processing, waste heat utilisation, industry clusters and education and training."

## 6.2 Research activities

**Centre profile**
HighEFF focuses on technologies and processes with potential for large reduction in specific energy use. The stated goal namely to "enable 20-30% reduction in specific energy use and 10% in emissions through implementation of the developed technologies and solutions" is commendable and ambitious. In terms of this objective the Centre aims to deliver 15 to 20 new innovations to the Norwegian industry, develop tools and methodologies in support of the overall objective, build and enable competence in energy efficiency through educational goals of educating 22 doctorate and 50 master students, and build a leading international centre for industrial energy research. The significant and in-depth interactions with industry partners add tremendous impetus and value to the outcomes of the Centre.

The Centre has demonstrated capacity to produce high-quality scientific and educational outputs through a structured and intentional approach to energy efficiency and optimisation interventions across all industries. While this is undeniably a grand challenge, the Centre has created a significant critical mass within a relatively short time with a number of excellent success stories at various stages of implementation. The research objectives are well defined into six research areas (RAs), addressing cross-cutting concepts that can be implemented across a broad range of industrial applications, including such diverse applications as metal production and retail applications. Excellent, world-class research contributions are being generated through the research conducted under the auspices of the Centre, evidenced by the admirable portfolio of publications, presentations and the quality of doctorate candidates. The research areas are well defined and formulated at a high-level in the project description; it is crucial for the Centre to be defined clearly due to the broad-based research theme and size of the Centre. It is noted that there is a sound system in place to monitor the outcomes at the project level. There is also an annual strategic planning process that ensures the research is elevated and linked to the Centre goals. The different Research Areas are actively engaging with the industrial partners, and evidence of an activity or engagement tracker and

planner is commendable. It especially notable that the industry partners indicate that the researchers are capable and enthusiastic in their engagements. The Centre adapts the focus or priorities of research activities based on the changing needs of industry and society. And it tackles complex interdependencies across a broad potential application base extremely well.

HighEFF exists within a strong and experienced host eco-system, and this expertise contributes to the ongoing quality scientific outputs of the Centre. The management and reporting requirements of a Centre of this nature also benefits from the experienced hosts.

**Outputs**
The high number of publications (2016–2020) published thus far, namely 145 journal papers and 126 conference papers is indicative of the intensification that can be achieved through a research centre.

The Centre's focus is precompetitive R&D (typically TRL1-5), and a key mechanism implemented within the Centre, aiming to support implementation of novel applications, is via spin-off projects. The Centre demonstrates an in-depth understanding of the processes and constraints of lower-level TRL innovation, which enhances the positive impression of the HighEFF Centre. HighEFF acts as an incubator of innovative concepts, which stimulates a variety of parallel and supporting spin-out project opportunities. While some ideas may be practical and implementable within a short time, and achievable directly from the Centre, the Centre’s funding is not applied to implement. The spin-off projects contribute towards a much broader impact from the work that evolves from the systems within HighEFF and thus delivers a significant contribution to the research and innovation system.

Systems engineering aims to optimally design, integrate, and manage complex systems over their life cycles. A process energy system, especially if integrated, is an example of a highly complex system. The Centre's approach towards energy optimisation has many hallmarks of a sound systems engineering approach, also evidenced by the use of case studies, for example. The case study approach, supported through RA6, is a valuable contribution to the Centre's success, and also requires a strong systems-thinking approach. The case studies draw on the research innovations and knowledge from the various research areas and bring the industry into the fold of innovation in a practical and approachable manner. Excellent examples of the benefits of the case studies illustrate the value of the approach. The use of case studies is very successful and influential output of the Centre as it clarifies the Centre's goals to all involved and creates direct value for industry partners and researchers alike.

Research Area 5 is another example of the Centre’s approach to applying a broad-based implementation strategy. RA5 connects applicable social sciences with technical researchers and supports the research goal of implementation, through a number of research projects and interventions to support innovation management. By investing in initiatives directed under this research area, the Centre demonstrates a keen understanding of the complexities of delivering and understanding research impact, as well as the interplay between innovation and society. The Centre also leverages the experiences gained by other Centres to improve the implementation rate and impact of the research emanating from the Centre. This ongoing and prioritised effort to maximise impact and innovation is noteworthy, while it is also noted that the self-assessment of the Centre highlighted that this area may be underfunded. This again reflects the maturity of the Centre.

## 6.3 Internationalisation

**Summary**
In judging progress on internationalisation, the following aspects are considered as relevant.

- Research partners

    - The group of research partners consists out of 14 partners, where of 8 are non-Norwegian. These non-Norwegian partners include partners from EU, UK, US, JP and CN. These partners include well known universities and research institutions, which can be considered as the frontrunners in refrigeration and heat pump related R&D.
- User partners
    - The Centre currently has 26 company partners and 2 public partners. The company partners include four direct non-Norwegian partner companies, with all of them being well known manufacturers for the global market. One of them is an important industrial refrigeration compressor manufacturer from Japan. The other three are European manufacturers with worldwide distribution and operation networks. The involvement of these partners is most significant, as within the Centre's WPs important developments with these companies is done. It includes R&D on key components such as new compressors for HTHP, new compressor valve design as well as heat exchanger and ejector development for new cycles and their investigations. Thus, this international partnership is most important for the Centres workpackages.
- PhD students
    - About 25 PhD students and postdocs have been recruited for the Centre. Roughly, one third are Norwegian students. The remaining have nationalities from EU, America and Asia. Some of them working directly at a foreign research partners location. There is a good integration of these partners and their students into the overall Centres activity and the PhD workshops of the Centre - even so the students would like to have a higher level of integration.
- Masters students
    - About 50 Masters students are, or have been, part of the Centre's activity and research. This includes also a certain number of Masters students from foreign universities. They are getting involved in the Centre and thus into the partnership with international research partners, user partners and students.
- Publications
    - Publications and presentations are done in international journals and in the relevant international conferences. Thus, knowledge is brought to an international forum. Key researchers within the Centre such as Armin Hafner and Petter Nekså are well known inside the community and are approached for advice on a regular basis.
- EU Framework program and other
    - Further strong international visibility, networking and activity can be derived from the associated projects, which include several EU Horizon 2020 projects and applications.

**Comments and criticism**

Internationalisation in the Centre is at a good level on all relevant aspects. The evaluation interview revealed that certain workpackages clearly depend on the active and high performing cooperation in research with international research and user partners. More integration and communication for the students would take the international integration to an even higher level.

## 6.4 Researcher training and engagement in education

The students (Masters and PhD) are embedded within the workpackages and the doctoral students interviewed were very complimentary about the manner in which they were integrated into the workpackages and their inclusion in the Centre's interactions with industry. The students were keen to become even more involved in the Centre's activities, indicative that they are engaged with their

work, but that there may be opportunities to increase communication with the students, especially with regard to the results and projects generated within the Centre, but not directly linked to their particular project. The doctoral students' positive feedback highlighted that alignment with industry is intentional, and the examples provided of their own involvement in defining their projects are admirable and encouraging. The cohort of 20 students (2 completed) is an exemplary example of the efforts by the researchers within the Centre.

The diversity of the students is also commendable, and the impact of the Centre's educational goals will undoubtably continue to be felt throughout the global community into the future. The immense investment in postgraduate development is very impressive and the research partners' efforts in this regard, combined with embedding the students within the Centre's project work, is highly commendable. While the students within the Centre meet annually and build their own networks with other project teams, there is a need for more regular interaction with the students hosted by the Centre. There is evidence that even students not located in Trondheim participate in annual meetings, and other engagements, but it appears the opportunities of virtual workshops and webinars are not embraced more broadly by the Centre. Regular student meetings would enhance a very good system and further leverage the strength of the educational program.

**Recommendation 1:** That the Centre increase (virtual) meeting days for PhD students especially during COVID and also ensure they are being adequately supported in this time in their particular workpackages.

## 6.5 Plans for final three-year period

**Summary**

- From the interview during the evaluation, it became clear that there is a well-structured assessment and updating of the project plans but limited details were provided to the Evaluation Panel. The interview also revealed that the research in several areas is at a very high technical level, higher than is visible from the different documents distributed for the evaluation.
- From the 2021 workplan together with information presented at the interview, it can be concluded that ongoing research is needed to build sufficient knowledge on the technologies to bring them up the TRL levels high enough for RA6.
- The interview also revealed that serious consideration is given to the demands of industry, and that the workpackages are industry driven. As industry partners have high expectations there are additional important activities planned for RA6, for example the activities for the case studies.

**Comments and criticism**

Future plans are nearly the same as the original Centre description. It is not so easy to see exactly from the documents what the activities in the last years will be, especially as some of the workpackages are scheduled to terminate significantly before the end of the Centre. However, the interview was helpful to get better visibility on this issue. There are time charts in the workplan for 2021 for each research activity, that give a rough overview of the project status and future plans. We expect that significant activity will be turned into the case studies, while the ongoing research activities on components and systems allow for a better foundation of the studies.

## 6.6 Organisation and Management of the Centre

The Centre has an enthusiastic and dedicated board under the chairmanship of Arne Ulrik Bindingsbø and an able management team led by Petter Røkke.

It has appointed a Scientific Committee with local and international membership. This Committee submitted a report in December 2020 which provided a detailed critique of the quality and relevance of the Centre's research and education programs to date. This provided useful input to this evaluation.

Four reference groups have also been established under the leadership of SINTEF executives to enhance interaction between industry partners and researchers (including PhD students and postdocs) in four fields – energy and energy analysis, energy storage, process improvements, and energy recovery.

Generally, the Centre's partners seem pleased with their interactions with it. At interview the Evaluation Panel heard good examples of where partners had benefited from close links to particular projects. As the Director pointed out several times, and the Panel agrees, partners who put more into the Centre (a judicious mix of cash, time, management enthusiasm and other in-kind) tend to get the most out of their investment.

The Centre is very visible in the international research community as it has worked hard to build international connections. Its international visibility in industry circles has been assisted by the decision to include international industry partners and Norwegian industry partners with wide extensive industry networks, as noted above.

The Centre has a laudable range of communication initiatives and these include a good website and a social media presence. Nevertheless, it was clear from talking to the students that more networking and communication internally is needed especially for those students during COVID. (see Recommendation 1 above).

## 6.7 Innovation and value creation

**Innovation especially through collaboration with partners**
The Centre's focus on heat recovery for different types of industries to increase their overall energy efficiency and decrease their carbon footprint is commendable and its focus on innovation is a good strategic choice to increase value creation and knowledge awareness for involved partners and to increase overall impact.

The Centre has cumulatively engaged with 49 industry and research partners since it started. The majority of partners remain connected with the Centre. Industry partners were involved in the original proposal application under which umbrella the Centre was funded.

The Centre demonstrates through the impressive list of partnerships that it conducts industry-relevant research through close collaboration with a large consortium of industry partners, including equipment vendors and end-users. Every workpackage and project within all the research areas engages with industry partners. Besides the connectedness with industry, the Centre is well-connected with several like-minded research institutions with excellent skills in relevant energy efficiency research incorporated within the Centre.

The Centre, through a well-established research system, provides all partners with access to world-class expertise and innovation. The high number of partners participating in the Centre is highly commendable and, while the high number of partners also creates complexity, it offers a unique opportunity to solve real-world problems for the industry partners. There is strong evidence that the scientific output from the Centre is highly valued by the industry partners. Industry partners

generally have high expectations from the Centre, and the Centre's management team demonstrates a keen understanding of this, acknowledging the need to manage expectations.

The continued participation of a large group of diverse partners is admirable. The industry partners are generally supportive and engaged, indicating that industry sees value in participating in the research activities, even though some implementable interventions may require time to develop. It seems that the relationships between the industry and the research teams are well-established. Balancing the research goals and industry relevance and needs within a constrained system requires careful management, and the Centre is handling thus well. The Centre Director described the need to prioritise efforts to achieve the overarching goals very well. There is some potential to improve the articulation or representation of the research priorities in a succinct format, especially to contextualise the research at the workpackage and project level to demonstrate the strategic choices that need to be made by the Centre.

**Comments and criticism**

Developing methodologies to optimise energy systems is listed as a strength of the Centre. The adage 'to measure is to know' is highly applicable in efficiency and optimisation work. The emphasis placed on the development of methodologies, testing rigs, and optimisation tools is noted and endorsed. It is worthwhile reflecting on the fact that the Centre's self-assessment identified life cycle analysis as a weakness. Life cycle analysis is a very useful tool that can be used to evaluate the systematic benefits of and identify opportunities for optimisation and it would be wise if this capacity were developed in support of the Centre’s goals.

The Centre's awareness of the need to interact with industry and the notable efforts in this regard are essential considering the very high number of partners and the diverse nature of the industries involved in the Centre. Suppliers and end-users often have divergent expectations and needs, and while there are obvious potential benefits from creating such a diverse platform, the ambitious nature of this complex collaboration could be resource-intensive and requires creative and varied communication practices. There is a delicate balance between inclusive collaboration and administrative intensity, but it appears that the Centre has found a fair balance between the research, communication and reporting requirements associated with a Centre of this nature. While the overall impression from the partner assessments and the students is that they are satisfied with the Centre, some issues need attention. In particular there are opportunities to improve communication to particular stakeholders. In this regard, the Evaluation Panel notes that Centre has done a detailed analysis of partner feedback and will act on this feedback in planning for the next funding period.

Data is an integral part of the Centre's activities. There are protocols and guidelines in place to manage confidentiality and intellectual property information, a consequence of the well-established management system of the Centre. A Centre of the size of HighEFF could benefit from a digital system approach to data management and reporting, allowing for more in-depth assessments of the outputs and results. Researchers and industry share information and experiences predominantly via traditional platforms such as workshops and contact sessions and transfer of data and information directly to researchers. There may be significant benefits in assessing the data generated within the Centre with a view to unlocking a possibly underutilised asset via a more advanced data management system.

