MOZEES
Mobility Zero Emission Energy Systems

FME Forsknings-senter for miljøvennlig energi
Norges forskningsråd

Annual Report 2018

Message from the Chair of the Board

I'm delighted to see that the MoZEES organisation is strengthened in the second year of operation. The Director Øystein Ulleberg and his team of RA leaders and IFE staff have succeeded in developing procedures for good planning, implementing and reporting of the centre research and other activities. The MoZEES Research and Training Network has become an important arena for PhD students and young researchers. MoZEES outreach and international cooperation have also developed significantly last year. The Scientific Advisory Committee of distinguished experts from excellent research groups abroad is successfully established. And, importantly, the centre is on the way to develop a larger network aimed for international cooperation and mobility of MoZEES researchers. Representatives of the centre are frequently invited to present at important events, and scientific papers and reports emerge from the more than 100 MoZEES researchers and students involved.

Our society's needs for zero emission mobility solutions is steadily increasing. The ambitions of MoZEES to deliver on research should consequently be very high. It is therefore an inspiration as well as a responsibility that research results from MoZEES support decision making in industry and authorities on topics from selecting appropriate zero emission technology to national transportation policies. With this perspective I'm excited about being part of the centre, and to continue working with all partners to build for excellent research and impactful contributions in the transition to a greener future.

I would like to thank all MoZEES participants and our collaborators for their excellent contributions to the centre during the second year.

Rune Bredesen
Chairman of the Board

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Letter from the Center Director

FME MoZEES has now been in operation for two years and we are starting to get results, as shown in this Annual Report. There is a strong interest among our partners to participate in the Center. In 2018 there were 85 key researchers, 3 post.doctoral fellows, and 7 PhD students from NTNU, UiO, USN, FFI, TØI, SINTEF, and IFE that contributed with research work in MoZEES. In addition, we have a strong participation from our 25 industry and 7 public partners and the Board. All in all, there are more than 100 persons active with MoZEES-related research and development. That is a lot of brain power!

An important part of the FME scheme is to create a platform for exchange of knowledge between students, researchers, professors, technology developers, project managers, business developers, and decision makers. When I am asked to describe the main objective with MoZEES, I often use the slogan "Research for Development and Innovation". To achieve this, we need to host inspiring and interesting meetings and create common projects where close collaboration between stakeholders in academia, research, business, and public sector can occur. This is exactly the approach taken in MoZEES. Here I would like to highlight the success of the MoZEES Battery Days in February and the MoZEES Annual Meeting in April, both now established as annual events. It has also been very encouraging to see the collective effort made on the MoZEES Maritime Case Study. In 2019 we will strengthen the work on the MoZEES Heavy Duty Truck Case Study, which I hope will engage many of you.

The MoZEES meetings are highly relevant for anyone interested in zero emission transport. Now that we are firmly established and start to produce our own independent results, we will begin to open meetings for external partners and stakeholders. In addition, all partners are encouraged to present their MoZEES-results at national and international meetings, seminars, and conferences. Society needs independent advice, quality assured, peer-reviewed information, and realistic projections on what is possible to achieve with battery and hydrogen technology, now and in the future. People are asking the difficult question: How, When, and Where can we achieve Zero Emission transport? The MoZEES research community can provide valuable inputs to this discussion.

Policy makers are also seeking our advice. I was happy to see that the MoZEES consortium was able to provide some recommendations to the Ministry of Transport when they asked for input to the national plan on alternative fuel infrastructure in April. However, the query also demonstrated the need for a lot more research in this area. We still need to identify the best near-term business cases and provide more specific policy advice. I am therefore looking forward to the results from our ongoing socio- and techno-economic studies, and hope many of you will be able to contribute to this research.

I would also like to remind all of you that MoZEES is open for international research collaboration. In 2018 we signed agreements (MoUs) with three well-renowned universities: RWTH Aachen University, Uppsala University, and UC Davis. This opens wonderful opportunities for exchange of students and researchers, who now can apply for travel funds from our MoZEES Mobility Program. I am also happy to see that we have been able to establish a proper MoZEES Research Training Network.

Finally, I would like to thank all Partners for their contributions in 2018. A special thanks goes to the MoZEES Coordinator, the RA Leaders, and the Board. From 2019 there will be a new RA1 leader. On behalf of the MoZEES family I would like to thank Fride for the very successful start-up of battery research activities in RA1. At the same time, I would like to warmly welcome Prof. Ann Mari Svensson from NTNU as the new RA1 leader. Besides this there have been relatively few changes in personnel, and we are in very good shape for the next few years!

Keep up the good work, and remember:
You are making a difference!

Øystein Ulleberg
Center Director

About MoZEES

MoZEES is a Center for environment-friendly energy research with focus on battery and hydrogen technologies for zero-emission transport on road, rail, and sea.

Background & Motivation

Norway has access to vast amounts of renewable power, some of which can be used to produce electricity and hydrogen for transport. Ambitious national and regional climate policies on low and zero emission transport are currently being implemented, including economic support for the introduction of battery and hydrogen fuel cell electric vehicles. There is also a strong national policy to stimulate existing and new businesses to create new "green jobs". Hence, there is now a need to couple national and regional climate policies with long-term industry-driven business development strategies.

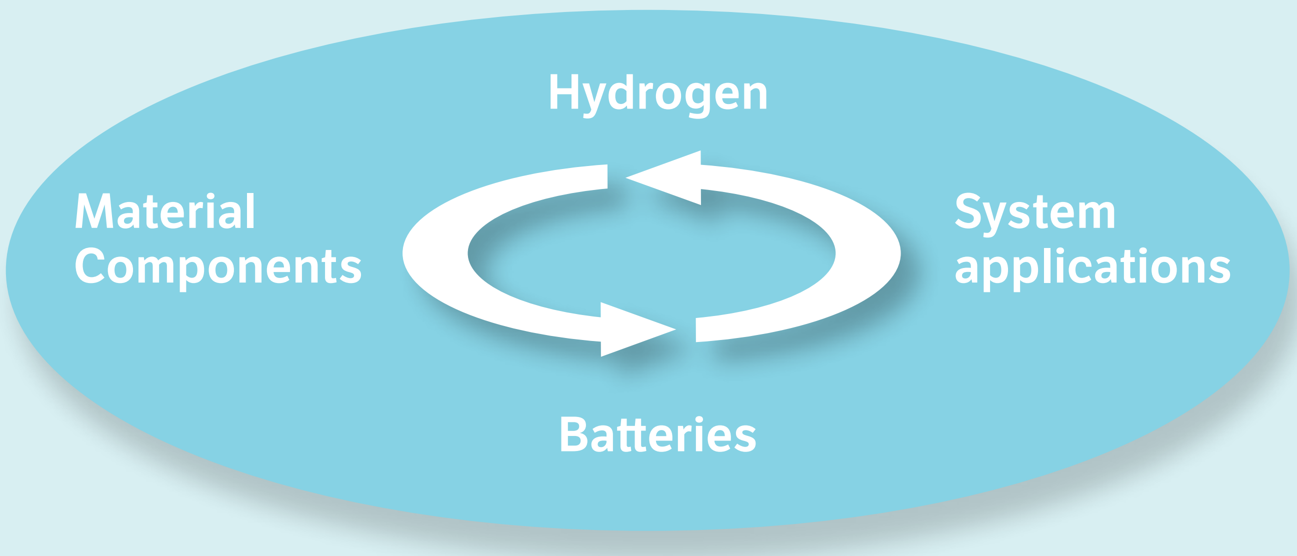
Battery and hydrogen technologies have been demonstrated for use in zero emission transport systems in many countries and regions around the world. However, further developments are needed before these technologies can be introduced into other transport sectors, such as heavy-duty transport by road, rail, or sea. MoZEES focuses on battery and hydrogen value chains, systems, and applications where Norway can take leading position in the future.

Main Objectives

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 heavy-duty zero-emission transport applications. The Center contributes to the design and development of safe, reliable, and cost competitive zero-emission transport solutions. There is also a strong focus on education and international collaboration.

Markets

The maritime sector has been identified as an important area where Norway can and should develop new zero emission technologies, systems, and solutions, both for domestic and international markets. One of the main

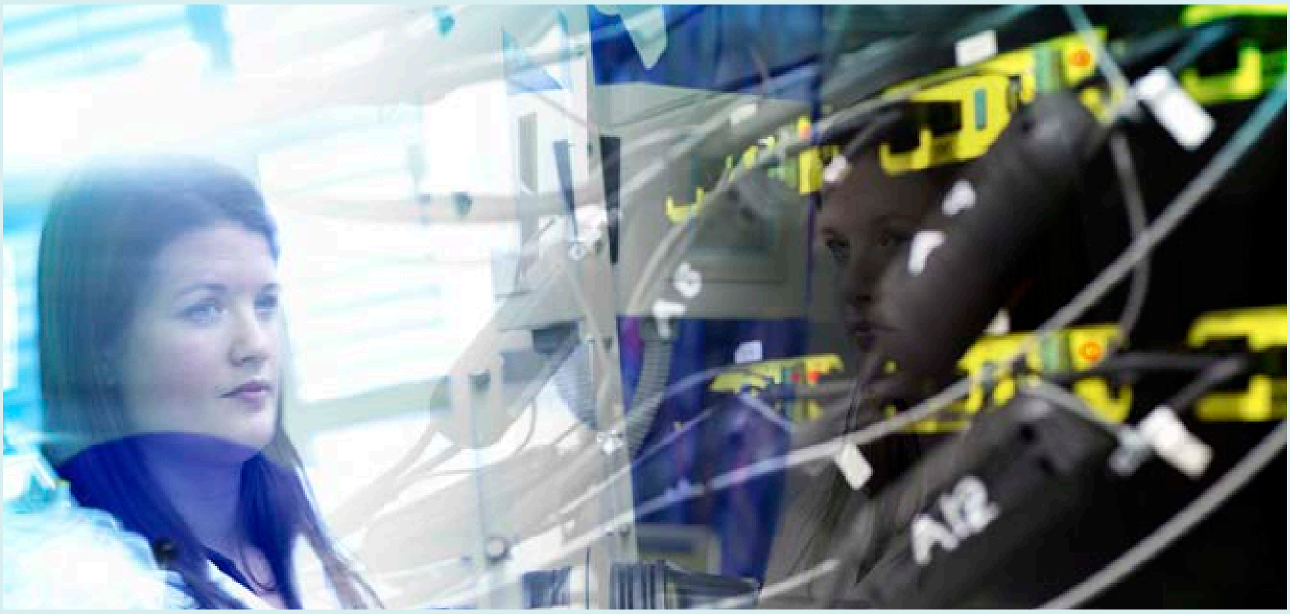


ambitions in MoZEES is to show how zero emission technologies can be a viable technical and economical alternative for the maritime sector, both in Norway and abroad. MoZEES also supports R&D performed by the Industry Partners that intend to participate in the international battery and hydrogen technology value chains.

Mission of the Center

In summary, the Center will add value to the society and user partners in the following way:

- Innovation: The Center promotes research that supports industrial R&D and other innovation activities undertaken by the Industry Partners, including: (1) Synthesis and fabrication of materials and components (2) Application and system integration of key technologies, (3) Design of integrated zero-emission transport systems and infrastructures (road, rail and sea).
- International Research Network: The Center is an international contact point for research on batteries and hydrogen for use in transport. The Center also serves as a network and meeting place for researchers and students to discuss interdisciplinary issues, ranging from basic to applied research.
- National Research Infrastructures: The Center maximizes the use of research infrastructure funded by the RCN and various EU programs. The use of existing research infrastructures among the Research and User Partners provides a solid foundation for the initial growth phase of the Center's activities.
- Guidelines and Roadmaps: The Center provides decision makers in public and private sector with guidelines for safe battery and hydrogen systems and road maps for technology development and application into transport applications (road, rail and sea).