The Evaluation Panel noted several very positive and impactful interventions and activities worth recognising including the following.

- The Centre's efforts to entrench the use of a common language for complex energy and thermodynamic concepts will undoubtedly add tremendous value in the long term
- The Centre's acknowledgement and understanding of the interaction of science and engineering innovation within society is prioritised, and the manner in which the results from the Centre is communicated to the partners and the community reflects this awareness and proactive approach. One example of this is the involvement in the initiative "FME Innovation task force" and the "Forum for innovation leaders". These will help the Centre, as well as another FMEs, to increase the understanding of how to drive innovation effectively across the clean energy sector in Norway. It is also very good that this initiative will continue.
- The Centre demonstrates maturity and understanding of the broadness of the research scope and manages this complexity well by adapting the research focus on an ongoing basis, in response to the fast-changing industry needs
- Imbedding postgraduate students within the research areas offers students an invaluable insight into the interaction between industry and research and will develop a cohort of high-quality researchers as a result.

There are excellent examples of industry collaborations on PhD projects with industry-focused research as a consequence, but there are opportunities to increase industry-based students. Increased focus on collaborative publications among all the partners, research and non-research, would enhance the portfolio of evidence. There is evidence that the Centre is aware of the benefits of this and is actively engaging with industry in enhancing these types of collaborations. An excellent example comes from RA4 where an industry-based PhD student is supported within the RA to complete relevant industrial research for his doctorate. Another example is the commendably large number of Masters students connected to the Centre - continuing high numbers of Masters student in the second funding period will help interconnect industry with research partners in a mutually beneficial way.

The Centre is an exemplary model of a well-coordinated and effectively managed research centre with an extraordinary stakeholder portfolio, both within Norway and internationally. The Centre functions across a vast research topic area, which necessitates deliberate and active management of goals - and these goals are very ambitious.

As noted above, there seems to be some tension about whether the Centre has a role in helping partners with projects and innovations that are higher up in the value chain, higher than TRL5. It also seems that the Centre is yet to find ways to leverage its achievements for the good of a broader industrial community. In this regard the Evaluation Panel notes the Centre’s strategy to set aside budget for “open calls”. Maybe projects can be initiated through this excellent mechanism to address the Centre’s impact on the broader industrial community.

**Recommendation 2:** That the Centre aim to increase awareness across all its members on what an innovation is in the context of the areas in which the Centre operates and how potential innovations should be moved forward speedily or abandoned quickly. This could involve education/training on this matter for industry, for Masters and PhD students and for postdocs.

## 6.8 Funding and financial aspects

The Centre’s partnership engagement is impressive and has the potential to be a role model for other FMEs. It is organised so that industry and end-user partners are connected to case studies and

appropriate research areas. The fact that some partners have left and new ones joined does not seem to have affected the overall Centre funding. In the next period, the Centre could look to complement its funding with yet more spin-out and spin-in projects to increase its impact and help set itself up for whatever it chooses to do beyond the FME funding period (see Section 10 below).

The balance of in-kind and cash is appropriate. The Centre could consider investigating if some partners would increase their in-kind contribution in the final period to get even more impact on their businesses, especially through case studies.

## 6.9 Gender aspects

The Centre director is highly aware of the importance of gender balance across the organisation. However, gender balance in the various parts of the Centre is mixed. While it is laudably good for the PhD students supported by the Centre, it hovers around 30% for other parts of the Centre (board, scientific committee, senior scientist cohort). The Evaluation Panel encourages the Centre to improve the gender and diversity balance in these parts of its organisation.

## 6.10 Future activities

The Centre notes that it is important that new research/industry collaborations and capacity building projects in the fields it operates will need to be initiated beyond the FME funding period and that the infrastructure build up through HighEFF$_{lab}$ should continue to be available. It also sees the need for some form of centre activity coordinating research. It has yet to work out exactly what form these successor activities to HighEFF should take but has commenced discussions on the issue. This is appropriate but the Evaluation Panel suggests that the board and management prioritise this issue when planning the second period as the way it is structured can set the follow-on activities up for success.

## 6.11 Conclusion and recommendations to the centre

HighEFF is performing very well. But there are aspects that can improve. Accordingly, the Evaluation Panel makes the following two recommendations.

**Recommendation 1:** That the Centre increase (virtual) meeting days for PhD students especially during COVID and also ensure they are being adequately supported in this time in their particular workpackages.

**Recommendation 2:** That the Centre aim to increase awareness across all its members on what an innovation is in the context of the areas in which the Centre operates and how potential innovations should be moved forward speedily or abandoned quickly. This could involve education/training on this matter for industry, for Masters and PhD students and for postdocs.

**Evaluation Panel**
Mary O'Kane (Chief Evaluator)
Isabel Geldenhuys
Ullrich Hesse
Mattias Lundberg

# 7 The Research Centre on Zero Emission Neighbourhoods in Smart Cities - ZEN

## 7.1 Introduction

**The evaluation**
On 2 March 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, project leaders, industry representatives, researchers, PhD students, and representatives of the host institution, NTNU. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation report, "the ZEN Centre will enable the transition to a low carbon society by developing sustainable neighbourhoods with zero greenhouse gas emissions".

The Centre builds on the work of an earlier FME, ZEB (Zero Emissions Buildings).

## 7.2 Research activities

**Summary of aim and scope**
The FME Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) increases the boundary of earlier FME activities (in FME ZEB) from the building level to smaller communities and neighbourhood level. This expanded system level raises a whole set of new challenges and research problems: How can we define zero-emission neighbourhoods? Through which performance indicators can they best be characterised? How can they be integrated into the existing energy (and more specific electricity) system and what are the challenges and demands that will have to be addressed, e.g. load management and peak shaving? What new solutions for the design and operation of energy flexible neighbourhoods can be developed? Which business models are appropriate? Etc. The ZEN Centre systematically deals with these questions in a comprehensive and interdisciplinary way and develops definitions, performance indicators, and ways of modelling ZEN. It explores the implementation of decision support tools and models, and tests these in a series of nine neighbourhood-scale Pilot Projects and Living Labs around Norway.

Research activities in the Centre are organised through six workpackages. Two of these are aimed at integrating the dimensions and perspectives of the four more specific workpackages: WP1 develops an analytical framework for the design and planning of ZEN, including definitions, an LCA database, and a suite of planning and modelling tools; and WP6 applies and tests the findings and tools from the other work packages in pilot projects and living labs. Of the more specific workpackages, WP2, focuses on policy measures, innovation and business models and analyses regulatory barriers to the implementation of ZEN; WP3 deals with the development and modelling of responsive and energy efficient buildings; WP4 with energy flexible neighbourhoods and the modelling and optimisation of local energy systems; and WP5 studies the optimisation of local energy systems within the context of the larger energy system. An interesting feature to keep the work program flexible and open are so-

called ZEN cases which are shorter-term studies (ca. 6 months) of specific problems and upcoming questions and can be decided by the board on a rolling basis.

**Overall outcome**

The quality and outcome of the research carried out in the Centre is impressive at different levels including in terms of its broad scope and the variety of problems and research issues it covers: from more engineering-orientated questions of building design and modelling to questions of integration into the wider energy system; questions of low-carbon transport; and social science issues of stakeholder participation; citizen engagement; and business model development. This broad range of issues could pose a formidable challenge to the organisation and management of research in such a Centre, but at the same time the critical mass achieved in such a research Centre also provides a unique opportunity to deal with such questions in their connectedness and interrelatedness. The Centre does so in an excellent manner and contributes to the forefront of international research on the transition towards low-carbon settlements and societies. Moreover, there is a good mix of industry focused and research-based projects, supported by the ZEN Labs and Pilots.

Also, from a long-term perspective, the ZEN Centre opens research fields and avenues which will remain highly relevant in an international research context, providing a high potential for future collaborations and building a competence base (not least through the high number of PhDs engaged on the program) for future excellence in sustainable energy research in Norway.

The high quality and volume of research output is well documented in the self-reporting provided for the evaluation – around 60 peer-reviewed scientific articles, a large number of conference presentations and other publications, a series of ZEN reports (28 until the time of reporting), various outreach and popular science activities, but also outputs in terms of PhD students affiliated and financed by the Centre (18 PhDs funded by the Centre, 11 more affiliated). The Centre research activities have also led to a number of associated projects – 12 so far, including coordination of a Horizon 2020 project.

**Comments and criticism**

Generally, the Evaluation Panel considers that the work of the Centre is of excellent quality and that the productivity is extensive both within research teams as well as in collaboration with the industry and international partners. However, given the breadth of research topics and disciplinary perspectives covered by the Centre, the identification and in-depth study of critical problems for the development of ZEN; the creation of a significant impact on the practical development and implementation of zero-carbon neighbourhoods; and the generation of sufficient added value for the participating industry partners will remain a constant challenge and high on the agenda for the final period of Centre activities.

Furthermore, perhaps due to the breadth of the project scope, it is difficult to gain an understanding regarding the extent to which the ZEN project is making a difference in terms of moving the country as a whole towards the ZEN goal, in terms of winning hearts and minds and spreading word beyond the pilot projects.

Reports from partners vary in terms of perceived benefits of the relationship – particularly with industrial partners for which the relationship has been positive but has not resulted in changes to the way they do business. The Centre seems to be relatively successful on a project-by-project basis, but the feedback suggests that only in a few cases is there a change in the way these organisations do business and in their recruitment processes.

There is mention of ‘practice-based instruments’; ‘new business models, roles and services’ and development of technologies, models and decision support tools for optimisation of energy systems.

This is laudable but remains high level. Making these achievements more concrete and specific seems also important for communicating the achievements of the Centre to other stakeholders and a wider public.

**Recommendation 1:** That in the second funding period, the Centre extensively test its various models & tools in the 'real-world' settings that its partners can provide, with an additional focus on reaching the general public.

This recommendation reflects the situation that the Centre has to move from an initial phase of problem identification, development of tools and models and creation of a relevant knowledge base for the development of zero-emission neighbourhoods, to a phase of practical implementation, testing and dissemination of tools and strategies. This shift in focus is mentioned at different places in the Centre reports, but still could be developed and planned in an even more systematic way. This would also include the testing and implementation of ZEN-specific business models as well as (if possible) the testing of new regulations in 'regulatory sandboxes'. This should extend beyond an academia to business and industry approach to include citizens and communities in the municipalities where the project is most active.

**Recommendation 2:** That the Centre formalise the process used to manage the diversity of topics that come within the purview of zero emissions neighbourhoods. While the broad scope of the Centre should be maintained and the development of new topics should be encouraged, transparent and strategically informed decisions need to be taken as to which of these topics should be incorporated into the program, which put aside for associated projects, and which left altogether.

An additional way of handling the balance of breadth and depth of Centre research, or in other words the focus on key critical problems while retaining a broad scope and perspective of the Centre, could be to invest more of the Centre funding in the shorter term 'ZEN Cases' as a mechanism for opening up and generating new perspectives, while developing clear procedures as to decision making around which of these cases are taken up for further research in the Centre. Another mechanism to address this challenge would be to intensify and systematise the collaboration with other FME Centres which often intersect with ZEN in their research scope (e.g. on mobility).

**Recommendation 3:** That the Centre increase efforts to improve longevity of the program by expending effort in the last three years on facilitating knowledge transfer from academia and research partners to the industry through researchers spending time in industry and industry partners spending time in the Centre.

The extent of knowledge transfer between the ZEN Centre and its partners is crucial to delivering a step change in business attitudes and also in supporting new markets. This was also raised by the Scientific Advisory Committee in 2019. The Evaluation Panel's observation was that while this was being addressed to an extent internally, more could be done.

There are two aspects to this:

- there is the need to continue to exploit opportunities for PhD and Masters students to work in an interdisciplinary way across work packages and
- in terms of Centre-to-industry, the Centre could (for example) be developed by a knowledge exchange programme within the ZEN project - whereby researchers are embedded within the industry and industry staff work to transfer knowledge from the Centre via short- or long-term projects.

In order for this to be effective, the industry will have to see the value. This could be achieved by identification of specific opportunities, challenges and barriers by industry and the development of

these into ZEN Cases, which would then be run as short-term projects in order that those engaging from the industry side gain a sense of the timescale to which they are committing. Inviting the industry to identify the key areas of interest, will increase the incentive in terms of ensuring that participants remain engaged and will add real value.

**General points**
The Centre activities are well in line with the original plans. There are no obvious delays in deliverables, and workplans are updated once per year and sent for approval by the Research Council, which can be seen as a good procedure.

There is potential for further improvement and clarity in the reporting on innovation in the Centre. While the high number of innovations listed in the current Innovation Report is laudable, many different kinds of innovations (often rather ideas, concepts or inventions) are lumped together and could profit from a clearer structuring; estimation of the likely impact (with details of how this will be measured); potential of the innovations reported; and a clear strategy of which innovations to emphasise in the report.

Overall, the research aspects of the project are strong, some focused on the science and engineering aspects of the project and others more specifically linked to solving the challenges for industry in delivering various aspects of the delivering the ZENs of the future. There is a good mix of industry focused and research-based projects, supported by the ZEN Labs and Pilots. But, as noted previously, perhaps due to the breadth of the project scope, it is difficult to understand to what extent the ZEN project is making a difference in terms of moving the country as a whole towards the ZEN goal.

## 7.3 Internationalisation

**Summary**
Generally, good early progress was made through early collaborations with China and USA (LBNL) but opportunities have not grown significantly particularly outside of Europe. Mention of a potential initiative with India is noted; this should be pursued.

Researchers in the Centre have been active in the EU H2020 program, coordinating or being part of more than 15 applications, which include ZEN user partners.

The Centre has received funding for and is coordinating the *Sustainable Plus Energy Neighbourhoods project* ***syn.ikia***, an EU Horizon 2020 innovation action project involving 13 research and industry partners from six countries focused on sustainable neighbourhoods with surplus of renewable energy in different climates and markets in Europe.

NTNU and SINTEF are part of the newly funded project ***iclimabuilt*** on *Functional and advanced insulating and energy harvesting/storage materials across climate adaptive building envelopes*. NTNU leads a workpackage on living labs and is part of the project management team.

Centre researchers are currently coordinating an application to the Green Deal call on Building and renovating in an energy and resource efficient way (LC-GD-4-1-2020).

The Centre is also the Norwegian advisor to the SET-Plan Smart Cities and Communities Action 3.2 Funding Agency Working Group (FAWG), which aims to create 100 plus energy areas (PEDs) by 2025.

NTNU is the R&D manager for the European Stakeholder Group, a role that is in addition to the work of developing a research and innovation program coordinated by the joint program Smart Cities within the European Energy Research Alliance (EERA JP Smart Cities).

SINTEF and NTNU also participate in The European Construction, built environment and energy efficient building Technology Platform (ECTP) which is a leading membership organisation promoting and influencing the future of the Built Environment.

The Centre is involved in several International Energy Agency (IEA) projects, such as IEA EBC Annex 72 Assessing Life Cycle Related Environmental Impacts Caused by Buildings, IEA EBC Annex 81 Data-Driven Smart Buildings, and Annex 83 Positive Energy Districts.

The Centre participates in various projects aimed at countries outside the EU/EEA area. For example, it leads a research cooperation project with China on energy named *Key technologies and demonstration of combined cooling, heating and power generation for low-carbon neighbourhoods/buildings with clean energy* – ChiNoZEN, which started in 2020.

Exchange visits: 5 ZEN Centre PhD candidates/researchers have stayed more than 4 weeks abroad and the Centre has received 9 visiting researchers/candidates during the last 4 years.

**Comments and criticism**
Collaborations within Europe are strong, but more and looser alliances could also be advantageous. What does not come out strongly in the reports is the output from and impact of international research collaboration and researcher mobility, etc. This could be strengthened in the remaining years. COVID restrictions notwithstanding, more effort on researcher mobility and adjunct professorships would also be beneficial.

## 7.4 Researcher training and engagement in education

**Summary**
Recruitments of postdoc and PhDs are prioritised activities in ZEN, with support from external (industry and authority) partners. According to the self-evaluation, 18 PhD students have so far been recruited and funded by the Centre budget, 3 of these completed their theses before the end of 2020. The Centre is in the process of recruiting 6 additional PhDs. There are currently only 7 PhDs who are women, so the intention is to improve the balance in this round of recruitment. There are also around 11 associated PhD students who are working in Centre projects with financial support from other sources. There are currently 4 postdocs with 3 more planned in the next phase. The distribution of PhD students across work packages is as follows:
WP 1: Analytical framework – 4 PhD and 2 Post Docs
WP 2: Policy measures – 3 PhD and 1 Post Doc
WP 3: Responsive and Energy efficient Buildings – 5 PhD and 1 Post Doc
WP 4: Energy flexible neighbourhoods – 4 PhD and 1 Post Doc
WP 5: Local energy system optimization within a larger system – 3 PhDs and 1 Post Doc
WP 6: Pilot projects – 5 PhD candidates and 1 Post Doc

The number of PhD projects underway and completed is impressive, but there remains a question around how well these PhDs are integrated in the Centre's activities. The Masters program is also extremely active with over 40 students engaged currently or having graduated.

**Comments and criticism**
The total number of Masters students is slightly below total outlined in project for the midway point at 40 vs 91 over the life of the project, however, ramping up of this is noted in the project description for the final three years.

Although there is some evidence of cross-workpackage working, the extent of crossover and inter-WP collaboration on PhDs and Masters remains unclear. It would be helpful if this was included in the reporting.

The success of the summer school activities (pre COVID) is evident and should be resumed, if possible, at some point in the near future.

As outlined in **2. Research Activities** above, the extent of knowledge transfer between the ZEN Centre and its partners and vice versa is crucial to delivering a step change in business attitudes and also in supporting new markets. This aspect of the Centre could be developed by a knowledge exchange programme within the ZEN project - whereby researchers (especially PhD students) are embedded within the industry and industry staff work to transfer knowledge from the Centre – thus enhancing researcher training and industry engagement in education.

## 7.5 Plans for final three-year period

**Summary**
From the interviews it was clear that this is a well-structured and successful Centre. The focus to date has been fairly academic in the sense of lining up tools and research ideas and testing these in a semi-live but fairly safe environment. The Centre has changed little over the past three years but it has built-up significant momentum. Now it is time to begin to test the project outcomes in the real world on live projects and against the additional pressures brought by real communities who do not behave like researchers!

**Comments and criticism**
Questions still remain around how the next three years will make a difference in terms of a lasting legacy and changes at both policy and delivery levels with a view to making ZEN the norm rather than the exception. Pilot projects can only go so far to improve engagement. The Evaluation Panel noted the intention to work towards greater influence over Government policy and engagement with the general public in order to understand and influence behaviours at citizen and community levels.

However, from the plan, we also noted a reduced ambition for the development of user-centred tools such as visualisation tools or stakeholder dialogues, which is a pity. While it is understandable that tools already applied should be given priority, it would be desirable to adapt such tools to the specific situation and features of ZEN.

The Panel is of the view that the next three years should continue to build and increase focus on cross and interdisciplinary engagement at all levels: between students and researchers across workpackages; between the Centre, researchers and the industry partners; and between the Centre, researchers and citizens and communities in real neighbourhoods.

See also Recommendations 1, 2 and 3 above.

## 7.6 Organisation and Management of the Centre

The Centre has a highly engaged and proactive board, ably led by Tonje Frydenlund. Its management team headed by the Director, Arild Gustavsen, is also very good. The board and management are advised by two committees, a Scientific Advisory Committee, comprising international research experts, and an Innovation Committee with members drawn from the partners.

The Evaluation Team was impressed the Board's initiative in 2018 in introducing "Zen cases", sprint projects generally lasting 6 months, initiated by a user partners and carried out as a collaboration between researchers and personnel from one or more user partners. Ten have been completed and eight more started. As noted above, they are an excellent way to strengthen user involvement, to

solve issues, and work up new concepts. At interview the Panel heard that the output from cases can lead to changes in the workplan when it is adjusted annually or they can lead to the establishment of associated projects.

While much of the Centre's communication material is very well designed and easy to use, aspects of the website are out of date and material is missing. Given the Centre's generally very strong professional image and its strong commitment to community, it is important that communication materials are kept up to date.

From the interview day, it is clear that the Centre has built an inclusive and supportive culture. Many members of the Centre participated knowledgeably in the interview and the PhDs the Panel met with were a particularly well-networked and mutually supportive group who identified strongly with the Centre. This is an important achievement.

From the partner assessments, it is clear that partners are generally pleased with the Centre (though see Section 2.3 above for discussion on when this is not so much the case). End-user and industry partners who attended the interview offered several interesting examples of how they could derive benefits from being involved in Centre projects.

## 7.7 Innovation and value creation

The Centre has 22 industrial partners and 11 public partners including two government agencies. Most of the partners are involved in some of the Centre's commendably wide-ranging activities. From the self-evaluation report and the interview, the Evaluation Panel gained the impression that the Centre is seen as a very promising asset by most of the partners. As noted above, some aspects could be improved e.g. mutual mobility and technology transfer.

There are three, major, application-oriented processes in this Centre:

- Pilot projects
- Living lab
- Case studies

So far, the pilot projects seem somewhat immature from the information on the Centre's website and from the written mid-term evaluation material. There seem to be only 5-6 industrial partners involved as stakeholders altogether in the 8 pilot projects. However, the ongoing and finished ZEN cases involve around 8 industrial partners and 6 public partners. The end-user partners clearly know about the living labs, but it is somewhat unclear to what extent they get involved in them. Taken together, this gives the impression that, on one hand, the Centre has organised and built up very good capacities to meet industrial needs, but on the other hand, these seem rather underexploited so far, with the exception of the ZEN Cases. The Evaluation Panel suggests the Centre work to achieve higher end-user partner involvement in these three important schemes for the next funding period.

The Panel also suggests that the Centre considers increasing the annual budget for ZEN Cases to enhance the overall impact and knowledge transfer in the final 3 years.

One important goal for the Centre is to make a broader long-term impact on the building sector and other related areas, e.g. energy suppliers. The need to generalise and implement the knowledge created in the Centre for broader industry and the public sector is an important issue for the final 3 years. In this regard, one very good case study is the "ZEN and legal framework in Norway" (ZEN OG LOVVERKET). It concludes that it is somewhat unclear to what extent and when the barriers actually will be dismantled in Norway. The Panel suggests the Centre consider taking this work further,

developing a possible timeframe with milestones for dismantling the barriers by responsible stakeholders. Other possible topics worthy of further investigation are standardisation and safety. The FME Innovation Forum, a mechanism for co-operation across all FMEs, is a very good initiative that enhances the impact of all the centres involved.

The Evaluation Panel also heard that the Centre has good co-operation with FMEs carrying out related work e.g. MoZEES and CINELDI. What was less clear is how the centres actually influence each others' activities – do they co-fund projects, for example? We suggest the Centre should try to identify the mutual impact of these activities in its annual reporting.

The number of reported associated projects is commendable. The Panel suggests the Centre report the spin-out projects categorised by origin from the research activities/output in the Centre. In addition, we suggest the Centre report on associated projects that deliver knowledge to the Centre, i.e. spin-in projects.

The Centre has identified 5 DOFI. This is good, but we were somewhat surprised of the PhDs low awareness of this kind of activity.

## 7.8 Funding and financial aspects

The funding situation in terms of balance of in-kind and cash is very good. The reporting of total budget for associated projects could be done using a better structure (see section 7) to show the total impact from and on the Centre.

## 7.9 Gender aspects

The Centre leadership is very conscious of the importance of gender balance and generally the Centre is doing well with good gender balance in the board, key researchers, Scientific Advisory Committee and Innovation Committee. It is not so good for PhDs and postdocs, but the Centre indicates it intends to address this issue for the next funding period.

## 7.10 Future activities

The Centre notes that there will be a continuing significant need for industry-focused research beyond the FME funding period and that there will be a need also for co-ordination of research in this broad but important field. Centre members are committed to continuing to work together in some form on the ongoing challenges after the Centre wraps up. This will be aided by the proposal to have the Centre as part of a Norwegian Research Centre on Sustainable Buildings and Neighbourhoods (in the form of a NTNU-SINTEF Gemini Centre), to be located in the new ZEB Laboratory.

## 7.11 Conclusion and recommendations to the Centre

FME ZEN is an impressive FME. The Evaluation Panel makes three recommendations aimed at making its long-term impact and the take up of its research results by industry and end-user partners even stronger than it is at present.

**Recommendation 1:** That in the second funding period, the Centre extensively test its various models & tools in the 'real-world' settings that its partners can provide, with an additional focus on reaching the general public.

**Recommendation 2:** That the Centre formalise the process used to manage the diversity of topics that come within the purview of zero emissions neighbourhoods. While the broad scope of the Centre should be maintained and the development of new topics should be encouraged, transparent and strategically informed decisions need to be taken as to which of these topics should be incorporated into the program, which put aside for associated projects, and which left altogether.

**Recommendation 3:** That the Centre increase efforts to improve longevity of the program by expending effort in the last three years on facilitating knowledge transfer from academia and research partners to the industry through researchers spending time in industry and industry partners spending time in the Centre.

**Evaluation Team**
Mary O'Kane (Chief Evaluator)
Mattias Lundberg
Lori McElroy
Harald Rohracher

# 8 Centre for intelligent electricity distribution - CINELDI

## 8.1 Introduction

On 3 March 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, workpackage leaders, industry and university representatives, PhD students, and representatives of the host institution, SINTEF Energy Research. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

## 8.2 Research activities

The overall goal of CINELDI "is to enable a cost-efficient realisation of the future flexible and robust electricity distribution grid, such that distributed generation from renewable energy sources, electrification (incl. transport) and more efficient power and energy use can be realized while ensuring security of electricity supply". The research comprises the disciplines of electric power engineering, cybernetics, information and communications technology, and is supported by social sciences research (social economics and consumer behaviour related to flexibility). The scientific work was originally organised in six workpackages (WP), four of which with leaders from SINTEF Energi and two with leaders from NTNU. A new WP concerning pilot projects was established during the first 5-year period. Strong partnerships have been established with grid operators, technology providers, and authorities, which all can provide data and important information to the researchers. Experimental work is carried out in the National Smart Grid Laboratory (NSGL) in Trondheim, and in living labs and pilot projects with the partners.

The workpackages cover all the important technical aspects of the future distribution grid and are in line with international developments, even though the work primarily is focused on Norwegian conditions. Four WPs address specific technical issues: Smart grid development and asset management; Smart grid operation; Interaction DSO/TSO; and Microgrids, whilst two WPs have a more embracing character: Smart grid scenarios and transition strategies, and Flexible resources in the power system; the final WP concerns the pilot projects. The most important results obtained so far are listed on page 2 of the Centre self-evaluation, and these results seem to be according to the plan given in the project description.

The interdisciplinary approach taken is very ambitious. It has taken a lot of effort to establish a common playing field for collaboration between the different domains, and especially as interdisciplinarity between the power system area and the ICT area has increased very substantially during the life of the Centre. Sufficient knowledge and skills in power distribution systems are important, and it took time to convey these to non-experts. However, it seems that the research connected to the social science aspects (market aspects, social economics and consumer behaviour) is still rather limited and mainly focuses on user perspectives and market, whereas regulatory aspects and how they influence the technical solutions could be profitably included.