Partners

Industry and Public Partners

National Research Partners

tøi Institute of Transport Economics
Norwegian Centre for Transport Research

UiO : University of Oslo

USN University of South-Eastern Norway

NTNU
Norwegian University of Science and Technology

IFE Institute for Energy Technology

SINTEF

FFI Forsvarets forskningsinstitutt
Norwegian Defence Research Establishment

International Research Partners

UPPSALA UNIVERSITET

UCDAVIS
UNIVERSITY OF CALIFORNIA

RWTHAACHEN UNIVERSITY

Members of the Management Team


Øystein Ulleberg (IFE)


Ragnhild Hancke (IFE)


Fride Vullum-Bruer (NTNU)


Magnus Thomassen (SINTEF)


Erik Figenbaum (TØI)


Katinka Elisabeth Grønli (UiO)

Members of the Executive Board


Arve Holt (IFE)


Patrick Bernard (Saft)


Gina Ytteborg (Statens vegvesen)


Jorunn Voje (Elkem)


Andreas Bratland (NFR)


Anders Søreng (NEL Hydrogen)


Per Ivar Helgesen (ENOVA)

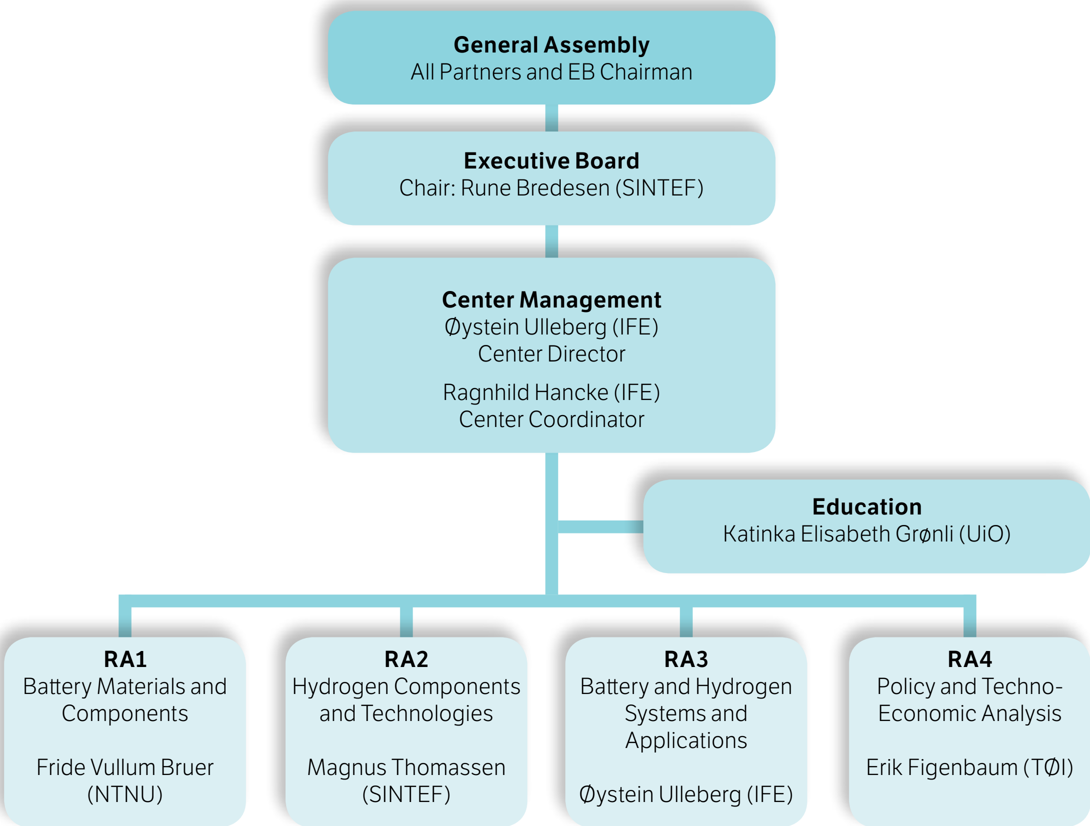

Matko Barisic (ABB)


Rune Bredesen (SINTEF)


Jo Døhl (University of Oslo)


Jostein Mårdalen (NTNU)

Organisation



The consortium gathered at the MoZEES Annual Meeting 2018

Education

MoZEES aspires to integrate our educational activities with the scientific development of the Center. Our three academic partners (UiO, NTNU and USN) offer basic educational programs and PhD programs at relevant departments. A major goal of the Center is to supply outstanding candidates for future positions in the transport and energy sector. This is enhanced by the active participation of user partners in all tasks at the Center, and in the development of our cross-disciplinary training network.

As of March 2019, the Center engages 9 PhD fellows and 3 post docs/researchers. In addition, there are a number of young researchers and master students linked to MoZEES through associated projects. They have been integrated in local research environments and introduced to their closest collaborative partners in their respective Research Areas. Several of the PhD students have an industrial specialist as a co-supervisor. Most participated at the first Annual Meeting in April 2018, and four contributed with presentations of their own research in the main program.

MoZEES Research Training Network (RTN)

The Center is developing a dedicated research training network to ensure active interaction between students and researchers across the different tasks and institutions as well as with relevant user partners. We aim to develop an interactive arena for all the participants at the Center where students and young researchers will have a dedicated session at our annual conference. In particular, we will develop a scheme for fruitful interactions between international renowned mentors and our younger scientists.

MoZEES RTN had a dedicated session on outreach at the MoZEES Annual Meeting. MoZEES RTN has also established their own web-page where the members are presented, and a blog that is run by the network itself.

In addition to presenting their work at the Annual Meeting, most members of RTN also presented their work to central members of the MoZEES consortium at Kjeller in September 2018. The presentations were followed up by fruitful discussions among RTN members and senior scientists connected to MoZEES through engagement in our SAB or as members of the Management team or Board.

During 2018 we have developed and adopted principles and a funding scheme for International and Industry Exchange for PhDs and young researchers. The MoZEES Mobility Program is designed to promote research exchange with International research partners and with the user partners of the center, aiming to foster increased interactions and mobility of candidates. During 2018, PhD fellow Ika Dewi Wijayanti was granted support for an international exchange with BASF-Ovonic, Rochester Hills, Michigan, USA. In spring 2019, PhD fellow Elise Ramleth Østli has been granted support for a 6-month stay at Uppsala University.

One of the student contributions to the outreach session at the Annual Meeting. The task was to prepare an illustration or drawing explaining the scientific scope of the project.

International industry exchange with support from MoZEES Mobility Program

During the summer of 2018, Ika Dewi Wijyanti - PhD fellow from NTNU/IFE – went on a three month industry exchange to BASF – Ovonic, Rochester Hills in Michigan USA. Ika's research project focuses on metal hydride batteries, and her work at BASF gave her an opportunity to take advantage of both their expertise knowledge and state of the art infrastructure. Her work focused on three themes:

- Metal hydride anode characterization
- Ionic liquid electrolyte studies and
- Studies of core shell cathode materials with enlarged electrochemical capacity.

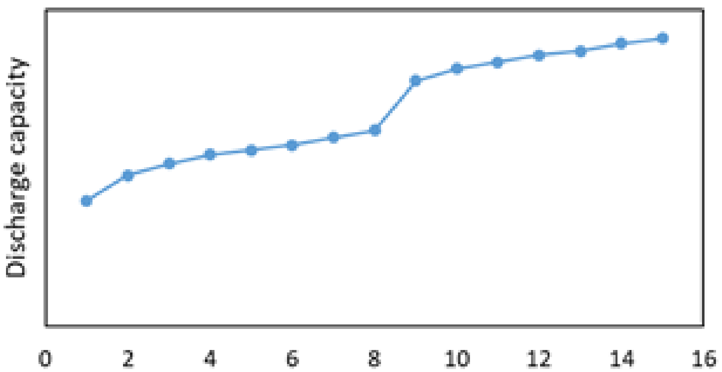
At BASF Ika was supported by a team of scientists allowing her to accomplish experiments within such a wide array of subjects according to plan. The infrastructure at BASF is complementary to what is found at IFE and allowed her to expand her research foci and obtain new results.

During her stay at Michigan, Ika was also part of a group of summer fellows, in total 10 young researchers. She became part of a wider international competence group of young scientists within her field, and got to know potential future collaborative partners.

2018 summer fellows at BASF: From left to right: Meng Xu (PhD student intern of Oakland University), Tucker Zalinsky (PhD student intern), Ika Dewi Wijayanti (PhD student intern of NTNU-IFE), James Weekly (Engineer), Dr. Lu Liu (Researcher), Pei Chen (PhD student intern of Michigan State University), Shiuan Chang (PhD student intern of Wayne State University), Hongkang Tian (PhD student intern of Michigan State University), Liwen Zhang (Master student intern of Oakland University), David Wang (PhD student intern).

Example of results: Core-shell cathode materials with enlarged electrochemical capacity

$Ni_{0.84}Co_{0.12}Al_{0.04}(OH)_2$ based core-shell samples were used as cathode materials in the experiments towards advanced Ni-MH batteries with enhanced capacity.



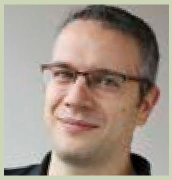
Left: Core-shell cathode structures were utilized with the goal to protect the core from electrolyte allowing to electrochemically charge and discharge it and to reach higher capacity. Right: Discharge capacity of cathode core shell sample.

MoZEES would like to thank Ikas supervisors during her stay at BASF, Prof. Kwo Young (Group Leader Metal Hydride BASF, Rochester Hills, Michigan, USA), Dr. Jean Nei (Research Scientist BASF, Rochester Hills, Michigan, USA), and Shiuan Chang (PhD student of Wayne State University, Michigan, USA).

The Research Training Network

Dr Alok Mani Tripathi *is employed as a postdoctoral researcher at the University of Oslo where he is performing in operando diagnostics of Li-ion batteries. This work is relevant for all the battery research in MoZEES as it will give a better understanding of the behavior and performance of battery materials.*

Dr Athanasios Eleftherios Chatzitakis *(a.k.a. Sakis) is a postdoctoral researcher at the University of Oslo. He is exploring the properties of non-porous, protonic conducting composite membranes for use in PEM fuel cells and electrolyzers in collaboration with prof. Truls Norby.*

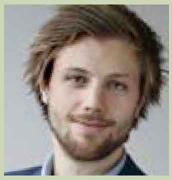


Dr Gaylord Kabongo Booto *is a postdoctoral researcher at IFE assessing the environmental impacts of Heavy Transport Vehicles – with a defined zero emission technology – by means of Life Cycle Analysis. The environmental benefits at full scale deployment are quantified in order to inform decision makers and enable strategic environmental management.*

MSc. Eivind Hugaas‘ *project at NTNU focuses on hydrogen storage tanks, and he is studying fatigue data via experimental testing and modelling, in close collaboration with the Norwegian industrial partner Hexagon. Eivind's supervisor is prof. Andreas Echtermeyer.*

MSc. Hamid Reza Zamanizadeh‘s *PhD project focuses on Ni-based bipolar plates for alkaline water electrolysis cells. The work covers surface engineering, corrosion investigation and electro-catalytic activity evaluation for both the oxygen- and hydrogen evolution reactions. He started his studies at NTNU in 2018 under the supervision of Profs. Frode Seland and Svein Sunde.*

MSc. Daniel Tevik Rogstad *embarked on his PhD studies at NTNU the fall 2017, with prof. Ann Mari Svensson as his supervisor. Daniel is investigating Silicon anodes and ionic liquids in Lithium-ion batteries.*