Up to November 2020, CINELDI researchers have published more than 80 scientific publications, 40% in journals and 60% in recognised international conferences. This is in line with the set-up goals but seems maybe a bit low compared to the number of actual researchers involved (31 professors and scientists together with 18 PhD students and 5 postdocs). The papers cover the subjects of the different workpackages well. More than 20 additional papers are in the pipeline as at autumn 2020. During 2020 two papers were recognised as best and second-best papers at conferences. The number of papers per year is increasing well during the Centre lifespan.

There seems to be good cooperation with the user partners and some mobility during the project period, though less than planned. But CINELDI has had good usage of data and pilot tests from its partners, and there has been lot of workshops and meetings for technology transfer. Still, the implementation of new ideas seems to be lacking in many respects.

The research program is of international interest and relevance. Through publication of papers and participation in conferences, CINELDI gets international visibility. Further, many of the CINELDI researchers are active in international expert groups, networks, and standardisation bodies, e.g. CIGRE, CIRED, ISGAN, IEC, CENELEC, and, through this, the work of CINELDI is internationally exposed. Additional aspects of international collaboration are discussed below under Section 3 Internationalisation.

Evaluation/Assessment:

- The research program and structure are timely and well positioned in the national and international context.
- The interdisciplinary approach taken is ambitious and should be encouraged, even if progress has been slower than foreseen.
- The results obtained so far seem to correspond to the original progress plan. (Though it would have been of value to have more exact and concrete statements of the main milestones in Figure 3 of document 3.3 Project description)
- The scientific output in the form of publications is good with regard to both quantity and quality, even though it is maybe a bit low compared to the number of researchers, PhD students and postdocs involved.
- Implementation of new findings seems to be lacking, even though good cooperation with user partners can be seen.

## 8.3 Internationalisation

CINELDI has made significant efforts to increase the international visibility of the Centre and to establish international collaborations. The Scientific Committee has six foreign members from prominent research institutions in smart grids. These members have given valuable research advice and have been instrumental in establishing connections to other research groups. The report from the Scientific Committee is not very explicit on these matters, but our impression is that CINELDI has used this opportunity to increase international cooperation.

The Centre has contributed to 55 project applications 2017–2020, 40 of which have been decided, 21 with success. The project portfolio covers national and international projects, including EU projects.

The scientists in CINELDI work in international expert groups including CIGRE, CIRED, ISGAN, IEC and CENELEC, as noted above. But it seems as though the user partners are not that much involved in the international cooperation unless they are involved in the international projects. More visibility could be gained if scientists and end-user partners also participated in international fairs, trying to ensure larger markets and replication also outside Norway.

Researchers from CINELDI have visited other countries and guest researchers have been in Trondheim. Due to the pandemic during 2020 some visits have been shortened or cancelled.

Of the 18 PhD students working in the Centre in 2020, 9 are Norwegian and 9 are from other countries. Five postdocs are working in the Centre, four of these coming from abroad. A clear majority of the senior researchers employed at NTNU and SINTEF Energi is Norwegian.

Evaluation/Assessment:

- CINELDI has implemented a clear strategy to increase international cooperation.
- The Centre has managed to recruit PhD students and postdocs internationally.
- Due to the pandemic, international research stays and visits have been shortened or cancelled.
- It is natural that the research mainly addresses the Norwegian power system with its specific conditions and characteristics. However, it would be of value if more work could be devoted to exploring how the results could be extended and applied to systems in other countries.

**Recommendation 1:** That the Centre think about how to get its partners to be more adventurous in the international arena, and that they should see international research and replication as a focus area as well, not only focusing on the Norwegian perspectives of today, since the future energy system will be more multi-energy oriented everywhere.

## 8.4 Researcher training and engagement in education

An important part of CINELDI's activities is training the next generation of researchers. In 2020, 18 PhD students and 5 postdocs were active at NTNU in the thematic areas of the Centre. It was anticipated in the Centre description that the first round of PhDs theses would be submitted by the end of 2020, but it seems that they are delayed. It can be expected that the first PhD degrees in the program will be awarded in 2021.

Research results from CINELDI have been integrated into different Masters level courses at NTNU. A new 3-year bachelor study program on intelligent electric power systems will be launched at NTNU in 2021 followed by a two-year Masters program in 2024.

Close to 100 MSc theses has been submitted at NTNU up to the end of 2020. These numbers are tracking well since the total number in the whole CINELDI period should be 150. In 2020, 31 students at NTNU did their Masters projects in areas connected to CINELDI's research, some with personnel from industry partners as co-supervisors.

Evaluation/Assessment:

- The activities have had a tangible impact on the training of young researchers and on the teaching and training of Masters students at NTNU.
- The new bachelors degree study program at NTNU, from 2021, is a commendable result of work done in the Centre.
- It would be good to see more partner involvement in the Masters thesis projects, since it seems that currently most of them are based on ongoing research projects or ideas from the supervisors, and not from actual needs from industry.
- The Centre could consider inviting other universities in Norway to take part in the Centre, so they also could benefit from the good industrial cooperation.

One issue that came up in meeting with CINELDI PhD students was that they had found networking events (lunchtime seminars etc.) very beneficial but these had dropped off during COVID, a time when such support is needed more than ever.

**Recommendation 2:** That the Centre provide more support to the PhD students in terms of networking events and explicit support when needed for those students who have been significantly affected by COVID.

## 8.5 Plans for final three-year period

In the project description for the final three-year period, it is suggested that the research tasks should progress along the established main fields. This means that the current structure of the workpackages will be retained. Also, the plans concerning PhD students and postdocs are more or less aligned with those of the first phase of the project. These plans, which are motivated by external conditions, i.e. the power system, have not changed significantly and the existing structure has been successful. This might be true, but it would have been of value to reassess the research organisation of the Centre afresh. The SWOT analysis in the self-evaluation would be useful in such a review as would general consideration of speeding up global moves towards decarbonisation.

**Recommendation 3:** That the Centre reassess its proposed work program for the second period in the light of the accelerated decarbonisation agenda worldwide and in the light of the partner feedback. The SWOT analysis is also a very useful input to this process.

The Centre's focus in 2021 is on flexibility and on security of electricity supply in 2022 (though no details for this are given). However, it is not fully clear from the plan which kind of flexible resources should be considered and how to address the issues about user engagement and market perspectives which are largely missing from the overall goal for the Centre. It is also difficult to see if the aspects described for 2021 and 2022 are new, compared to what has been done already. Also, the focus seems to be very much on the situation in Norway today, rather than trying to look forward to gain even more flexibility from private households, and also from industry (something which has not been much addressed until now), as well as from electrification of transport and the heating/cooling sector - looking into scenarios for 2030-2040 that the Centre should address. The coupling to other energy carriers through a multi-energy system analysis is in many countries used as a method to explore new flexibility sources. This approach should also be considered by CINELDI in its future plans.

There are good plans for further cooperation with other FMEs and projects, also on the international level. But exploitation plans for how results can be implemented nationally by user partners or spin-offs and internationally is somewhat missing, even though there is discussion about innovation.

Evaluation/Assessment:

- The Centre says that it intends to retain the current research organisation for the final three years. However, it is not clear how the SWOT analysis has been used to investigate a possible alternative organisation of the Centre or the research tasks in the future.
- More focus should be put on exploitation and technology transfer to ensure implementation of the Centre's results nationally and internationally.
- There are good plans for the future in relation to recruitment and education.
- The Evaluation Panel suggests the Centre try to apply for more associated/demonstration projects both nationally and internationally, aiming to get the innovation higher up in TRL.

**Recommendation 4:** That if the Centre chooses to pursue multi-energy as a major focus, it allocate significant resources to develop an effective working arrangement with other appropriate FMEs and that it involve industry partners in this arrangement from the start.

## 8.6 Organisation and Management of the Centre

The board chair, Sigurd Kvistad, and other board members made active contributions and observations at interview and are clearly committed to the Centre being successful. The director, Gerd Kjølle, leads a highly competent management team. And the scientific coordinator (Kjell Sand up to and including 2020, Olav B. Fosso from 2021) oversees a strong research program producing good results as discussed above.

The board and management have taken notice of the feedback from the partners' assessments and intend to use this information along with the present evaluation and other inputs in careful planning for the next period. The Evaluation Panel endorses this and suggests that the Centre also look particularly at the changing situation with regard to energy and climate change (see Recommendations 3 and 4 above).

The host institution, SINTEF Energy Research, strongly supports the Centre and has worked not only to support it but to provide common support structures across several FMEs.

As noted above, the Centre has established a Scientific Committee chaired by the scientific committee leader Magnus Korpås, but with the remaining members all international appointees. The Evaluation Panel was informed that the quality of advice both on the research program and connections from this group had been invaluable.

The Centre also has an Innovation Committee comprising representatives of industry and end-user partners. According to the self-evaluation, this committee has played a useful role in advising on Centre innovation processes and industry partner involvement. As noted below, the Evaluation Panel suggests such involvement should be a greater feature in the second funding period than it is at present – the Innovation Committee will have a critical role in making this happen.

Communication has been a point of emphasis in the Centre. It does very well in formal scientific communications, but it needs to pay more attention to communicating with the general public through podcasts, interviews, articles in the popular press, social media, etc. At interview, the Evaluation Panel asked the Centre about measuring the impact of communications activities and how it will know when communications success has been guaranteed. We acknowledge this is a complex issue but urge the Centre to keep working on it.

Overall, the partners seem pleased with their membership of the Centre. At interview, several board members from industry partners explained what the benefits of Centre membership to them were - variously ranging from informal education/training leading to changing techniques and processes, through to culture change in the industry, as well as, for certain partners, working on specific projects of particular interest to them. We note, in this regard, that the pilot projects are very popular with both research and industry partners.

## 8.7 Innovation and value creation

The Centre's industry and end-user partners comprise of grid companies, technology providers, one transmission system operator (TSO), three authorities and one market operator. Together they cover the major electricity market of Norway and cover the entire distribution value chain in Norway. The

Centre is aware of the importance of the end-user perspective and the industry perspective more broadly. This has resulted in very good co-operation with other FMEs and other initiatives to cover a much broader value chain to secure mutual impact to and from CINELDI. The Centre explained that it is exploring even more collaborations with other FMEs. One example is to have a common PhD student with FME ZEN. Another good example is the ongoing work with the FME Innovation Forum, a common co-operation mechanism for all FMEs, that should increase the overall impact of CINELDI.

From the self-evaluation and at the interview, the Centre says it currently has 14-16 potential innovations. The Centre indicates it has various activities and "tools" to move these innovations higher up the TRL scale. It also has its "checklist", pilot projects, and living labs as mechanisms through which to develop innovations.

However, the Evaluation Panel has concerns as to the actual impact of the Centre's work on end-user partners. The Centre seems well aware of this, but it seems to be focusing more on moving its discoveries to a higher TRL rather than seeing how it can make an impact on end-user partners through its research. Nevertheless, the overall impression from the partners' self-assessments and the interview is that the Centre partners are largely satisfied with the Centre, though they raise some issues which the Centre will investigate in planning for the next period e.g. knowledge transfer, mobility and recruitment of qualified personnel. The smaller grid companies have lower capacity to engage in the Centre for obvious reasons (due to their size). There is a risk that those companies will not derive any real value from their involvement in the Centre. SINTEF can play an important role as an intermediary to secure knowledge transfer in this respect but also through initiatives such as its coming involvement in the Smart Grid Services Cluster (SMEs). The Evaluation Panel suggests that SINTEF increase its effort to secure knowledge and technology transfer from the Centre to all partners.

The Centre's activities in and awareness of standardisation, policy and legal issues are very good. However, the Centre could put more effort into identifying barriers in a more structured way and coordinate its efforts on this with similar activities at a European/international level.

The Centre has so far not produced any patents or spin-out companies of its own. We suggest this is missing an opportunity and encourage the Centre to ramp up activity in this regard in the second funding period.

The reporting of affiliated/associated projects could be more structured, reporting to show the Centre's actual impact through spin-out projects originating explicitly from the Centre's research, and also noting how other affiliated/associated projects deliver knowledge into the Centre.

The lack of good grid data, identified in the Centre's SWOT analysis, is a weakness. The Evaluation Panel was informed at the interview that there are initiatives afoot to secure better data. We think that the Centre as a matter of urgency needs to increase its efforts to remove this serious barrier, to secure mutual benefits for research and industry partners.

**Recommendation 5:** That the Centre find ways for the second funding period to involve industry partners (small and large) much more in the whole research program so that they derive maximum and preferably immediate benefit from their membership of the Centre.

**Recommendation 6:** That the Centre put more focus on exploitation, technology transfer and high-quality data to ensure implementation of its project results nationally and internationally.

## 8.8 Funding and financial aspects

The arrangements for the partnership are generally good. Some partners have left but new ones have been recruited. Overall, this does not seem to have affected the financial situation of the Centre.

The balance of in-kind and cash contributions from partners is appropriate. The Centre has succeeded in securing a rather high proportion of in-kind contributions in the form of access to useful equipment from different partners in a commendable way.

The total budget for affiliated/associated projects originating from the Centre's research and spin outs should be reported in a transparent and structured way to make it possible to estimate the Centre's total impact (see also section 7).

## 8.9 Gender aspects

The Centre has made good progress towards gender balance in its board, Scientific Committee and senior management. It also does well in gender balance for the PhD students funded directly by the Centre (though not with those associated with the Centre but funded through other means). Still, given it is operating primarily in disciplines that struggle to achieve gender balance, the Centre is doing well in this regard.

## 8.10 Future activities

The Centre notes the significant challenges that will remain in its domain after the end of the FME funding period and indicates that it would be appropriate to apply for a follow-up FME, if possible. The Evaluation Panel suggests considerations about this could profitably be incorporated in the Centre's proposed planning for the second funding period.

## 8.11 Conclusion and recommendations to the Centre

CINELDI is now fully established and is performing as a very good centre which could, however, improve its impact in ways that provide significantly more benefits to its partners and the wider industry it serves. The Evaluation Panel makes 6 recommendations to assist with this.

**Recommendation 1:** That the Centre think about how to get its partners to be more adventurous in the international arena, and that they should see international research and replication as a focus area as well, not only focusing on the Norwegian perspectives of today, since the future energy system will be more multi-energy oriented everywhere.

**Recommendation 2:** That the Centre provide more support to the PhD students in terms of networking events and explicit support when needed for those students who have been significantly affected by COVID.

**Recommendation 3:** That the Centre reassess its proposed work program for the second period in the light of the accelerated decarbonisation agenda worldwide and in the light of the partner feedback. The SWOT analysis is also a very useful input to this process.

**Recommendation 4:** That if the Centre chooses to pursue multi-energy as a major focus, it allocate significant resources to develop an effective working arrangement with other appropriate FMEs and that it involve industry partners in this arrangement from the start.

**Recommendation 5:** That the Centre find ways for the second funding period to involve industry partners (small and large) much more in the whole research program so that they derive maximum and preferably immediate benefit from their membership of the Centre.

**Recommendation 6:** That the Centre put more focus on exploitation, technology transfer and high-quality data to ensure implementation of its project results nationally and internationally.

**Evaluation Panel**
Mary O'Kane (Chief Evaluator)
Göran Andersson
Brigitte Bak-Jensen
Mattias Lundberg

# 9 Norwegian CCS Research Centre - NCCS

## 9.1 Introduction

**The evaluation**
On 4 March 2021 the Evaluation Panel met with the Chair and members of the Board, the Director, project leaders, industry representatives, PhD students, and representatives of the host institution, SINTEF ER. In the morning the discussions focused on the research at the Centre followed by a meeting with PhD students. In the afternoon, discussions focused on industrial and organisational matters and the future of the Centre. This evaluation is based on these interviews and on the self-evaluation report and other written material supplied beforehand. We thank all members of the Centre for their efforts in providing information for the evaluation and the helpful and frank discussions on the interview day.

No panel member had a conflict of interest with the Centre or any of its members.

**The Centre**
According to the self-evaluation report, “the NCCS vision is to enable fast-track CCS deployment through industry-driven science-based innovation, addressing the major barriers identified within demonstration and industry projects”.

## 9.2 Research activities

**Research activities including competence profile, critical size, research program**
The Centre conducts thematically relevant research of high international standard in the CCS field. Research is theme-focussed in 12 Tasks intended to reduce cost, enhance safety and support scale up and demonstration of CCS. There is close engagement in the R&D activities with industrial sponsors and international collaborators. Innovations from NCCS are expected to have a direct impact and be picked up by equipment manufacturers, vendors and operating companies in the emerging technological market, which is opening up for CCS, both in Norway and further afield.

Looking at the R&D track record of all Task Leaders and the Centre´s technical/scientific management, it is evident that there is a strong competence profile in all 12 Tasks. The critical size of the teams seems adequate for the scope of the Tasks and the ongoing research program is delivering the right outputs in the forms of technical publications, peer-reviewed material, open-access tools (e.g. Thermopack), PhDs and other measures of scientific excellence. There is room for some improvement on these points as noted in the recommendations, but the assessment and interview have revealed that the staff of NCCS are aware of some of these shortcomings. The research program followed so far is according to the plans laid out in 2015. Each task has annual phase gates. The Evaluation Panel discussed the efficacy of this process with the Centre board, management and researchers, as the tasks remain largely the same from 2017 onwards. But there is evidence of the need to review future planned activities under the current tasks and the need to expand activities and adapt to some new priorities in the CCS R&D field (see section 5). Concerns raised by the Panel on complementarities amongst Tasks were addressed satisfactorily during the interview, with clear examples of inter-task interactions provided, highlighting the interdisciplinarity of the task teams. Continued emphasis on the opportunities for cross-Task collaboration (e.g. through modelling and simulation activities) remains important however.

It is evident to the Panel that the Centre has created a critical mass of intellectual excellence, from the articulate and knowledgeable PhD students to the high-achieving senior researchers and Centre

managers. The Centre is well-supported (and critically challenged) by industrial partners and members of the various committees participating in the process of shaping R&D activities.

**Long-term research in the field outlined in the project description**
The main project objective is linked to the need to close knowledge gaps by carrying out R&D in areas that can accelerate the deployment of CCS systems in Norway, Europe and the world. Indeed, several tasks are closely linked to the "Deployment case 1" in the proposal, referring to a particular choice of technologies (i.e. solvent technology for CO2 capture, CO2 transport by ship, and identified storage sites in the North Sea) though others are not (i.e. Tasks 3, 5 and 6 are not linked to the deployment case). The long-term research being carried out is of high quality (e.g. proton conducting membranes, H2 combustion turbomachinery) but very specific. The choice of these specific tasks appears to have been influenced by the requirement to have a supporting industrial partner.

Current activities on the core tasks have changed little from the original proposal (and the first major review in 2017), but the research portfolio has been (and is continuing to be) expanded into new areas, through Premium Projects and other collaborative 'spin-in' and 'spin-out' projects. These are both within and beyond the 12 task areas and involve both NCCS and a wider range of partners. Whilst this is a very positive move, the current projects appear opportunistic based on the partners' interest. The Scientific Committee and, to some extent the Special Advisory Group, have encouraged the Centre to think more strategically about and adapt to research priorities in the broader CCS R&D landscape (e.g. BECCS, capture from air, emerging capture technologies for industrial non-power sources, etc): the Evaluation Panel fully supports this.

There is further discussion on this in Section 5.

**Scientific publications**
The scientific output (in terms of publications in peer-reviewed SCI journals and international conferences) is reasonable and consistent with the applied nature of the R&D activities being carried out in NCCS. 48 SCI publications to date have been found in the 2020 Annual Report (after removing 6 non-peer-reviewed SSRN congress proceedings from the list). The current, fairly low level of publication in the peer-reviewed literature (350 were promised in the proposal) may be linked to the close links with industrial stakeholders and associated confidentiality rules. The explanation provided for the current gap between actual and targeted publications in peer-reviewed journals is credible: most PhD students are only just entering the productive stage with the consequent delay between writing and publication. The Centre has reaffirmed its target to publish over 300 peer reviewed papers. The publication numbers and pipeline need to be monitored closely over the next 1-2 years to check the target remains achievable.

We should highlight here a particularly successful publication that is not in the form of a peer-reviewed paper, and which will have a large positive impact on the CCS scientific community: the decision to make the thermodynamic software Thermopack publicly accessible. The Centre has played an important role in this work for several years in close collaboration with other leading experts in Europe.

**Research profile and international visibility**
Engagement with international partners is very intense in most tasks and provides further credibility that the work is of high standard. The presence and influence of the Centre or its key partners in all major EU research entities, organisations and networks (JP of EERA CCS, ZEP, groups linked to the SET Plan, ECCSEL, etc.) are extremely impressive. NCCS partners have been successful in attracting EU and ACT funding.

Premium ('Spin-in') Projects also include international partners. The international participants in the NCCS activities are all of the highest excellence standards. However, it is not clear if all Task Leaders are sufficiently encouraged to set up their own initiatives regarding international collaboration using a bottom-up approach: in other words, promoting wider international exchanges around specific research topics and research groups, with excellence as the only criterion, irrespective of institutional framework agreements that may or may not exist at higher levels.

**Recommendation 1:** That the Centre maintains and builds on the considerable strengths associated with its research quality and research portfolio and continue to enhance cross-task and cross-discipline integration.

## 9.3 Internationalisation

**International research cooperation**
NCCS has a distinct profile centred around supporting major Norwegian projects, and this focus has strengthened as Project Longship has developed. This provides an attraction to international partners given Longship's high profile. The International Objective for the Centre is "To be a CCS research hub benefitting from close cooperation between highly ranked academic institutions in Europe and North America."

NCCS partners have been successful in attracting EU and ACT funding, although the main partners have high profiles in their own right and therefore the added value of NCCS is unclear. Premium Projects also include international partners and have significantly enhanced the Centre's international reach. There may be a risk that the extensive funding through the FME scheme may be a disincentive to seek additional funding from the EU's most competitive calls. It may be valuable to look at application rates of NCCS participants compared with other Norwegian R&D groups active on CCS in areas or sub-areas not included in the NCCS Centre.

The presence/influence of the Centre and its partners in major international initiatives (e.g. EERA, SET Plan, ZEP) and global initiatives (CSLF, Mission Innovation, etc) is very robust. However, this is mostly limited to a small group of the most senior Centre representatives (Nils Røkke, Mona Mølnvik, Marie Bysveen). There is more room to promote bottom-up type international cooperation by engaging Task leaders more in such internationalisation efforts at research group level.

**Collaboration with international research groups**
This is clearly a strong point in the Centre. It became evident during the evaluation that the very creation of the Centre, with the gathering of such a large and strong number of research teams around a single NCCS structure, has reinforced the influence at European and global levels (i.e. in setting research priorities in line with those of the Centre) and the attractiveness for international partners to get engaged with the Centre's scientists in specific research topics at task level. There are many examples of excellent collaboration at a Centre level through partners, engagement with other CCS centres, and more general international activities. Links to Longship provide a valuable catalyst to enhance Norwegian research. The formal academic partners provide the strongest international links with European organisations (i.e. TNO, BGS and many others) and other relevant actors around the world.

**Foreign senior researchers, postdocs and PhD students in the Centre**
The Centre aims to attract outstanding international researchers, including research fellows and senior staff, as visiting researchers. It has successfully recruited PhD students from a range of nationalities (over half are non-Norwegian) and postdocs (all non-Norwegian).

An NCCS Mobility program is in place which has funded 8 mobility grants. This appears to have been successful at a researcher level. The Panel's meeting with the PhD students indicates an excellent and meritocratic choice of PhD candidates.

The Centre has excellent international visibility and connectivity. Nevertheless, the Evaluation Panel suggests that the Centre leverage its significant international reputation to increase the engagement of senior staff members in major international initiatives still further.

## 9.4 Researcher training and engagement in education

**Researcher training**
The Centre has an effective framework in place for researcher training and helps to train highly skilled personnel in the Centre's areas of specialisation. In 2018 NCCS hosted the IEAGHG Summer School for 58 students. There is strong 'cohort training' of the PhD students, e.g. through summer schools, consortium days, etc. and new initiatives designed to encourage increased social interaction amongst the cohort. At interview the PhD students described the added value of the Centre, mainly in giving the PhD candidates a good understanding of the full CCS chain and technical/non-technical aspects of CCS deployment, giving them a better perspective of the value of their work and its context.

**Engagement in education on Masters and PhD levels**
The Centre is actively engaged in education, especially at the Masters degree level, and promotes recruitment to the Centre's subject areas with special focus on increased recruitment of women. Whilst no new Masters courses have been developed by the Centre, SINTEF, NTNU & UiO run a range of Masters courses and other training relating to CCS. Research outputs from NCCS have been fed into and greatly enhanced these courses. However, it is evident considering the ratio of senior researchers to PhD students (about 5 to 1) that there is room to push and increase the number of PhD projects, in particular when considering the academic nature of many of the researchers. Increasing PhD student numbers could be a win-win strategy for NCCS, including for the industrial partners: early access to young talent will be important in an expanding business area that may face shortage of skilled people.

**Recommendation 2:** That the Centre establish a more ambitious PhD program in the expanding topics covered to fit to current priorities. A mechanism (such as a special NCCS grant scheme) to attract bright international candidates for PhDs in NCCS should be considered.

The number of M.Sc. theses is good. It was unclear to what extent those were connected to PhD projects and/or industry. It would help if this information was included in reporting.

## 9.5 Plans for final three-year period

**Assessment of the plans for research activities for the Centres' final three-year period**
There are four of the supplied documents relevant to this section: «3.4 NCCS work plan 2021», «2.E Project description for final three-year period NCCS», «3.5 NCCS Budget tables» and «Annual Report 2020_NCCS_LR_draft». Paradoxically, we find the most clear and transparent vision of the workplan for the next three years in the Annual 2020 report (pp. 39-87: plans and tasks innovations and results). The other documents largely fail to detail *and justify* a workplan for the future. There is a lack of clarity in many Tasks and in some cases no rationale to support the continuation of the current Tasks. To simply carry on doing what you are doing, because of a good track record of results, is not sufficient reason for continuity. A justification of the workplan (e.g. by using a project proposal format) is needed even in a Centre with such as impressive track record of results as NCCS.

A budget has been provided for the final three years, but the Evaluation Panel found it difficult to relate this to the work program. Concern was also expressed that an increasingly large proportion of the budget was taken up by the host institution (85% by 2024). It is understood, though, that there is additional, unallocated, industrial funding.

As mentioned in Section 2, the Scientific Committee and the Special Advisory Group have recommended that that Centre takes a broader look at current CCS R&D priorities and consider opening up new work in new priority areas. The Evaluation Panel strongly supports this view. With the success of its first four years, positive Longship investment decision, an increase in interest in CCS around the globe, and robust funding position, the Centre is in a strong position to consider a broader, more ambitious program for its remaining 4 years. As pointed out in Section 4, this could be delivered, at least partially, through an increase in PhD recruitment.

**Recommendation 3:** That the Centre, supported by its various advisory committees and other bodies as appropriate, undertake a strategic review of research priorities for the remainder of its lifetime informed by emerging R&D priorities and international developments in CCS. Based on this, the Centre should produce a more detailed, costed and fully justified research plan for approval by RCN. This should also include initial consideration of the direction of the Centre post-2024.

## 9.6 Organisation and Management of the Centre

The Centre has an engaged board ably led by its Chair, Tord Lien, who, as a former Minister for Petroleum and Energy, brings an excellent background and connections to the role. The management under the leadership of Mona Mølnvik, is very strong, commendable, and highly motivated.

The Centre has established a good structure to provide advice to the board and management through three committees:

- Scientific Committee, chaired by Philip Ringrose with several leading CCS international research figures
- Technical Advisory Committee consisting of one representative from each industry partner
- Special Advisory Group with leading CCS figures from industry and research organisations.