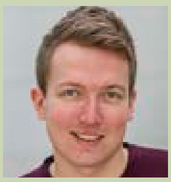
MSc. Xinwei Sun *started her PhD studies on hydrogen technology in 2018. The objective of her project is to develop low cost, high performance composite membranes for PEM fuel cells, which can be operated under higher temperatures (> 80˚C) and low relative humidities (RH < 20%). Her studies are carried out at UiO under the supervision of prof. Truls Norby.*

MSc. Elise Ramleth Østli *started her PhD studies at NTNU in 2017, with RA1 manager Prof. Fride Vullum Bruer as supervisor. She aims at the development of water-based manufacturing routes for electrodes in an effort to stabilize the electrode/electrolyte interface.*

MSc. Halvor Høen Hval *started his PhD studies at UiO in 2018, working on batteries. He aims at developing new, as well as improving existing, high-voltage cathode materials with supervision from prof. Helmer Fjellvåg and prof. Ola Nilsen. Parts of the work will also be conducted in collaboration with FFI.*

MSc. Ika Dewi Wijayanti *joined MoZEES as a PhD student at NTNU and IFE from 1 January 2017 and is working on Nickel metal hydride batteries. The study is undertaken in collaboration with our international industrial partner BASF-Ovonic, aiming to develop high voltage and high power non-aqueous metal hydride batteries.*

MSc. Vegard Østli (TØI) *is a PhD student at NTNU and has prof. Fredrik Carlsen as supervisor. The project focuses on developing behavioral models for travelers and firms in order to predict the market impact of introducing new technologies in the transport sector. Another key aspect is to evaluate how public policy can contribute to the uptake of new technological solutions.*



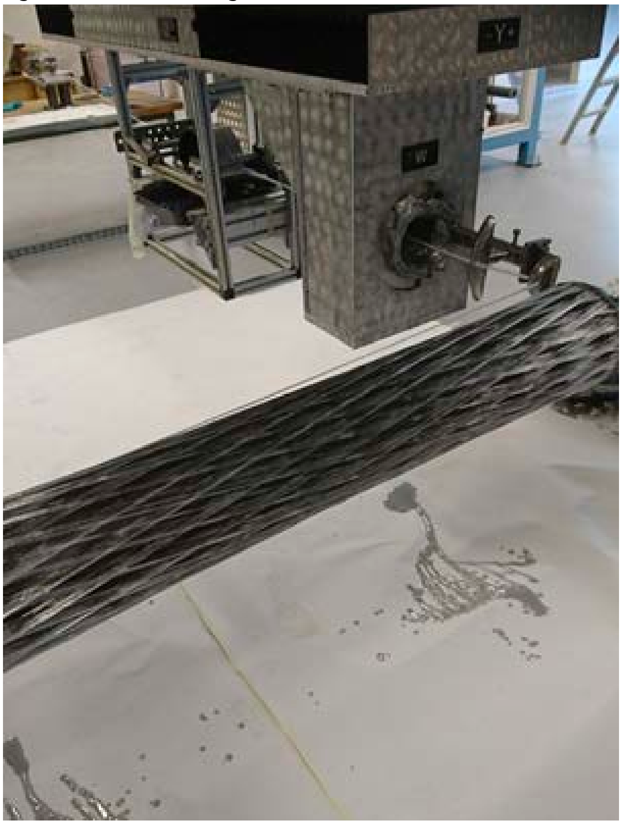
MSc. Mathias Henriksen *emarked on his PhD studies at USN in 2017, and focuses on hazards – such as explosions – related to accidents with Li-ion batteries in transportation. The work is supervised by prof. Dag Bjerketvedt and conducted in close collaboration with FFI.*

PhD Blog: Composite Pressure Vessels and Why it's Worth Researching

In this blog post, published 20 August 2018 on www. mozees.no, PhD student Eivind Hugaas gave the readers an exclusive glimpse into his world of light-weight hydrogen pressure vessels.

My name is Eivind and my work makes up the larger part of Research Area 2.5 in MoZEES, which focuses on hydrogen pressure vessels made out of carbon fiber reinforced polymer (CFRP). Currently I'm just finished with the compulsory subjects and ready to work with research full time while also producing some hopefully exciting content for MoZEES!

Figure 1: Filament winding in the lab at NTNU.



Complex Composites

To achieve sufficient strength and avoid hydrogen cracking issues encountered when using metals in combination with hydrogen, CFRP is a good alternative to steel for hydrogen pressure vessels. However, CFRP and composite materials in general are complex compared to steel. Additionally, composites have seen less research than steel, partly because steel has been around for much longer than composites, in a modern sense.

The limited knowledge and the complexity of the materials results in costly and inefficient testing procedures for composite pressure vessels when used to store such a highly sensitive medium as hydrogen. The testing is a huge cost driver and high safety factors are employed in design compared to steel structures to counter any uncertainty in the material behavior, prohibiting use of the material's full potential on par with steel. As a result, there lies great promise in increasing the material knowledge through research so that analytical approaches can replace some of the testing and more of the materials potential can be employed in the design.

The testing is a huge cost driver and high safety factors are employed in design compared to steel structures to counter any uncertainty in the material behavior.

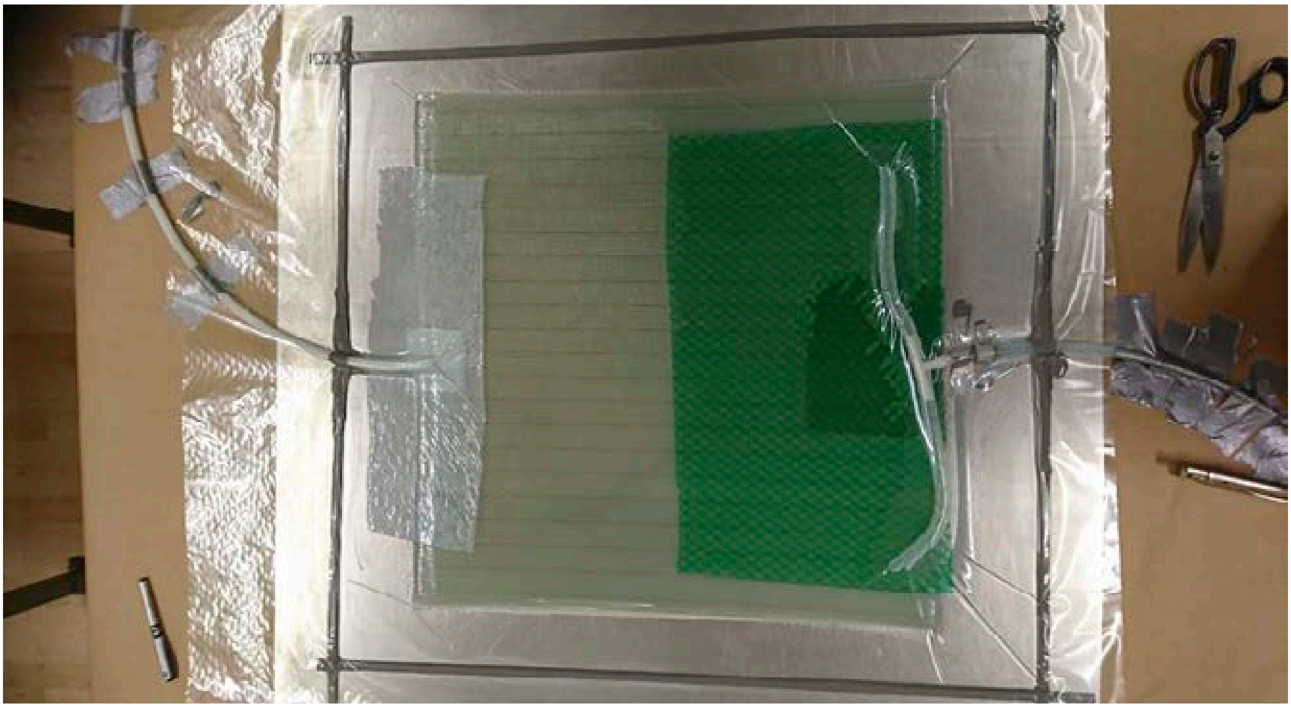
Production of fiber reinforced polymers can roughly be divided into two different production methods; either fiber mats are stacked as mostly flat panels or strands are woven onto a structure. How the polymer/epoxy is introduced into the structure varies. The former method is the preferred method for producing pressure vessels and is called filament winding.

Figure 1 shows a pressure vessel being produced on NTNU's filament winding machine and Figure 2 shows a flat specimen being produced. The material behavior of the two production methods differ, even though the same constituent materials are used. Most of the current research has been carried out on specimens made out of mats and less on filament wound ones. This is largely due to that flat specimens are more convenient to work with and simpler to produce compared to filament wound specimens.

The core idea of this PhD is to allow for use of simpler testing procedures and higher confidence in analytical estimations of fatigue in filament wound pressure vessels.

One of the most promising alternative test methods for filament wound pressure vessels is the use of split disk testing on pressure vessel cut outs.
Figure 3 shows the split disk test fixture along with pressure vessel cut outs from the vessel shown in production in Figure 1. During the summer and autumn the plan is to establish better knowledge on how pressure vessel cut

Figure 2: Production of a flat glass fiber reinforced polymer sheet at NTNU with mats stacked on top of each other using vacuum to infuse the epoxy into the layup.



outs behave when using this test method, logging strain throughout static and cyclic loading using optical fibers glued to the samples.

Figure 4 shows optical fiber glued onto a flat GFRP specimen and Figure 5 shows how the strain fields from the fiber can be visualized. Optical fiber allows for measurement of near continuous strain fields making for convenient comparison with numerical models. Employing correlation between numerical models and experiments using key parameters such as strain allows for better simulation of full scale designs.

Composite materials are fickle to work with and can often surprise even the most experienced

Figure 3: Split disk test rig with a pressure vessel cut out installed. The two cut outs with the black ring inside has not got the liner removed yet. The liner can be seen as the winding mandrel in Figure 1.

There lies a great potential increase in confidence of analytical estimations if the already existing research on flat specimens can be applied to pressure vessel geometries. Establishing a link between material properties of flat and filament wound specimens holds great value. Therefore, along with testing using the split

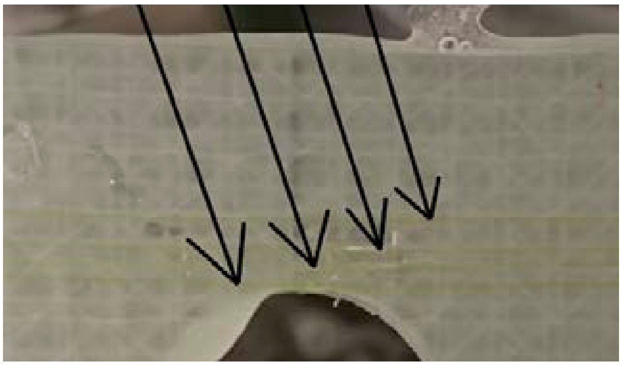


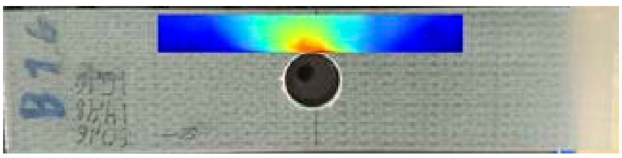
Figure 4: Optical fibers glued onto a flat specimen.

disk method, testing on flat specimens with the same constituent materials is also an important part of this PhD to compare.

Due to glass fiber reinforced polymer (GFRP) being a much more convenient material to work with as it is nearly translucent, this is used instead of CFRP for the larger part of the work. The material mechanics are the same for the interest of this work.