These committees have all provided very useful advice to the Centre. But the Centre could profitably call on their advice more frequently especially in planning for the second funding period and beyond (see Recommendation 3 above).

The Centre has good national and international visibility in the field of CCS research and in industry. It also understands the importance of communication in the popular press and social media given the controversial nature of CCS in some quarters and is directing appropriate resources to this.

From the interview it would seem that the partners are pleased with the Centre although some partner assessments give a somewhat more mixed picture. The Evaluation Panel suggests that the Centre use the information in the partner assessments to improve its overall performance in the beginning of final period.

## 9.7 Innovation and value creation

The Centre has a good number of important industrial partners mainly users and vendors which are important players in value chains for future, large-scale CCS. The market is currently very immature and timeframes for different technologies and issues are difficult to predict. The positive investment decision for the Longship Project in late 2020 will provide great impetus and will help speed up CCS

commercialisation in Norway and beyond. However, the statement from the Centre of its anticipation that it will have full-scale CCS in 2022 does not seem consistent with plans for the Longship Project which expects operations to start in 2024. The Centre is doubtless an important component of implementing the Longship project.

The Centre has commendably identified all sub-tasks for its two major deployment cases in a TRL scale map which is well aligned to industrial long- and short-term needs. In addition, the Centre has to date analysed 12 out of 25 potential innovations in impact studies. It was somewhat unclear if this also includes identification of mechanisms to get those innovations further up in TRL. The Evaluation Panel was surprised that the question of timescale seemed not to have been addressed explicitly as it is important to include it in TRL analyses and in impact studies. The Panel also suggests carrying out a risk analysis as a timeline can be "interrupted", e.g. unplanned need to go to a lower TRL due to unexpected findings. This means that in some cases the timeframe for identified potential innovations can be rather uncertain. On the other hand, much of the research at the Centre is around improved fundamental understanding of already-high TRL technologies meaning that there can be very short timeframes to impact as industrial partners can take the results immediately to improve the design and operation of their technologies and processes.

The Centre has identified no formal IP of its own so far. There can be good reasons for this depending of the nature of research/potential innovations and the need to balance publication versus protection. However, these tensions can be managed through adopting and implementing a formal IP strategy, in addition to the centre agreement, and using it when carrying out impact studies for all potential innovations. Spin-out projects can also play an important role as a mechanism to get results from the Centre higher up in TRL.

The Centre has a commendably high number of associated projects which it has categorised (in supplementary material forwarded to the Panel) in various ways including which projects are spin-in and which are spin-out projects. These associated projects also pave the way for continuation of Centre activity after the 8 years as noted in Section 10 below.

The Centre does not seem so far to have included life cycle analysis of the value chains for the two deployment cases. The same goes for overall cost estimates for the entire value chain, even if this is challenging due to the immaturity of this market at present. These issues could be important to address going forward.

## 9.8 Funding and financial aspects

The partners' contributions to the Centre are either in cash or in kind depending on the Centre's contract with each partner. We encourage the Centre to increase, if possible, the number of partners contributing both cash and in kind in the final period. During the interview the Centre said that there are soft in-kind contributions from partners as well. The Centre is encouraged to report this, to reflect the partners' total engagement in the Centre more completely. Also, the total budget for associated projects originating from Centre's research activities (spin outs) should be reported to demonstrate the overall total impact of the Centre.

## 9.9 Gender aspects

At present the Centre does not have good gender balance in many of its structures including the board, its three main advisory committees, its senior staff cohort and the cohort of PhD students associated with the Centre. While the Centre states in the self-evaluation "all partners follow standard recruitment guidelines to achieve gender equality", this is clearly not enough in what is,

admittedly, a male-dominated field. The Evaluation Panel is pleased to note what appears to be improvement in recent years – "increased proportion of women in the recruitment of candidates under the academic program - 42% women in 2020, up from 30% in 2018" (from self-evaluation report), but there is still some way to go. At the very least, to signal intent, the Centre can address gender balance issues in the structures where it and its partners make appointments (the board and the various advisory committees).

**Recommendation 4:** That the Centre work to achieve better gender balance as a matter of priority beginning with the structures where it and its partners make appointments (the board and the various advisory committees).

## 9.10 Future activities

The Centre notes, correctly, that there will be a need for further CCS research beyond the FME funding period and has the laudable objective to "continue the operation beyond this. This will be secured by the strong industry involvement, public funding and the research partners contributions" (from document describing project description for final three-year period). As recommended above (Recommendation 3), it should carry out initial planning for this as part of a strategic review of research priorities for the remainder of its lifetime.

## 9.11 Conclusion and recommendations to the Centre

NCCS is a successful and impressive FME. The Evaluation Panel makes four recommendations for improvement.

**Recommendation 1:** That the Centre maintain and build on the considerable strengths associated with its research quality and research portfolio and continue to enhance cross-task and cross-discipline integration.

**Recommendation 2:** That the Centre establish a more ambitious PhD program in the expanding topics covered to fit to current priorities. A mechanism (such as a special NCCS grant scheme) to attract bright international candidates for PhDs in NCCS should be considered.

**Recommendation 3:** That the Centre, supported by its various advisory committees and other bodies as appropriate, undertake a strategic review of research priorities for the remainder of its lifetime informed by emerging R&D priorities and international developments in CCS. Based on this, the Centre should produce a more detailed, costed and fully justified research plan for approval by RCN. This should also include initial consideration of the direction of the Centre post-2024.

**Recommendation 4:** That the Centre work to achieve better gender balance as a matter of priority beginning with the structures where it and its partners make appointments (the board and the various advisory committees).

**Evaluation Panel**
Mary O'Kane (Chief Evaluator)
Carlos Abanades
Andrew Green
Mattias Lundberg

# 10 Appendixes

## Appendix A

- **Panels for the FME midway evaluation in February/March 2021**

## Appendix B

- **Terms of reference**

## Appendix C

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- **D3 Public partner assessment**
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# Appendix A

## Panels for the FME midway evaluation in February/March 2021

**Norwegian Research Centre for Hydropower Technology, HydroCen**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Giovanna Cavazzini, University of Padova, Italy (Scientific expert)
Professor Anders Wörman, KTH, Sweden (Scientific expert)

**Norwegian Centre for Sustainable Bio-based Fuels and Energy, Bio4Fuels**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Anne Meyer, DTU, Denmark (Scientific expert)
Manager Lars Waldheim, Waldheim Consulting, Sweden (Scientific expert)

**Research Centre for Sustainable Solar Cell Technology, SuSolTech**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Marika Edoff, Uppsala University, Sweden (Scientific expert)
Professor Jef Poortmans, Interuniversity Microelectronics Centre (Imec), Belgium (Scientific expert)

**Mobility Zero Emission Energy Systems, MoZEES**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Sonia Yeh, Chalmers University, Sweden (Scientific expert)
Dr. Berit Hinnemann, Maersk, Denmark (Scientific expert)

**Centre for an Energy Efficient and Competitive Industry for the Future, HighEFF**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Ulrich Hesse, Technische Universität Dresden, Germany (Scientific expert)
Manager Isabel Geldenhuys, Mintek, South Africa (Scientific expert)

**The Research Centre on Zero Emissions Neighbourhoods in Smart Cities, ZEN Centre**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Harald Rohracher, Linköping University, Sweden (Scientific expert)
Professor Lorie McElroy, Univ of Strathclyde, UK (Scientific expert)

**Centre for intelligent electricity distribution, CINELDI**
Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Professor Birgitte Bak-Jensen, Aalborg University, Denmark (Scientific expert)
Professor Gøran Andersson, ETH Zürich, Switzerland (Scientific expert)

**Norwegian CCS Research Centre, NCCS**

Professor Mary O'Kane, O'Kane Associates, Australia (generalist - panel leader)
Dr. Mattias Lundberg, Swedish Foundation for Strategic Research, Sweden (generalist)
Dr. Andrew Green, Green Knowledge Limited, UK (Scientific expert)
Professor Carlos Abanades, CSIC-INCAR, Spain (Scientific expert)

# Appendix B

**The Research Council of Norway**

## Midway Evaluation of Centres for environment-friendly energy research (FME)Background and Terms of Reference

### 1. Framework for the evaluation

**1.1 Introduction**

The overall objective of the FME scheme is to help to solve key challenges in the energy sector, generate solutions for the low-emission society and enhance the innovation capacity of the business sector.

The FME scheme is designed to:

- Boost innovation and value creation both for companies and public institutions participating in the centre's activities and for Norwegian society at large;
- Help to reduce national and international greenhouse gas emissions, promote more efficient use of energy and increase production of renewable energy;
- Cultivate research groups that are in the forefront of the international research community and that are an integral part of dynamic national and international networks;
- Increase the visibility of research results and promote a knowledge-based debate on environment-friendly energy.

While the FME scheme will focus primarily on enhancing the innovation capacity of the business sector, it will also promote quality and efficiency in the public sector. The FME scheme provides user partners with the opportunity to employ long-term perspectives, increase continuity and reduce risks in their research initiatives. For research groups, the scheme makes it possible to achieve long-term development of expertise through research of high international calibre conducted in close cooperation with users of the research results.

The FME scheme is administered by the Research Council of Norway and funded by the budgets of the Ministry of Petroleum and Energy. Each of the centres may receive funding for maximum eight years; five years plus a final three-year period provided a positive outcome of a midway evaluation.

**1.2 Background for the evaluation**

The midway evaluation is outlined in the document "FME Requirements and guidelines". Under the auspices of the Research Council, roughly 3,5 - 4 years after the centres are established; there will be an evaluation of each centre. The evaluation will be based on a uniform scheme involving the Research Council's governing bodies.

The Research Council has formulated a number of success criteria for FME (Appendix 1). A key question for the evaluation shall be whether a particular centre is well underway to satisfy these success criteria and the centres own goals and ambitions. Further, the evaluation is to assess the plans for the centre's activities in the potential final three-year period.

**1.3 Purpose of the evaluation**

The purpose of the evaluation is twofold. First, the evaluation will form the basis for a decision made by the Research Council whether to continue the individual centre for the remainder of the

overall eight-year term, or to wind it up after five years. Second, the evaluation shall give advice on how to improve and further develop each of the centres.

**1.4 The evaluation panel**

Each centre will be evaluated by a panel of international experts:

- Two of the experts in the panel will have the competence and the task to evaluate the centre mostly from a scientific point of view.
- Two persons in the panel will have experience from similar programmes for academia/industry research collaboration. These “generalists” will mostly look at the centre from the view of organisation, innovation and value creation.

The scientific experts will participate in the evaluation of one specific centre, while the “generalists” will take part in the evaluation of all eight centres. Each centre may suggest up to five suitable scientific experts. The Research Council will decide whom to invite.

**1.5 Organisation of the evaluation**

The evaluation panel will write and complete an evaluation report consisting of one section for each of the centres and one section regarding overall issues. The panel itself decides on the distribution of work among its members. One of the "generalists" will lead the evaluation.

The background material for the evaluation will be distributed by the Research Council to the members of the evaluation panel not later than one month prior to the evaluation. The site visits will be carried out during week 8 and 9 in 2021.

The evaluation report is due within six weeks after the interview sessions.

The evaluation panel will perform one day site visit to each centre. During the site visit the evaluation panel should meet:

- The centre leader/centre director
- The chair of the centre board
- Representatives from the industrial and public partners
- Representatives from collaborating research institutions
- Host institution staff incl. representatives from the top management
- Research leaders active within the centre
- PhD students.

The Research Council staff will be present at the site visits. The staff will act as facilitators and should not take active part in the evaluation but can add information during work sessions.

The meeting of the evaluation panel with the parties from the centre will be divided into two main sessions, one session devoted to the research activities and one session devoted to organisation and innovation aspects. There will also be a separate session with the PhD students.

**1.6 Basis for the evaluation assignment**

The evaluation will review the progress of the centres, recognising that it is early in the centre period. The evaluators will form an opinion concerning the approach and measures taken so far by the individual centres to judge the potential for their long-term development towards a successful FME. Evaluators may offer suggestions for remedial action to enhance the prospects for centre success. The success criteria for FME (Appendix 1) are the main basis for the evaluation report.

**1.7 Background material for the evaluation**

The following written material will form the background for the evaluation:

- *Project description*
- *Budget tables from The Research Council project data base*
- *Annual reports 2017, 2018, 2019 and 2020 (draft) from the centres*
- *Work plan for 2021(summary) including tables for funding and cost*
- *Reports from the centre and its partners according to standardised templates*:
    A. A self-evaluation of the centre including sections on research accomplishments, important industrial or societal results, progress towards realizing the centre's potential for innovation, internationalisation, recruitment, financial aspects and organisation.
    B. Fact sheets including CVs for the management team, data for the staff working in the centre, lists of publications, PhD students, financial data and selected indicators.
    C. An assessment of the centre from the host institution.
    D. An assessment of the centre from each of the partners.
    E. Present description/plan for final three-year period, including a plan for the post-funding phase.
- *Report(s) from Scientific Advisory Committee, Innovation Committee and other relevant bodies* (for centres with committees) *if available.*
- *Documents describing the scheme (Research Council of Norway):*
    - The Centres for Environment-friendly Energy Research scheme (FME) – Description of the scheme, Dec 2014
    - Information for applicants for the funding announcement for the establishment of Centres for Environment-friendly Energy Research (FME), June 2015.
    - Centres for Environment-friendly Energy Research (FME). Requirements and guidelines, 2016

## 2. Terms of Reference

The evaluation panel will make the evaluation in the context of the success criteria for FME (Appendix 1).

The scientific experts in the evaluation panel will have the primary responsibility for reviewing the scientific activities and achievements of the centre focusing on the following parts of the success criteria:

- Research activity
- Internationalisation
- Research training and recruitment

The "generalists" in the evaluation panel will have the primary responsibility for reviewing organisation, innovation and value creation focusing on the following parts of the success criteria:

- Innovation and value creation
- Partners and funding
- Organisation.

The innovation activities and the cooperation between researchers and user partners in the centres have been paid particularly attention the last years, and must be thoroughly evaluated by the panel. It's important to elucidate the role of the centres in mobilizing both small and large enterprises to research and innovation activities.

In addition, the evaluation panel is asked to comment on:

- The extent to which relevant social science-related questions are addressed and are integrated in the centre's activities.
- The extent to which the FMEs contribute to a more well-structured energy research in Norway.

The evaluation panel will also comment on the present plans for activities for the centre's final three-year period and plans for the post-funding phase.

Although the individual centres will be the focus, the evaluators should also comment on the organisation of the FME scheme and the role of the Research Council of Norway.

*The evaluation reports will form the basis of a decision made by the Portfolio Board for Energy, Transport and Low emissions concerning continuation or discontinuation of each centre. To avoid giving a premature indication of the Research Council's decisions, the Evaluation panel should not comment specifically on whether a centre shall be continued or not in the evaluation report.*

Each evaluation report should be written in consensus by the evaluation panel and delivered to the Research Council of Norway. The centres will be given an opportunity to comment the factual content of the report before it is finalised by the evaluation panel.

The final report will be openly circulated to all the centres, the host institutions, relevant ministries and to any other agency or person who have expressed interest for this kind of information.

Appendix 1

# Success criteria for the Centres for Environment-friendly Energy Research (FME)

*In addition to fulfilling the formal requirements, a successful Centre for Environment-friendly Energy Research will be characterised by the following:*

**Research activity**

- The centre conducts long-term, thematically relevant research of high international standard in the field specified in the project description, and demonstrates this through its production of doctorates, scientific publications, papers for presentation at recognised international conferences and other measures of scientific excellence.
- The centre has a distinct research profile and has been successful in achieving recognition at the international level (e.g. researchers associated with the centre have received awards or been invited to be keynote speakers at international conferences).
- There is genuine cooperation between the research partners at the centre and the centre has helped to improve the national structure of research carried out within its thematic area.
- The centre's user partners have increased their research commitments both through participation in the centre's activities and their own R&D activities on topics of relevance to the centre.

**Innovation and value creation**

- The centre's research activity has generated or is expected to generate the potential for innovation and enhanced competitiveness among user partners from the business sector and strengthen the knowledge base for user partners from public sector organisations (better administration and management).
- The centre's research activity has ramifications for society beyond that of the partners directly participating in the centre's activities.
- The centre has achieved reciprocal mobility of staff between the centre and user partners. Researchers from partners work at the centre, and research fellows and researchers from the host institution are seconded to the user partners for periods of time.
- The centre uses work processes that ensure that the research activity is relevant for the user partners and that the expertise and results achieved by the research activity are effectively transferred to and utilised by the partners.
- The centre has a framework for enabling results that fall outside the user partners' core areas to be commercialised by other means, e.g. through establishing new research-based enterprises.

**Internationalisation**

- The centre has a distinct profile and clearly articulated objectives for international cooperation.
- The centre is successful in international research cooperation, e.g. as an actor under the EU's framework programme.
- The centre engages in active collaboration with international research groups and has contributed in other ways to the internationalisation of Norwegian research and business and industry.
- The centre attracts outstanding international researchers, including research fellows and senior staff, as visiting researchers. Researchers and research fellows at the centre have conducted stays at research institutions abroad.

**Researcher training and recruitment**

- The centre has an effective framework in place for researcher training and helps to train highly skilled personnel in the centre's areas of specialisation.

- The centre is actively engaged in education, especially at the master's degree level, and promotes recruitment to the centre's subject areas with special focus on increased recruitment of women.

**Partners and funding**
- The centre receives long-term funding from the host institution and partners, and these have increased their funding beyond the minimum requirements.
- Active efforts are made to attract new user partners, and the user partners include large companies as well as small and medium-sized companies with a high technology and innovation profile.
- The centre has been successful in securing other external funding.

**Organisation**
- The centre has a visible profile, a strong identity and has established successful collaboration between its partners.
- The centre is organised in a manner that is well adapted to the host institution's organisation.
- The centre has a board and management which ensure that the intentions and plans on which the centre is based are followed up.
- The centre has a common administration with a high degree of scientific and administrative autonomy.
- The centre has achieved a satisfactory gender balance among the management staff and research fellows.

# Appendix C

**Templates for**

- **A Self evaluation**
- **B Fact sheets**
- **C Host assessment**
- **D1 Corporate partner assessment**
- **D2 Research partner assessment**
- **D3 Public partner assessment**
- **E Project description for final period**

The Research Council of Norway

# Midway Evaluation of the Centres for environment-friendly energy research (FME)

## A - The Centre Self-evaluation

……
(Name of centre)

……..
(Project number)

**Deadline 11. December 2020**

*To be prepared by the centre and signed by the Centre director and Chairman of the Board.*
***Maximum length 12 A4 pages (exclusive front page).***
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

## Background

This self-evaluation should devote special attention to the items listed in "Success criteria for Centres for environmentally friendly energy research". The main sections below are the same as in this document. The points listed under each section are indicative and we recommend you to take a close look at the success criteria. We also encourage you to add other aspects that you consider important in an evaluation context.
In addition to the self-evaluation for the centre each of the partners should submit their own reports (template C and D).

## Brief summary (approx. ½ page)

*Progress of the centre, highlights, breakthroughs etc.*

Write here….

## 1. Objectives

*Primary and secondary objectives of the centre as stated in the contract..*

Write here….

## 2. Research (approx. 2 pages)

- *Research achievements*
- *Core competence of the research team*
- *Research facilities of the centre*
- *Comment on new types of collaboration since establishing the centre (within core group and between host institution and research/user partners)*
- *How has the centre stimulated establishing leading national research groups across institutional boarders, i.e. collaboration between universities and research institutes?*
-
- *Comment on cooperation with other FME's if applicable*
- *Comment on contribution to improvement of the national structure of research carried out within the thematic area of the centre.*
- *More…*

Write here….

## 3. Innovation and relation to Centre user partners and society (approx. 3 pages)

- *Steps taken to improve the innovation process in the centre*
- *The involvement and participation of user partners in the centre activities*
- *The mutual mobility of personnel between the centre and the user partners.*
- *Utilisation of research results both by user partners and by others if user partners not are interested in implementing the results.*
- *The generation of additional concurrent R&D projects between research institutions and companies*
- *Impacts beyond the centre partners – for society at large.*
- *More…*

Write here….

4. Internationalisation (approx. 1 page)

- *Objectives for international cooperation*
- *Collaboration with and contribution from the international partners in the centre*
- *Organisation of and work with international R&D cooperation in general and specifically with EU's framework programme*
- *The role of the centre staff in international strategic fora*
- *International exchange of researchers; both centre staff going abroad and visiting foreign researchers.*
- *More…*

Write here….

5. Recruitment (approx. 1 page)

- *Organisation of researcher training at PhD level.*
- *Engagement in education, especially at the master's level.*
- *Involvement of user partners in education and PhD training*
- *Status for and efforts made to improve the gender balance.*
- *More…..*

Write here….

6. Partners and funding (approx. 1 page)

- *Discuss concerns regarding financial matters. Note that numbers are to be submitted by RCN (budget tables).*
- *The situation regarding number of partners and efforts made to attract new partners?*
- *Has the centre been able to obtain other external funding?*
- *More…*

Write here….

7. Management and organisation (approx. 2 pages)

- *Describe role and activities of the:*
    - *Board*
    - *Centre director*
    - *Management team*
    - *International Scientific Advisory Committee (if relevant)*
    - *Other (if relevant)*
- *Comment on the scientific leadership of the centre.*
- *Centre activities for idea generation, project selection, project planning and project review.*
- *The status and role of the centre in relation to different organisational levels of the host institution.*
- *Status for and efforts made to improve the gender balance.*

Write here….

## 8. Communication (approx. 1 page)

- *Link to centre home page*
- *Communication activities both within the centre and to the public at large*

Write here….

## 9. SWOT analysis

Based on the previous self-evaluation of the centre a SWOT analysis should be performed. This is considered to be a useful way to present the highlights of the status of the centre and may constitute a basis for the plans for the final three years of operation for the centre.

This SWOT analysis should include the following steps:

***Describing internal factors:***
The strengths and weaknesses of the organisation. These are related to organisation's resources (people, knowledge, financial means, and activities). The sources for this are the analyses mentioned above.

***Describing external factors:***
The opportunities and threats in the environment that have an effect on the organisation. These include changes in the policy domain, technological developments and economic factors. The analysis of the environment provides input for this.

***Confronting internal factors (strengths, weaknesses) with external factors (opportunities, threats):***
It is important to weigh the strengths, weaknesses, opportunities and threats by using a point system or a qualitative specification.

***Developing ideas on strategic options:***
Strategy development often occurs on the basis of a matrix in which the factors are presented in four cells based on strengths, weaknesses, opportunities and threats.

Example of SWOT table:

| | |
|---|---|
| **Strengths**<br>• Advanced knowledge development;<br>• The research is demand driven;<br>• The partners are closely involved;<br>• The activities have a clear effect;<br>• A wide and active network, both nationally and internationally. | **Opportunities**<br>• Extra attention and resources from public agencies for innovation in the sector;<br>• New technological breakthroughs in strategically important fields;<br>• Opportunities of interaction with innovation programmes<br>• Position to attract funding from EU framework programme |
| **Weaknesses**<br>• Transfer of knowledge not adequately addressed<br>• Resources are not prioritised well | **Threats**<br>• The partner companies is under pressure by the economic crisis;<br>• The end of centre funding will come before company partners are ready to implement results |

| | |
|---|---|
| • Number of partner companies too low | |

Signatures

Place and date

…….. …….

Centre director
(Signature and name in print)

Chairman of the board
(Signature and name in print)

…….. …….

The Research Council of Norway

Midway Evaluation of the Centres for environment-friendly energy research (FME)

# B - Fact sheet for the centre

……
(Name of centre)

……..
(Project number)

**Deadline 11. December 2020**

*To be prepared by the centre and signed by the centre director.*
***Maximum length 6 A4 pages (exclusive front page).***
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

Contents

1. ***General information***

**The centre**

Name of centre
Name of centre director (Short CV, Enclosure 1)
(Indicate if there has been a change of centre director)
Management team (Short CVs, Enclosure 1)
Address
Host institution
Partners
(Indicate if the partner has joined the centre after the start or has left the centre)

- Research partner(s)
- Company partners
- Public partner(s)
- International partners

**Governance**

Board members
Scientific Advisory Committee (if relevant)
Innovation Committee or similar (if relevant)
Other (if relevant)

**Additional comments to General information**

2. ***Staff***
    a. List senior staff members that spend more than 10 % of their time working in the centre in 2020 (name, affiliation, university degree, gender, position within own organisation, % of full time in centre).
    b. List administrative and technical staff (name, position)

**Own hard and soft indicators**
The centre is requested to come up with their own hard and soft indicators (quantitative and qualitative) in addition to the sub-items in 3-6. These should be the indicators that they find relevant to give a good documentation of the results of the centre.

3. ***Research***
    a. The (up to) 20 most important publications (for the centre so far) that are a direct result of the work in the centre
    b. (Up to) 5 publications (for the centre so far) co-authored with user partners (industry and/or public partners)
    c. (Up to) 5 publications (for the centre so far) co-authored with international partners
    d. Complete lists of publications (peer reviewed) given in Enclosure 2.
    e. Any other research indicators.

4. ***Innovation***
    a. List patent applications and patents (for the centre so far).

b. Any other innovation indicators.

5. ***Communication and outreach***
    a. List of conferences and seminars on your own account
    b. List of workshops
    c. Other relevant activities.

***6. International cooperation[1]***
    a. List organisations in other countries that are taking active part in centre projects in 2020 (name of organisation, country, time period of project).
    b. List researchers in other countries that are taking active part in centre projects in 2020 (name, position, organisation, country, time period of project).
    c. List visiting senior researchers from other countries with a stay of more than two weeks in 2019 and 2020 (name, position, organisation, country, duration of stay).
    d. List researchers from the centre with a visit of more than one month to other countries in 2019 and 2020 (name, position, organisation, country, duration of stay).
    e. Any own indicators for international cooperation.

***7. Recruitment***
    a. List PhD students working in the centre in 2020, both those financed by the centre budget and those that work in the centre and receive funding from other sources (name, affiliation, source of funding, gender, nationality, period worked in the centre).
    b. List Post docs working in the centre in 2020, both those financed by the centre budget and those that work in the centre and receive funding from other sources (name, affiliation, source of funding, gender, nationality, period worked in the centre).
    c. List PhD thesis completed on projects in the centre so far (name, sex, title of thesis, adviser, institution granting degree).
    d. List M.Sc. thesis in centre in 2020 (name, title of thesis, sex, adviser, institution granting degree). A master student in the centre is writing his/her thesis on a topic within the research agenda of the centre and is supervised by one of the senior researchers in the centre.
    e. Any own indicators for recruitment.

***8. Affiliated projects***

List of projects affiliated to the centre:

- RCN-projects
- Horizon 2020-projects
- Other sources.

[1] In c and d 2019 is added, since 2020 not will be a representative year for international exchange activities due to the Covid-19 pandemic.

Signatures

Place and date

……..

Centre director
(Signature and name in print)

……..