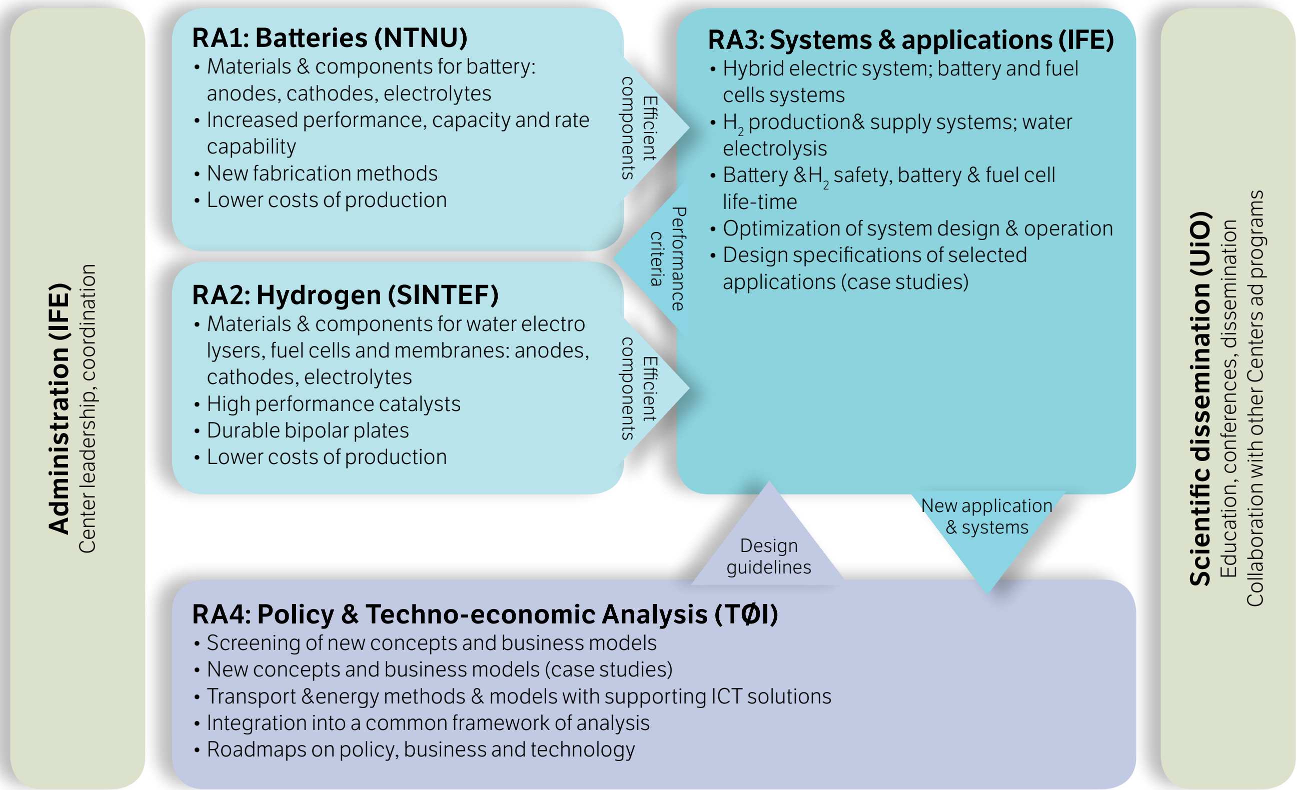
The day to day work is very much based on logging practical experience in the lab. Composite materials are fickle to work with and can often surprise even the most experienced; this makes for a dynamic and interesting workflow demanding flexibility in both mindset and planning.

Figure 5: Post processing of optical fiber strain readings during a tensile test can give a fancy visual representation of the strain distribution.



Research Areas

An overview of the four main Research Areas (RAs) of the Center is provided in the figure below. RA1 and RA2 focus on research that can lead to breakthrough development in materials and key components for batteries and hydrogen technologies. The focus is on building strong research teams to take advantages of multi-disciplinary expertise and cross sectorial capabilities. RA3 focuses on the design and operation of battery and hydrogen systems for specific applications. Detailed technical studies on safety, reliability, and energy efficiency is performed, and used to develop system specifications and guidelines. In RA4 the focus is to establish a common framework of analysis, allowing new transportation concepts to be analyzed comprehensively under varying assumptions on technology, policies, incentives and governance measures.



RA1 Battery Materials and Components

The research activities in RA1 are mainly focused around materials for Li-ion batteries (LIB), but there is also one task concerned with development of new electrode materials and electrolytes for metal hydride batteries (MHB). Below follows a summary of the most important work performed in 2018, including a few examples of results achieved.

Some highlights for the LIB activity includes the work performed by PhD candidate Daniel Tevik Rogstad at NTNU. He has focused on synthesis and characterization of new ionic liquid electrolytes. Four different ionic liquids mixed with a specific Li-salt (LiFSI) have been investigated using Elkem's eSi-400 as anode material. Based on these results, one ionic liquid was chosen for further studies. By exchanging standard electrolytes for ionic liquids, issues arose with the common separator used. This was solved by replacing the polyethylene/polypropylene separator with a material that is more compatible with the ionic liquid. Figure 1 shows cycling results for these four electrolytes compared to a standard commercial electrolytes based on carbonates. In Figure 2 an SEM image of a cross section is shown for the electrode, showing a very nice an homogeneous film.

Work has also been performed at IFE and SINTEF on the use of Si anodes in LIB. Here, the focus has been on investigating new binder materials, which can both stabilize the Si and provide better performance, while at the same time using environmentally friendly materials based on Norwegian resources. Significant work is also performed on improving the knowledge on degradation mechanisms and understanding the relationship between particle morphology, electrolyte composition and degradation behavior.

For the LIB cathodes, work has focused on synthesis and characterization of high voltage materials, more

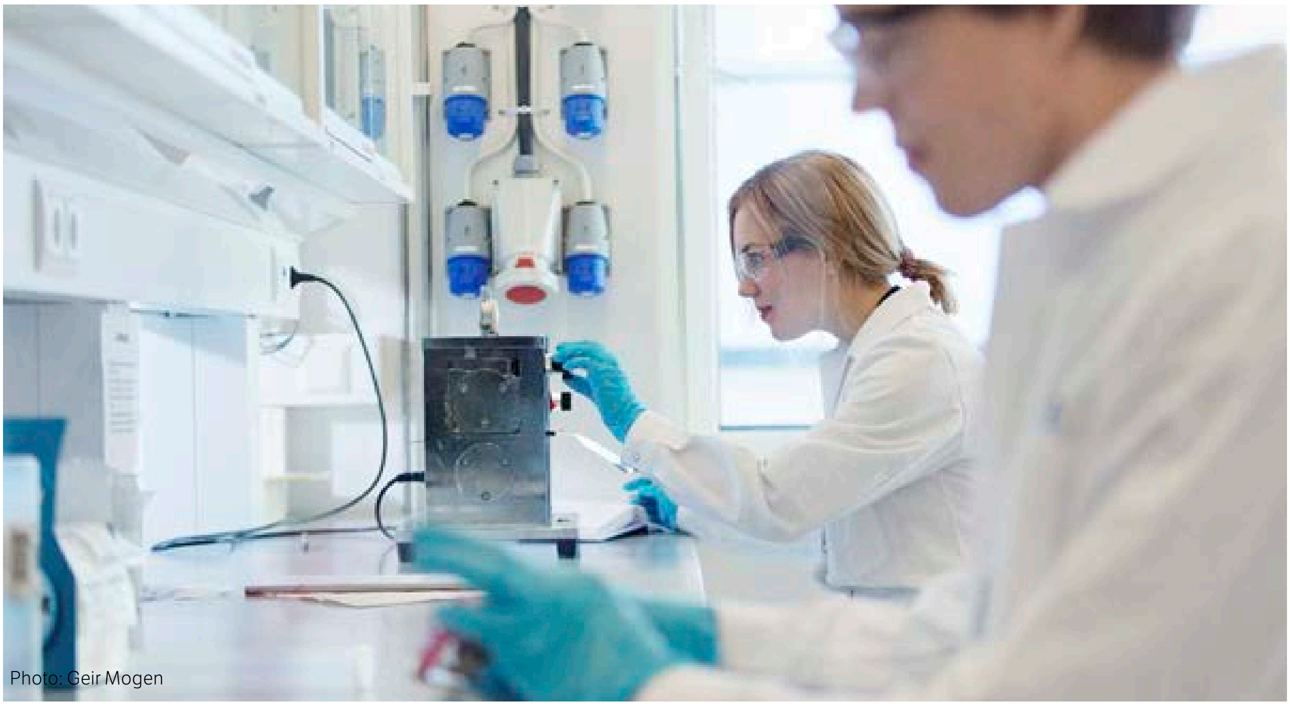
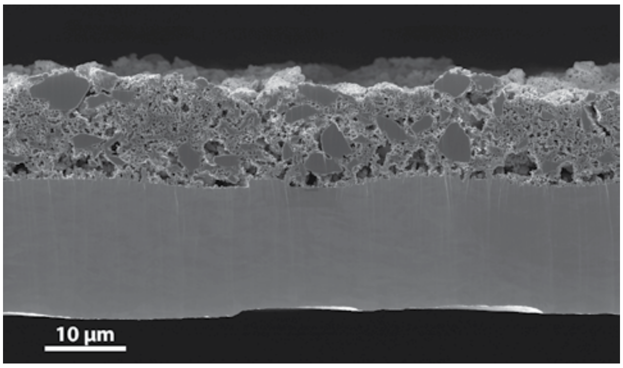


Photo: Geir Mogen

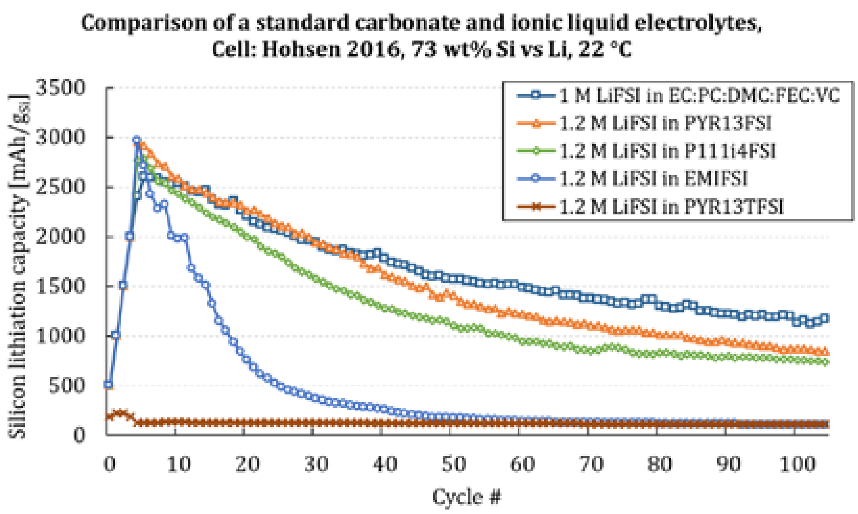
specifically $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO). PhD candidate at NTNU Elise Ramleth Østli has put significant efforts into synthesis of these materials by using a modified Pechini method. One issue with Mg-containing cathodes is the dissolution of Mg into the electrolyte, leading to accelerated degradation of the material and failure of the battery. One means of remedying this is to add a coating on the materials to prevent immediate contact between the active material and the electrolyte. Here, Baldur Coatings has been an important collaborator, and has used their atomic layer deposition (ALD) technology to provide materials with very thin coatings for further testing. Initially, TiO2 was chosen as the coating material. Results from these tests are shown in Figure 3 below. Further investigations into other coating methods and coating materials will be performed in 2019. And effects of the coatings will be investigated in collaboration with the University of Uppsala, where Elise will spend 6 months performing i.e. XPS and in situ XRD. These studies will be performed in full cell LIB configuration.

Some work on cathode materials has also been performed by SINTEF and PhD candidate Halvor Høen Hval at UiO. Halvor has mainly focused on developing advanced characterization techniques using i.e. synchrotron radiation to investigate structural changes during cycling. This work will continue in 2019 and will be supported by a new post doc at UiO (Dr. Alok Mani Tripathi) whom will also focus on advanced characterization methods.

SINTEF has synthesized and characterized NMC622 ($LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$), and investigated the relationship between morphology and electrochemical performance. These results were compared to electrochemical performance obtained using commercial materials supplied by SAFT. In addition to this activity, SINTEF has also worked on spray drying of cathode materials and optimization of parameters for achieving products of commercial grade with regards to morphology. Here, NMC111 supplied by CerPoTech was used for the experiments. Performance of spray dried materials was compared to non-spray dried materials by electrochemical cycling.



Figur 2: SEM micrograph of the cross section of an uncycled 73 wt% silicon electrode (eSi-400) on Cu-foil.



Figur 1: Comparison of cycling results from a standard carbonate electrolyte and four ionic liquid electrolytes. Cycled in Hohsen 2016 coin cells with a 73 wt% Si electrode vs Li. First four cycles @ C/20, next 100 cycles @ C/5 (C=3579 mAh) in RT.

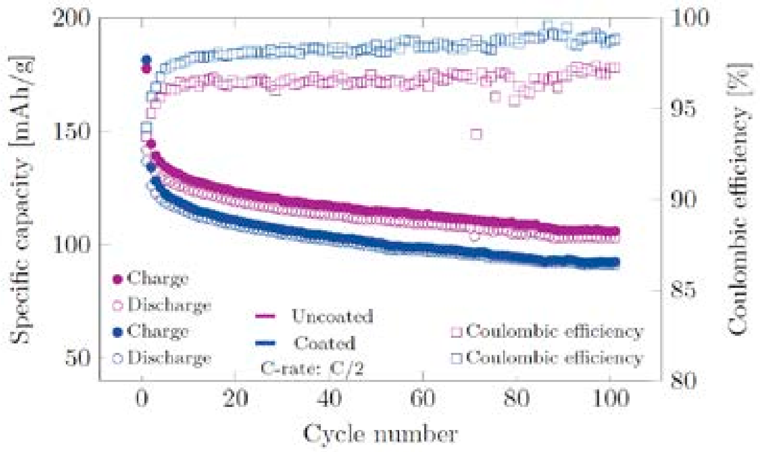
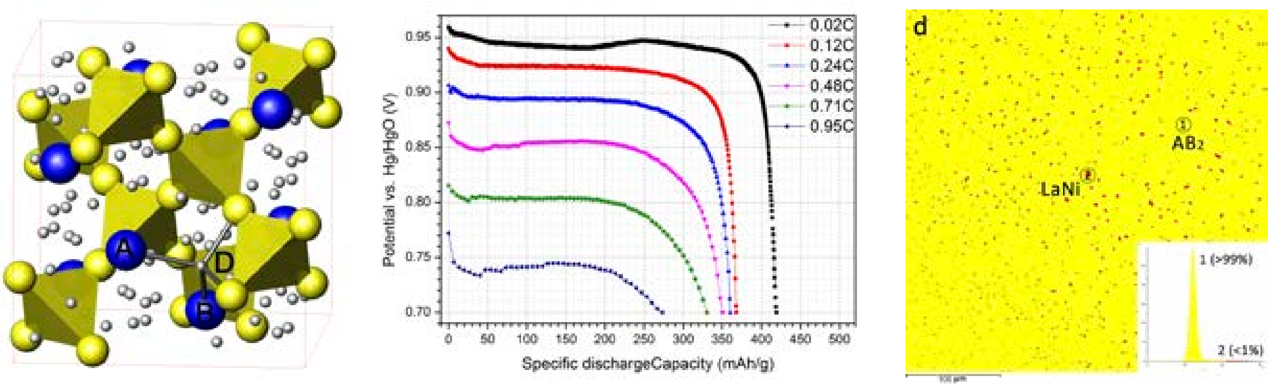


Figure 3: Charge/discharge capacity and coulombic efficiency of TiO_2-coated LNMO (blue) and uncoated LNMO (magenta) for the first 100 cycles.

There is one task in RA1, which is not focused on Li-ion batteries, but rather on development of metal hydride batteries. The work is a collaborative effort between PhD candidate Ika Dewi Wijayanti whom has her daily work place at IFE, IFE researchers, and external partners. The external partners include BASF-Ovonic (USA), University of Bordeaux (France), Russian Academy of Sciences, and Lithuanian Energy Institute.

In the summer of 2018 Ika spent 3 months at the BASF-Ovonic laboratory facilities in Rochester Hills, Michigan, USA. The work performed here was focused around anode characterization, investigation of ionic liquid electrolytes, and stydying core-shell particles as potential new cathode materials for improved capacity. One example of the work performed in 2018 is the synthesis and characterization of the complex alloy with nominal composition $Ti_{0.15}Zr_{0.85}La_{0.03}Ni_{1.2}Mn_{0.7}V_{0.12}Fe_{0.12}$. Electrochemical cycling characteristics of this material is shown in Figure 4 (centre). These results show significantly improved properties with a discharge capacity reaching 420 mAh/g. The left most part of Figure 4 shows the material's atomic structure and how hydrogen atoms fill the tetrahedral interstices, which is the key to the good performance. One of the most important aspects of this work is that excellent performance is achieved without the use of expensive rare earth metals commonly utilized in commercial MHB solutions. Nanostructuring of the materials by using rapid solidification methods has been a key issue to achieving this improvement.

Figure 4: Left shows the atomic structure of the alloy $Ti_{0.15}Zr_{0.85}La_{0.03}Ni_{1.2}Mn_{0.7}V_{0.12}Fe_{0.12}$. The center image shows the electrochemical performance at different current rates, and the right image shows the homogeneous distribution of elements on the alloy.



RA2 Hydrogen Components and Technologies

The main objective of RA2 is to enable the production of fuel cells, electrolysers and hydrogen storage tanks with lower cost and higher efficiency, and thereby contributing to reaching the 2025 targets (DOE & EU) for transportation fuel cells, hydrogen production from renewable energy sources and hydrogen storage. The work is prioritized within development of high performance electrocatalysts, low-cost bipolar plates and membranes and improvement of testing protocols for high pressure composite hydrogen pressure vessels.

Oxide powders mounted in apparatus for reductive treatment in Task 2.1.

Collaboration with user partners

In RA2 the collaboration with user partners in 2018 has been through discussions, transfer of knowledge and on-site training. On 14th March 2018 to 16th March 2018 Graham Smith, SINTEF, visited Dr Chris Zalitis at Jonson Matthey Technology Centre, Sonning Common, UK (JM). JM explained the experimental and analytical aspects of the floating electrode technique so that SINTEF and other partners in the MoZEES consortium can begin to use the technique for electrocatalyst testing.

Johnson Matthey has participated in several teleconferences with UiO and SINTEF on the discussions on materials selection, testing and preparation of hybrid membranes. Discussions with Cerpotech on manufacturing of the inorganic filler materials have been performed. NEL Hydrogen has given valuable input to materials and relevant experimental conditions for investigation of alkaline bipolar plates.

Hexagon, which is the key partner for RA 2.5, is expected to be more involved later in the research when test results and work on analytical models has progressed to a more mature level.

International collaboration

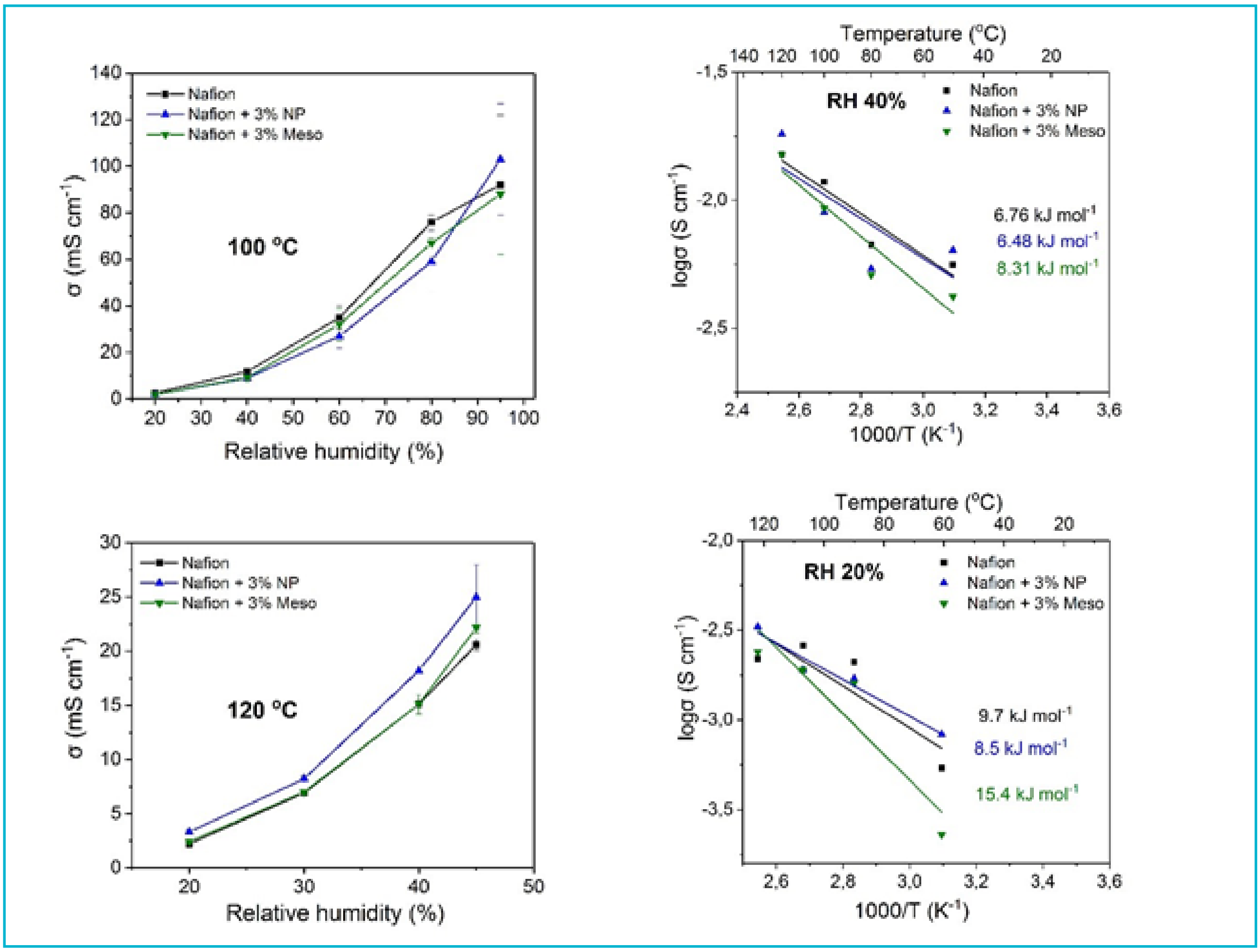
- Researchers at SINTEF have collaborated with Johnson Matthey Fuel Cells (UK) on developing new proton conducting composite membranes and in training on new techniques for electrochemical catalyst testing.
- Researchers at IFE have visited the Paul Scherrer Institute, Switzerland, to perform in operando neutron imaging experiments on a PEM electrolyser cell.