Enclosures

1. Selected CVs for the core team of the centre (max. 10 pages for the whole team)
2. Publications (only if not listed in the Annual reports)

The Research Council of Norway

Midway Evaluation of the Centres for Environment- friendly Energy Research (FME)

C – Host institution assessment

**Please return the completed assessment directly to Siri Ovstein, The Research Council of Norway (sov@rcn.no ) as an attachment to an E-mail**
**Deadline 11. December 2020**

……
(Name of host institution)

……
(Name of centre)

……..
(Project number)

*To be prepared by the host institution and signed by the Project administrator.*
***Maximum length 4 A4 pages (exclusive front page).***
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

Contents

1. *What is the total research activity of the host institution in the form of personnel and volume within the broad thematic area of the centre?*

Write here….

2. *Describe how the thematic area of the centre relates to the research strategy of the host institution.*

Write here….

3. *How do you evaluate the importance of the centre to realise the research strategy of your institution?*

Write here….

4. *How has the centre stimulated collaboration between researchers from your institution and other research partners and user partners in the centre?*

Write here….

5. *How has the centre's activities benefited your international reputation as a research institution?*

Write here….

6. *How has the centre strengthened international cooperation of your institution?*

Write here….

7. *What potential for innovation and value creation do you see in the results from the centre which is not expected to be commercialised by the company partners?*

Write here….

*8. Has the centre contributed to investment in research infrastructure in your institution?*

Write here….

9. *Has the centre contributed to improvement in doctoral education and/or study programmes at Master level (only relevant for universities)?*

Write here….

10. *How is the centre organised within your own organisation?*

Write here….

11. *How are the administrative and economic matters handled*?

Write here….

12. *Are there any other topics you want to report?*

Write here….

Host institution

…….

Place and date

……..

Signature and name in print of project administrator

……..

The Research Council of Norway

Midway Evaluation of the Centres for environment-friendly energy research (FME)

D1 – Corporate partner assessment

……
(Name of partner)

**Please return the completed assessment directly to Siri Ovstein, the Research Council of Norway (sov@rcn.no ) as an attachment to an E-mail**
**Deadline 11 December 2020**

……
(Name of centre)

……..
(Project number)

*To be prepared by the partner and signed by the contact person of the partner.*
*Maximum length **3** A4 pages (exclusive front page).*
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

Outline

1. *Describe the focus of your company's own R&D in the thematic area of the centre, within and outside the centre (strategic platform).*

Write here….

2. *What is the total volume of R&D of your company within the thematic area of the centre (man-years, number of employees or annual budget), please also indicate the size of the R&D-activity relative to the total activity of the thematic area within your company?*

Write here….

3. *What was the motivation for joining the centre and what expectations did you have to becoming a partner?*

Write here….

4. *How has your company interacted with the centre?*

| | Yes | No |
|---|---|---|
| Member of executive board | | |
| Participation in workshops for project plans and idea generation | | |
| Participation in expert groups or similar groups and committees | | |
| Participation in research projects, pilot projects or other research tasks in the centre | | |
| Involvement in evaluation of research and prioritization of research topics | | |
| Mechanisms for technology transfer | | |
| Mobility of personnel | | |
| Other (specify) …… | | |

If further comments, write here……

5. *How has the participation in the centre influenced the R&D activity of your company?*

Write here…….

6. *What opportunities have been created that would not have existed without the centre?*

Write here….

7. *Can you give any estimate of potential for increased income or reduced cost in net present value as a result of being a partner in the centre? If estimates and numbers cannot be given, please describe in words what your company gains from being a partner in the centre.*

Write here….

8. *Has the centre contributed to any other specific outcome within your company? Please specify.*

Write here….

9. *Has the centre contributed to specific innovations[2] within your company?*

| | Yes | No |
|---|---|---|
| Patents | | |
| New or improved products | | |
| New or improved processes | | |
| New or improved services | | |
| New or improved methods/models/indicators | | |
| Other (specify) …… | | |
| Other (specify) …… | | |

If further comments, write here……

10. *What is your impression of the centre's efforts to ensure that the results of the centre-activities are implemented by user partners and in society at large.*

Write here….

[2] *Innovation can be a product, a technology, a component, a process, a model or a service that is new or significant improved with respect to properties, technical specifications or ease of use. Innovation can also be new application of existing knowledge or commercialization of R&D results. The innovation should be adopted by somebody, or be ready for utilization provided that it is made probable that the innovation will be utilized within a limited timeframe.*

11. *On a scale from 1 (Low) to 6 (High), please give your score for each of the following questions:*

| | Score |
|---|---|
| A. Has the participation in the centre influenced the R&D and Innovation strategy of your company? | |
| B. How do you evaluate the centre wrt: | --------- |
| Level of competency of centre staff | |
| Project management of centre | |
| Communication between centre and partners | |
| The usefulness of research activities as seen from the company | |
| C. How has the centre's activities benefited the partner wrt: | --------- |
| Ideas for new products, processes and/or services? | |
| New or improved methods/models developed by the centre | |
| Improvement of products, processes and/or services | |
| Strengthened knowledge base of the company | |
| Improved access to competent personnel and knowledge institutions | |
| Recruitment of qualified personnel | |
| Improved network to other partners | |
| Increased competitiveness within the area of research of the centre | |

If further comments, write here……

---

Company partner

……..

Place and date

……..

Signature and name in print of reporting person from partner

……..

The Research Council of Norway

Midway Evaluation of the Centres for environment-friendly energy research (FME)

D2 – Research partner assessment

……
(Name of partner)

**Please return the completed assessment directly to Siri Ovstein, the Research Council of Norway (sov@rcn.no ) as an attachment to an E-mail**
**Deadline 11 December 2020**

……
(Name of centre)

……..
(Project number)

*To be prepared by the research partner.*
*Maximum length **3** A4 pages (exclusive front page).*
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

1. Contents

1. *What is the total research activity of your institution in the form of personnel and volume within the (broad) thematic area of the centre?*

Write here….

2. *Describe how the thematic area of the centre relates to the research strategy of the your institution*

Write here….

3. *How do you evaluate the importance of the centre to realise the research strategy of your institution?*

Write here….

4. *How has the centre stimulated collaboration between researchers from your institution and from the host institution, other research partners and user partners?*

Write here….

5. *How has the centre's activities benefited your international reputation as a research institution?*

Write here….

6. *How has the centre strengthened international cooperation of your institution?*

Write here….

7. *What potential for innovation and value creation do you see in the results from the centre which is not expected to be commercialised by the company partners?*

Write here….

8. *Has the centre contributed to investment in research infrastructure in your institution?*

Write here….

9. *Has the centre contributed to improvement in doctoral education and/or study programmes at Master level in your institution (only relevant for universities)?*

Write here….

*10. Are there any other topics you want to report?*

Write here….

---

Name of Research partner

…….

Place and date

……..

Signature and name in print of contact person

……..

The Research Council of Norway

Midway Evaluation of the Centres for environment-friendly energy research (FME)

D3 – Public partner assessment

**Please return the completed assessment directly to Siri Ovstein, the Research Council of Norway ( sov@rcn.no ) as an attachment to an E-mail**
**Deadline 11 December 2020**

……
(Name of partner)

……
(Name of centre)

……..
(Project number)

*To be prepared by the partner and signed by the contact person.*
*Maximum length **3** A4 pages (exclusive front page).*
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

Outline

1. *Describe the focus of your organisation's own R&D in the thematic area of the centre, within and outside the centre (strategic platform).*

Write here….

2. *What is the total volume of R&D of your organisation within the thematic area of the centre (man-years, number of employees or annual budget), please also indicate the size of the R&D-activity relative to the total activity of the thematic area within your company.*

Write here….

3. *What was the motivation for joining the centre and what expectations did you have being a partner?*

Write here ……

4. *How has your organisation as a partner interacted with the centre?*

| | Yes | No |
|---|---|---|
| Member of executive board | | |
| Participation in workshops for project plans and idea generation | | |
| Participation in expert groups or similar groups and committees | | |
| Participation in research projects, pilot projects or other research tasks in the centre | | |
| Involvement in evaluation of research and prioritization of research topics | | |
| Mechanisms for technology transfer | | |
| Mobility of personnel | | |
| Other (specify) ….. | | |

If further comments, write here…..

5. *How has the participation in the centre influenced the R&D activity of your organisation?*

Write here….

6. *What opportunities have been created that would not have existed without the centre?*

Write here….

7. *Can you give any estimate of potential for increased income or reduced cost in net present value as a result of being a partner in the centre? If estimates and numbers cannot be given, please describe in words what your company gains from being a partner in the centre.*

Write here….

8. *Has the centre contributed to any other specific outcome within your company? Please specify.*

Write here….

9. *Has the centre contributed to specific improvements/innovations within your organisation?*

| | Yes | No |
|---|---|---|
| New or improved products | | |
| New or improved processes | | |
| New or improved methods/models/indicators | | |
| | | |
| New or improved services | | |
| Other (specify) … | | |
| Other (specify) … | | |

If further comments, write here…..

10. *What is your impression of the centre's efforts to ensure that the results of the centre-activities are implemented by user partners and in society at large.*

Write here….

11. *On a scale from 1 (Low) to 6 (High), please give your score for each of the following questions:*

| | Score |
|---|---|
| A. Has the participation in the centre influenced the R&D and Innovation strategy of your organisation? | |
| B. How do you evaluate the centre wrt: | --- |
| Level of competency of centre staff | |
| Project management of centre | |
| Communication between centre and partners | |
| The usefulness of research activities as seen from the organisation | |
| C. How has the centre's activities benefited the partner wrt: | --- |
| Ideas for new products, processes and/or services? | |
| New or improved methods/models developed by the centre | |
| Improvement of products, processes and/or services | |
| Strengthened knowledge base of the organisation | |
| Improved access to competent personnel and knowledge institutions | |
| Recruitment of qualified personnel | |
| Improved network to other partners | |

If further comments, write here…..

---

Name of public partner

…….

Place and date

……..

Signature and name in print of reporting person from partner

…….

The Research Council of Norway

Midway Evaluation of the Centres for environment-friendly energy research (FME)

E – Project description for the final three-year period and further plans

……
(Name of centre)

……..
(Project number)

**Deadline 11 December 2020**

*To be prepared by the centre and signed by the Centre director and Chairman of the Board.*
*Maximum length **8** A4 pages (exclusive front page).*
*Word format, Times New Roman, 12 pitch font, single line spacing.*
*Guiding texts in the template can be deleted. All headings must be retained.*

## Background

Each centre has a current project description for the whole period of the centre and a work plan for each year. During the four to five years since the original project description was written, several things may have changed. Even if some centres have made revisions through the first years, it is expected that the centre now should perform a more in depth review of the different sections of the project description. ***This report should focus topics that, as a result of this review, is going to be changed in the project plans for the final years. Those items where the centre will continue to follow present plans need not be commented upon.***

The centres may not have budget plans for the complete eight year period. In any case the budget for the last years of the centre period should be presented.

### Objectives for the centre and background for changes in the project description

Write here….

1. Status

*National and international state-of-the-art of the relevant technologies and research topics for the centre.*

Write here….

2. Research methodology

*Describe the methodology and theories planned used, and explain why they are suitable for generating relevant knowledge in the field and promoting future value creation. Describe plans for publication in scientific peer-reviewed journals as well as plans for conferences and any patents.*

Write here….

3. Research tasks

*Identify and describe the research questions that will be examined. Define key research tasks and research-related targets and explain their significance for future innovation and value creation.*

Write here….

4. Researcher training and recruitment

*Describe plans for researcher recruitment. Specify the number of doctoral degrees planned within which research areas. Provide a target figure for the gender balance.*

Write here….

5. Significance for the business sector, public partners and society at large

*Describe how the research conducted and results generated by the centre will help to achieve the objectives of the FME scheme. Describe how the knowledge developed by the centre will be important to future innovation and value creation for the user partners. Describe the centre's relevance and benefit to society.*

Write here….

6. Organisation

*Describe how the cooperation at the centre will be organised and why this structure has been chosen. Describe how knowledge acquired through research activities at the centre will be transferred to the individual partners to stimulate innovation and value creation.*

Write here….

7. International cooperation

*Describe objectives and plans for international cooperation at the centre.*

Write here….

8. Gender balance

*Describe how gender-related considerations will be incorporated into the centre's activities and describe specifically what will be done to improve the gender balance (if still needed).*

Write here….

9. Progress plan with milestones

*The plan should provide a timeline for and describe the main activities and milestones, including project deliveries associated with the given milestones.*

Write here….

10. Budget

*General comments on budget situation. Action plans for the final three year period.*

Write here….

11. Costs distributed among the individual partners

*An overview of how the project costs will be distributed among each of the R&D-performing partners is to be presented in table form.*

| **Cost** | 2021 | 2022 | 2023 | 2024 | |
|---|---|---|---|---|---|
| Host institution | | | | | |
| Consortium partner A | | | | | |
| Consortium partner B | | | | | |
| Consortium partner C | | | | | |
| | | | | | |
| Consortium partner N | | | | | |
| Total | | | | | |

12. Financial contributions from the individual partners

*An overview of the partners that will contribute financing to the centre and their individual contributions are to be presented in table form.*

| **Funding** | 2021 | 2022 | 2023 | 2024 | |
|---|---|---|---|---|---|
| RCN FME-grant | | | | | |
| Host institution | | | | | |
| Consortium partner A | | | | | |
| Consortium partner B | | | | | |
| Consortium partner C | | | | | |
| | | | | | |
| Consortium partner N | | | | | |
| Other public funding | | | | | |
| Total | | | | | |

13. Plans for further activities after the eight year period of financing from RCN

*Describe plans for further activities after the funding from the Research Council ceases. Describe how results and values created by the centre will be preserved or continued, including any infrastructure established under the auspices of the centre.*

Write here….

Signatures

Place and date

| | |
|---|---|
| …….. | ……. |
| Centre director<br>(Signature and name in print) | Chairman of the board<br>(Signature and name in print) |
| …….. | …… |

**The Research Council of Norway**
Drammensveien 288
P.O. Box 564
NO–1327 Lysaker

Telephone: +47 22 03 70 00
post@rcn.no
www.rcn.no

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