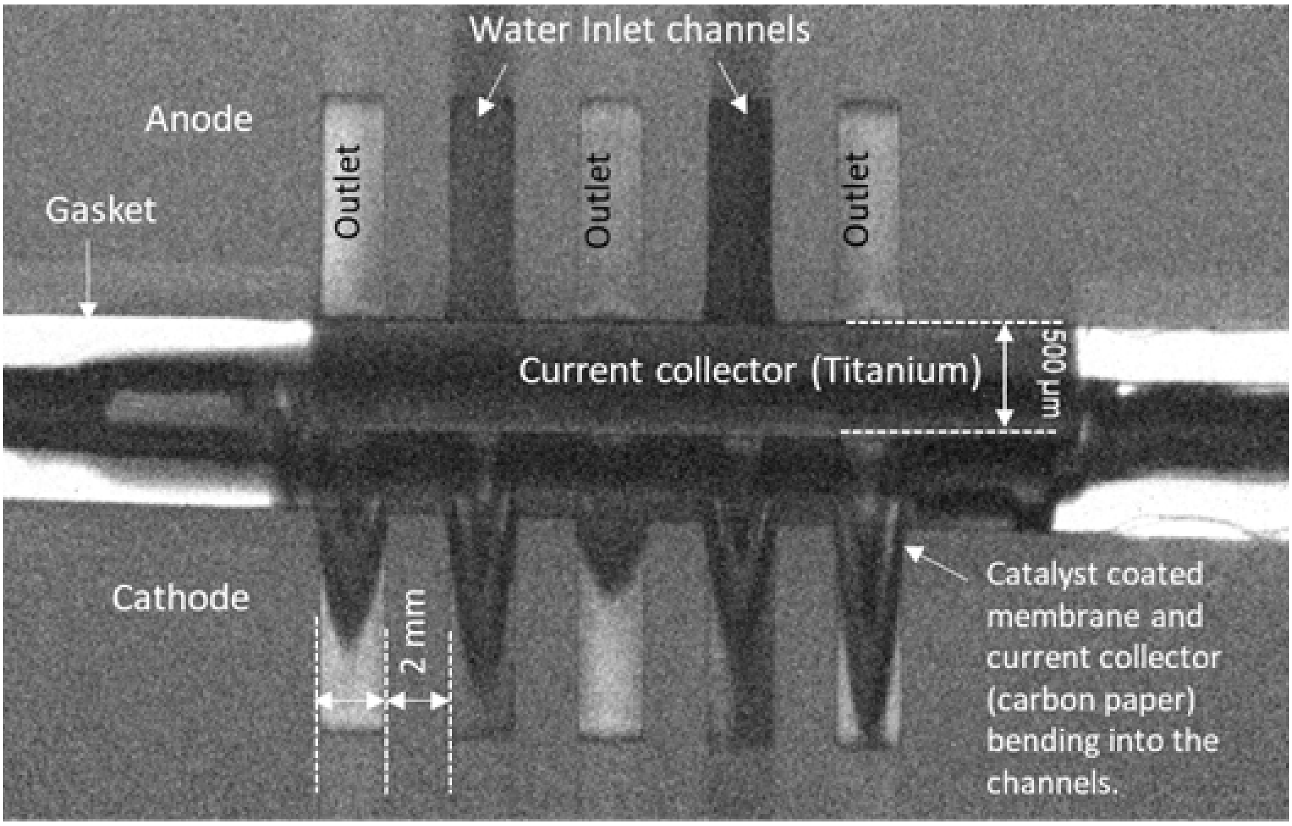
Task 2.1 – High-performance catalysts
Development of a novel methodology for synthesis of oxide supported noble metal catalysts for PEM fuel cells and electrolysers have been the main activity in this task during 2018. In 2018, the activity was focused on increasing the loading of the noble metal catalyst from around 5 wt% achieved in 2017 to the target 20 wt%. A thorough review of each synthesis step was conducted to elucidate mechanisms causing loss of sacrificial materials and ensure complete reduction/reaction in all steps. At the end of 2018, catalysts with the target 20 wt% was achieved with significant improvement in catalytic activity. In 2019, methods for increasing noble metal dispersion and particle size will be investigated.

Task 2.2 – Low cost bipolar plates
NTNU has hired a PhD student on bipolar plate materials for alkaline water electrolysis. Hamid Reza Zamanizadeh was hired in October 2018, and started immediately in attending courses and getting access to relevant laboratories and equipment. During the fall term he followed 2 PhD courses, where one is passed and the second has yet to organize a final exam.

An electrochemical cell of conventional design (in teflon) has been made for fine potential control of the plate material under study (working electrode). Discussion of relevant tasks in the PhD study has been discussed with affiliated partners at joint meetings and we expect an increased collaboration with user partners in 2019.

The graphs below depicts the proton conductivity of a composite polymer membrane as a function of RH (left column), and as a function of temperature (right column). The work was carried out in Task 2.3.





Neutron radiogram of a PEM electrolyser cell imaged in operando in Task 2.4

Task 2.3 – Improved membranes

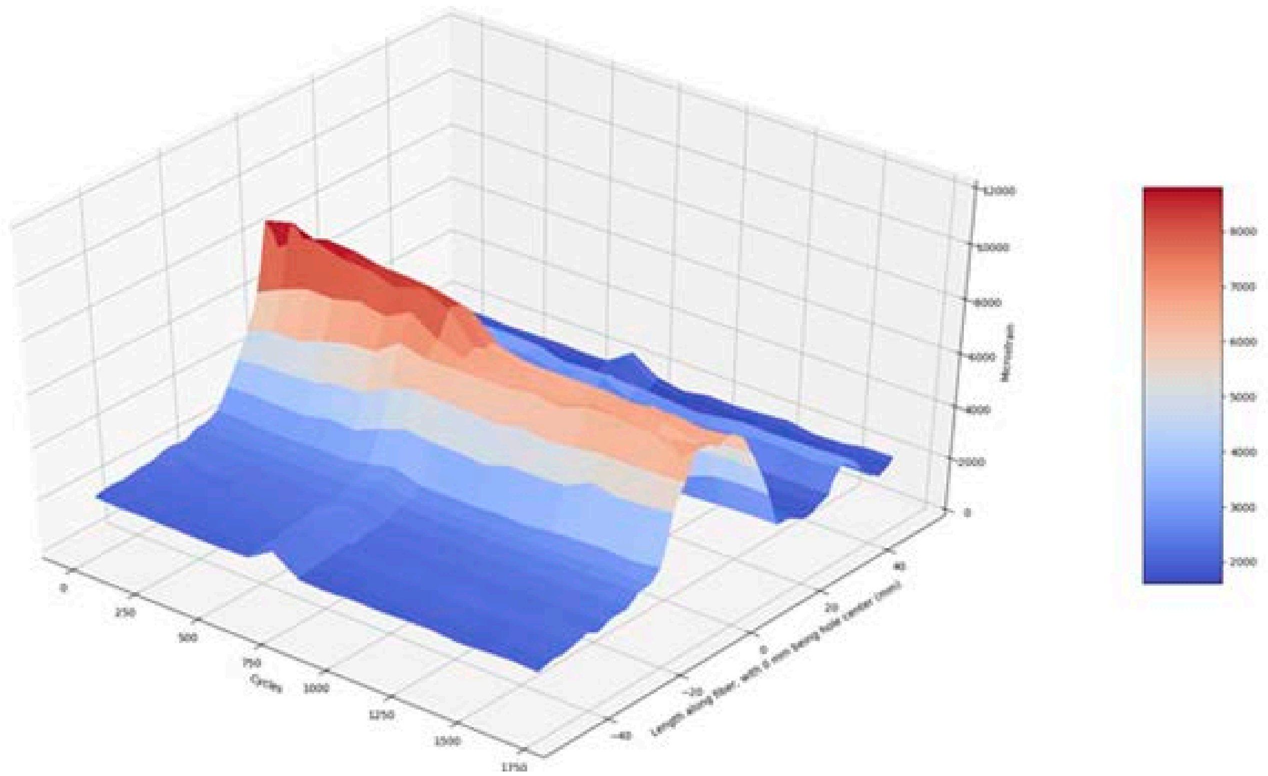
In September 2018, the Ph.D. candidate Xinwei Sun was recruited to the research group ELCHEM at UiO. She, together with researcher Athanasios Eleftherios Chatzitakis have carried out electrochemical measurements on polymer composite membranes under controlled atmospheres. The main objective was to precisely control the temperature and relative humidity (RH) supplied to a test cell for the determination of proton conductivity in composite polymer membranes. There was also a need to measure the proton conductivity of the polymer membranes under elevated temperatures (>100 °C) and low RH conditions (>40%). In order to cover a wide range of temperatures (30 < T < 140 °C), a commercial humidifying system was installed and tested. A few selected results are shown in the figureabove. In addition to this work, a review article with the title "Earth-abundant electrocatalysts in proton exchange membrane electrolyzers" was submitted for publication in Catalysts (MDPI).

Task 2.4 – Lifetime, durability and performance

During 2018, researchers at IFE carried out in operando neutron imaging experiments on a PEM electrolyser cell in the in-plane mode (neutron beam travels parallel to membrane) at the Paul Scherrer Institute in Switzerland. The radiogram above depicts the cell with interdigitated channels operated at a current density of 2.5 A/cm2 with water circulated on both the anode and the cathode. It demonstrates how the highly neutron-attenuating water in the cell is partly displaced by H2 and O2 when current is applied and, furthermore, that while the present cell design is very well suited for mass transport studies in the anodic porous current collector, different materials and flow field configuration must be implemented to study water drag and cathodic transport. Further image processing (applying the Beer-Lambert Law) will yield the gas fraction at each pixel, and the images will thus be able to shed light on mass transport issues such as gas accumulations and preferred pathways in the current collector.

Task 2.5 – Hydrogen Storage tanks

In 2018 the PhD student working on this task finished all compulsory projects and will in 2019 start full time research work. Testing of filament wound pressure vessels using split disk testing was commenced in 2018. Obtaining better knowledge on how pressure vessel cut outs behave when using this test method, logging strain throughout static and cyclic loading using optical fibers glued to the samples has been the main activity in 2018. The figure shows how the strain field closest to a hole in the sample relaxes a bit and widens at around 700 cycles, after which a stable state is reached for the remaining cycling protocol.



Carbon fiber strain measured over 1500 test cycles in Task 2.5.

RA3 Battery and Hydrogen Systems and Applications

The main objective with RA3 is to develop, test, validate, and study the performance of battery and fuel cell technologies and systems, and to optimize the design and controls of systems suitable for heavy duty road, rail, and maritime applications. There is a special focus on heavy duty hybrid battery/fuel cell systems, battery and hydrogen safety issues, and maritime applications.

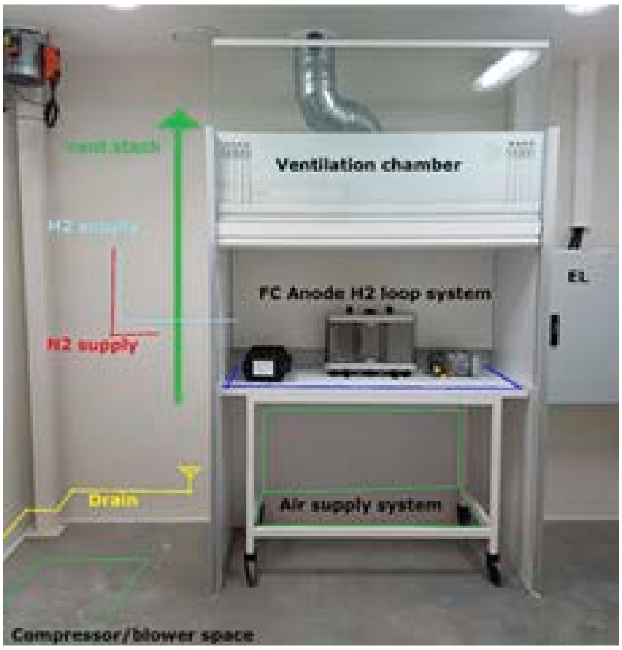
The main research questions in RA3 are related to:

- Design and control of battery and fuel cell systems (with the goal to maximize lifetime)
- Safety and risk management associated with heavy-duty battery and FCH-systems
- Design of RE-based water electrolysis and H2-supply systems (with the goal to reduce costs)

Task 3.1 – Advanced Fuel Cell Control Systems
The construction and commissioning of the N-FCH Low-Temperature laboratory at SINTEF was completed in November 2018 and the first PEMFC short stack tests were performed. Preliminary PEMFC stack test data (IU-curves) has been prepared for use by MoZEES partners. The construction of the N-FCH Fuel Cell System Laboratory at IFE Hynor was almost completed in 2018 and will be commissioned and made available for MoZEES research activities in 2019.

The more theoretical work on fuel cells also had some progress in 2018. A report on methods for prognostics and diagnostics for PEM fuel cells is about to be completed by SINTEF, while IFE has completed the first version of a MATLAB Simulink PEM fuel cell system model including a Li-ion battery model. User partners have provided technical information about maritime battery system design and operation (e.g. at the MoZEES Battery Days 2018) that will be used in the MATLAB fuel cell / battery hybrid system modeling in 2019.

Low temperature fuel cell stack test stations commissioned at SINTEF, Trondheim

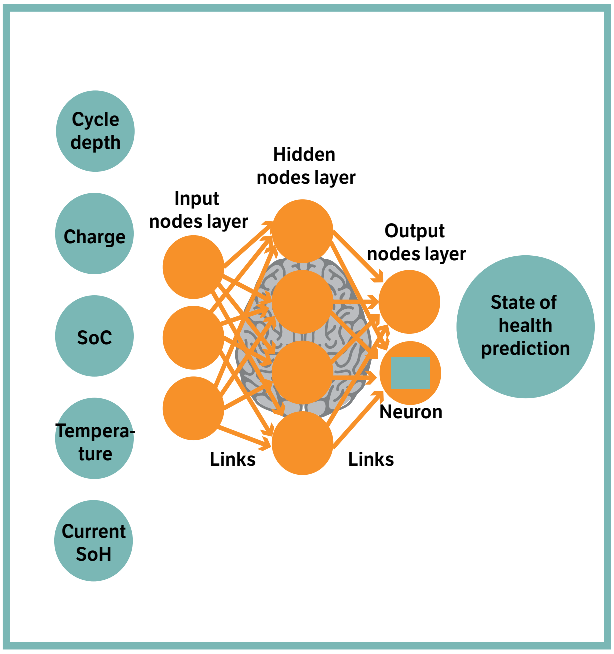


Fuel cell laboratory system under construction at IFE Hynor, Kjeller

Task 3.2 – Battery cell lifetime, durability, and safety
Battery cell design and operation is crucial for battery cell performance and safety. Numerous Li-ion battery cell performance tests have been carried out in IFEs battery laboratory over the past few years. Key results and conclusions from these experiments were presented at a couple of large MoZEES-meetings in 2018 (Battery Days and Annual Meeting), and an open report by IFE, FFI, and other MoZEES partners is currently being published. A strong research collaboration on Li-ion batteries has also been established with RWTH Aachen University, where there is a special focus on modeling of battery ageing.

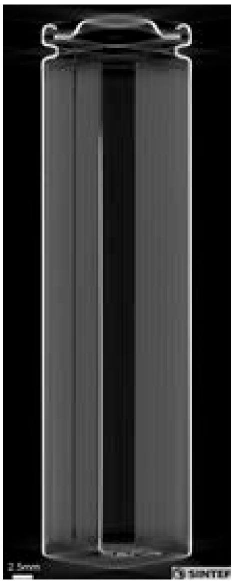
Some of the battery cell data collected at IFE was made available for MoZEES-battery modelling. A battery cycle life model based on an Artificial Neural Network and two sets of battery ageing data was developed and tested at IFE. The predictive capability of the model was excellent, within the parameter limits of the data sets. The modeling showed that complex ageing processes can be modelled without detailed knowledge of the underlying chemical processes. However, the model is limited by the parameter window of the input data and cannot reliably be used outside this parameter window.

Illustration of a mathematical Li-ion battery state of health model based on artificial neural network developed at IFE



In addition to battery cell testing it is important to develop different methods to study degradation occurring in the batteries as result of cycling. A non-destructive battery cell characterization method using micro X-ray Computed Tomography (CT) was tested at SINTEF on set of fresh 18650 battery cells (provided by Grenland Energy AS), with the aim to identify any protection circuit, internal damages and/or damage patterns. The results showed that similar materials were found in all the cells even though the cell specifications were very different. This highlights the importance of being able to identify material compositions when determining the properties of different battery cells. The battery cell characterization technique established will be used in further analyses on a MoZEES battery reference cell in 2019.

Procedure for non-destructive battery cell characterization:
(1) The batteries were first discharged to 1.8 V (for increased handling safety without undesired material changes), before they were disassembled in dry argon atmosphere and the electrolyte was extracted with a centrifuge.
(2) Head Space Gas Chromatography Mass Spectrometry (HS-GC-MS) was then used to get an overview of the various electrolyte components in the batteries.
(3) Electrodes and separators were parted, and the electrodes sampled and gently washed for further analysis.
(4) Scanning Electron Microscopy (SEM) combined with Energy-dispersive X-ray spectroscopy (EDS) was used to demonstrate the homogenous structures and approximate composition of the cathode materials (Ni:Mn:Co ratios) and demonstrated presence of (or lack thereof) Si in the anodes.



Cross section image from the side of 18650 battery cell produced by a micro X-ray Computed Tomography instrument at SINTEF.

Task 3.3 – Battery and Hydrogen Safety

Research on battery safety has been the priority in 2018, but some work on hydrogen safety has also been performed. At the MoZEES Battery Days 2018 there was a thorough discussion among the research and industry partners on Li-ion battery safety. A MoZEES-report on hazards related to Li-ion batteries (based on the DNV GL's Battery Handbook) was drafted by DNV GL, USN and FFF towards the end of 2018, and will be completed in 2019. At USN a Schlieren set-up and spark ignition system was built into their 20-liter explosion sphere. An experimental study on the explosion characteristics of Li-ion battery electrolyte was performed and is now published in Journal of Hazardous Materials as a joint publication of USN and FFI. Explosion characteristics of electrolyte solvents were also performed, and the results have been reported in a publication. The work on hydrogen fire and explosion hazards were published by USN in two papers submitted to the International Journal on Hydrogen Energy. Scientists from FFI and IFE contributed with a book chapter on Li-ion battery safety of aged batteries in Electrochemical Power Sources: Fundamentals, Systems, and Applications.

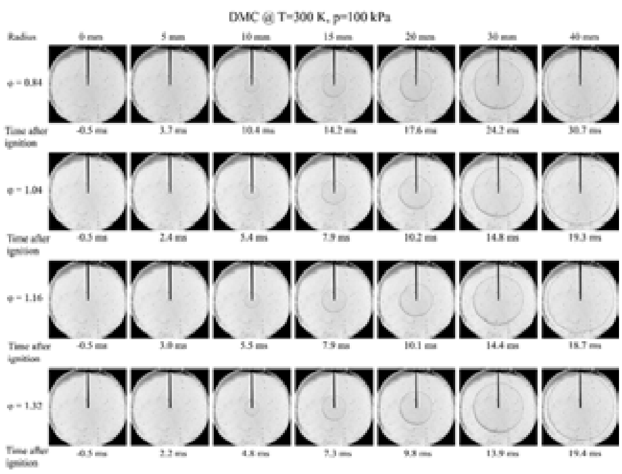
Flame front after it has passed a group of obstacles sized as 18650 Li-ion batteries. Propane is used to simulate the explosive characteristics of Li-ion battery electrolyte

Task 3.4 – Novel efficient low temperature water electrolysis processes

In 2018 an important part of the necessary N-FCH research laboratory infrastructure for testing of alkaline water electrolyzer cells and PEWE short stacks was commissioned at SINTEF in Trondheim, and the first preliminary tests were performed towards the end of the year. At IFE the detailed engineering design of a small-scale (5 Nm3/h) experimental high-pressure (200 bar) PEM water electrolyzer test system was completed and the construction of the test rig is currently under completion in a workshop at IFE Halden. This containerized PEMWE system laboratory set-up will be installed and commissioned at the N-FCH System Laboratory at IFE Hynor at Kjeller in 2019.

The work on the development of a generic water electrolyzer system model was postponed to 2019, since the work needed to be more clearly defined and scoped. It has been decided to focus the modelling on PEM water electrolyzer systems, and Nel has committed to provide operational data to validate the model. A techno-economic study on local hydrogen supply using small-scale water electrolysis was performed, presented at an international hydrogen and fuel cell conference, and a paper was submitted to the International Journal of Hydrogen Energy.

Shadowgraph images of dimethyl carbonate (DMC) experiments. Flame propagation with radii from 0, 5, 10, 15, 20, 30 and 40 mm with corresponding time after ignition in milliseconds. Initial condition for experiments at 300 Kelvin and 100 kPa absolute



Water electrolyzer cell and stack test stations commissioned at SINTEF, Trondheim

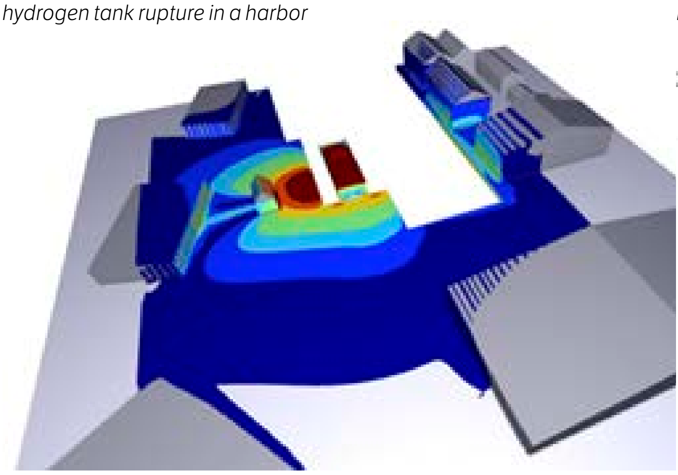
High-pressure PEM water electrolyzer test rig under construction at IFE

Task 3.5 – Design specifications for specific applications

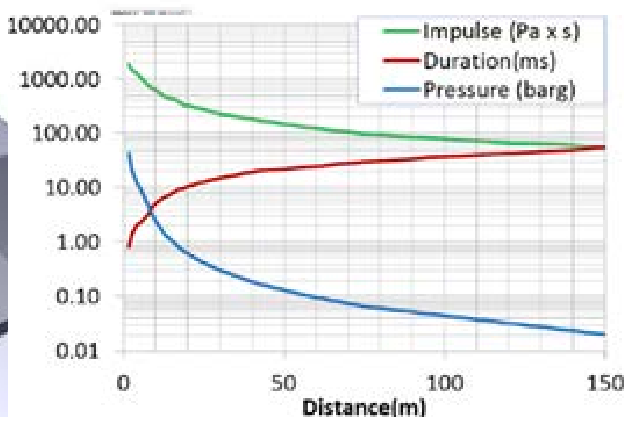
The first part of a maritime case study on a fuel cell driven high-speed passenger ferry concept was completed in 2018. The preliminary design of the hydrogen system on board the ship was completed in 2017 and a concept risk assessment was completed in 2019. The results were documented in a MoZEES-report by Lloyd's Register, presented at the H2FC2018-conference in Trondheim, and will be published in paper submitted to the International Journal of Hydrogen Energy. In the concept risk assessment there was a special focus on fatality risk related to the hydrogen systems on the vessel, both during operation and while moored in harbor overnight.

The main objective of the study was to evaluate whether the risk related to hydrogen systems is equivalent to that of conventionally fueled vessels and can be considered acceptable according to the requirements of the IGF-code (International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels). Since hydrogen behaves differently than other flammable gases, some adjustments to existing models and vulnerability criteria have been proposed. The results show that the estimated risk related to hydrogen systems is relatively low, and much lower than the expected acceptable risk tolerance level of 0.5-1.0 fatalities per billion passenger km. The risks with overnight mooring in the harbor was also found to be well within acceptable limits.

Example result from a CFD-calculation: Pressure distribution after hydrogen tank rupture in a harbor



Example result from hydrogen safety screening tool developed by Lloyd's Register: Predicted consequence of a catastrophic tank burst



RA4 Policy and Techno-Economic analysis

Research Area 4 identifies the market potential, business cases, and policy prerequisites for innovative and energy efficient transport concepts, based on electricity or hydrogen. There is a particular focus on markets that are supported by demanding national climate and transport policy goals, and applications where Norwegian industries and technology companies can assume a leading position.

MoZEES will support decision makers in different governance levels and businesses with a common framework of analysis, allowing new transportation concepts to be analyzed comprehensively under varying assumptions on technology, policies, incentives and governance measures. This comprehensive interdisciplinary approach will on one hand increase the reliability and quality of predictions on technology uptake and the need for (and dosage of) policies and incentives, and on the other hand decrease the uncertainty related to different business models. The overall result will be better planning and management of public transport infrastructures and assets and more reliable business decision support tools for the private sector.

Key questions in RA4 are how and when new technology can become competitive in the market and how public and corporate stakeholders can avoid the lock-in effects typical of current technologies and end user habits. Predicting the market for an entirely new mode of transportation is difficult, but not impossible. Analysis of international technology development road maps, policy options, incentives, and other governance measures will be required to produce national road maps for how the international and Norwegian value chains for the transport, energy and ICT sectors may undergo stepwise transformation towards 2030.

Specific case studies of new concepts and business models are made based on the needs of user partners within four prioritized transportation subsystems: (1) Urban mobility and logistics, (2) coastal line vessels and ferries, (3) long haul freight and passenger transport, and (4) transportation terminals. RA4 cooperates closely with RA3, and utilize the technology expertise in RA1 and 2 as well as the user partner expertise within RA4 to define relevant concepts and refine business models and values chains.

Illustration: TØI

In 2018 the work was focused mainly on two case studies investigating the early experiences, cost, barriers and opportunities of battery electric and hydrogen solutions for Heavy Duty Vehicles (HDVs) and buses, and passenger vessels. The work on HDVs and Buses is led by TØI, whereas the work on passenger vessels is led by SINTEF. Among the research activities carried out in 2018, were studies of additional cost of these technologies, potential for future costs, and semi-structured interviews with early adopters and other stakeholders in Norway. The interviews focused on costs, practical experiences as well as adoption barriers and drivers. The users see the potential for electrification of trucks, but the market is in a very early phase with costs, reliability and availability being the main barriers. Support from Enova has been essential to get the first pilot tests started. The market for buses is moving into full serial production with a major roll out of Battery electric buses underway in Oslo, Trondheim and Bergen. In the maritime case the use of AIS (vessel position database) enables studies of total energy use and it is possible to create speed profiles. Both of these case studies continues into 2019. The AIS speed profiles will be used in a joint RA4/RA3 case study on High Speed passenger vessels in 2019. 2018 was a year of data collection in these case studies. One report was published from this work in 2018, with three more to be published in 2019. A research article on the potential for Battery Electric Vans for use in Craftsmen and Service enterprises was also published. Four abstracts with results from the two case studies were in the fall of 2018 sent in and approved for presentation at the EVS32 conference in Lyon in May 2019.

The FME CENSES invited MoZEES to co-author a position paper on battery electric and hydrogen solutions for the transport sector which was published during the annual CENSES conference. EASAC, the European Academies Scientific Advisory Council, invited MoZEES to participate in the writing of a European level paper on transport greenhouse gas reductions. The work was done by RA4 together with MoZEES center director in 2018, but the report will be published in 2019. RA4 also aided IEA with the work on the Nordic EV Outlook which was published in early 2018.

The staff was increased during 2018. The PhD at TØI could finally start up with NTNU as the University. A temporary researched was recruited to IFE to work on Life Cycle Analysis of heavy duty vehicles and vessels. A "bonus" PhD was also supposed to be recruited to NTNU but no suitable candidate was found.

During 2019, RA4 will publish research results from both the case studies in the form of reports, conferences presentations and papers, as well as articles in scientific journals. MoZEES will thus contribute to the international research on electrification and hydrogen solutions for HDVs, buses and maritime applications.

Examples of MoZEES RA4 reports and papers produced in 2018.

Seminars and Outreach

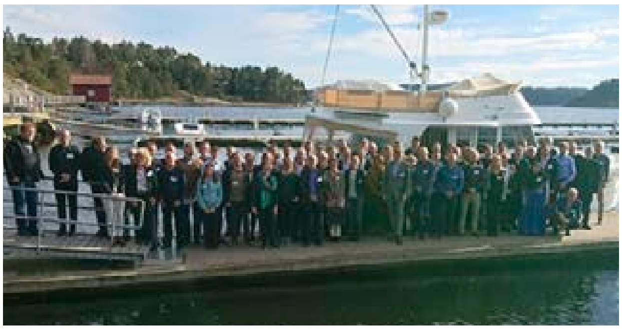
MoZEES Battery Days

Two very successful days of presentations, discussions and activities related to batteries where held at IFE on 14-15 February. Day 1 encompassed a Battery Seminar focusing on material synthesis and characterizations, lifetime, safety, and testing protocols. The seminar included presentations from a significant number of center partners such as UiO, FFI, ABB, DNV GL, ZEM Energy and Cerpotech. A Battery Lab Course focusing on both practical lab tasks and data analysis was hosted in the battery laboratory at IFE on the second day. The participants were a very mixed audience and included Master and Ph.D students, University teachers, industry partners and people who are not working directly with batteries; all having a mutual benefit of discussing the issues related to battery cell fabrication and testing.

MoZEES Annual Meeting

The Annual Meeting and General Assembly of MoZEES was held on 24 and 25 April in beautiful surroundings in Son, Norway. Almost 80 delegates participated during the two days which were filled with presentations

17 participants had the chance to learn about all steps of producing a battery during the MoZEES Battery Days 2018. At three different stations, everybody had the possibility to learn and also actively perform all necessary steps from the raw materials to a working battery.


The delegates to the Annual Meeting gathered on the pier

PhD student Ika Dewi Wijayanti received an excellent poster award during the MH2018 (Int'l Symposium on Metal-Hydrogen Systems)

and discussions on recent scientific, technological and industrial developments in the Center. The presentations took on the whole value chain of hydrogen- and battery technologies in transport applications, and the topics of the different sessions were:

1. Hydrogen and Fuel Cells for Transport
2. Policy for Zero Emission Transport
3. Battery Value Chains
4. Hydrogen and Battery Safety

The presentations covered themes such as Hydrogen-driven highspeed passenger ferries in Trøndelag, Zero emission freight trains, Proton conductivity in composites, Ageing and diagnostics of Li-ion batteries and Hydrogen safety – to mention a few!

There where also several keynote lectures which introduced the audience to the fundamentals of the different technologies. Prof. Ola Nilsen (University of Oslo), could for example give us the story of what was probably the world's first battery (composed of a clay jar, a copper and an iron tube) dated back to 200 B.C.

Conference participation

MoZEES partners participated with talks and presentations at approximately 20 international and 10 national conferences and large seminars. The most important events for MoZEES in 2018 was:

- Nordic EV Summit 2018, 1-2 Feb., Oslo
- H2fc2018 – Int'l Hydrogen and Fuel Cell Conference, 14-15 May, NTNU, Trondheim
- 48th Power Sources Conference, 11-14 Jun., Denver, Colorado


MoZEES researchers enjoying a traditional Japanese dinner during IMLB 2018 (International Meeting on Li-Batteries) in Kyoto.

- IMLB 2018 – Int'l Meeting for Lithium Batteries, 18-22 Jun., Kyoto, Japan
- SCCER 2018 – Annual Meeting SCCER Mobility Center, 11 Sep., ETH, Zürich, Switzerland
- Smartgridkonferansen 2018, 12 Sep., Trondheim
- f-cell 2018 – Int'l Fuel Cell Conference & Expo, 18-19 sep., Stuttgart, Germany
- SSPC19 – Int'l Conference on Solid State Protonic Conductors, 16-21 Sep., Stowe, Vermont
- KIFFE 2018 – Japan-Norway symposium for Researchers, 5-7 Oct., Tromsø-Trondheim
- MH2018 – Int'l Symposium on Metal-Hydrogen Systems, 28 Oct-2 Nov, Guangzhou, China
- CenSES Annual Meeting 2018, 21 November, Oslo

Appendix 1: Personnel

Postdoctoral Researchers with financial support from the Center Budget						
Institution	Name	Sex M/F	Nationality	Start date	End date	Topic
UiO	Alok Mani Tripathi	M	India	02.10.2018	31.03.2021	Advanced characterization of Li-ion batteries
UiO	Athanasios Chatzitakis	M	Greece	15.01.2018	14.07.2019	Photo electrochemistry and solid state ionics
IFE/UiO	Gaylord Kabongo Booto	M	Kongo	06.09.2018	05.09.2020	Life Cycle Analysis

PhD students with financial support from the Center Budget						
Institution	Name	Sex M/F	Nationality	Start date	End date	Topic
NTNU	Daniel Tevik Rogstad	M	Norway	01.09.2017	31.08.2020	Silicon anodes and ionic liquids
NTNU	Elise Ramleth Østli	F	Norway	21.08.2017	20.08.2020	Water-based manufaturing routes for electrodes
NTNU	Eivind Hugaas	M	Norway	01.09.2017	31.08.2020	Fatigue mechanisms of hydrogen storage tanks
NTNU	Hamid Reza Zamanizadeh	M	Iran	20.09.2018	19.09.2021	Bipolar plates for alkaline water electrolysis
USN	Mathias Henriksen	M	Norway	15.08.2017	15.08.2021	Explosion hazards of Lithium ion batteries
UiO	Halvor Høen Hval	M	Norway	01.01.2018	31.12.2021	High voltage cathode materials for Li-ion batteries
UiO	Xinwei Sun	F	China	01.09.2018	31.08.2021	Composite Proton conducting membranes

Key researchers		
Institution	Name	Main research area
NTNU	Fride Vullum-Bruer	Battery materials and components
NTNU	Ann Mari Svensson	Battery materials and components
NTNU	Frode Seland	Battery and electrolysis components and technology
NTNU	Andreas Echtermeyer	Hydrogen components, testing and modelling
NTNU	Ingrid Schjølberg	Battery and hydrogen systems for marine applications
NTNU	Asgeir Tomasgard	Policy and techno-economic analysis
UiO	Helmer Fjellvåg	Materials Chemistry; Batteries
UiO	Ola Nilsen	Materials Chemistry; Batteries
UiO	Truls Norby	Materials Chemistry; Hydrogen Technology
UiO	Katinka Elisabeth Grønli	Energy, Environment and Climate
UiO	Øystein Moen	Interdisciplinary Energy Education
USN	Dag Bjerketvedt	Hydrogen and Battery safety
USN	Joachim Lundberg	Hydrogen and Battery safety
USN	André Vagner Gaathaug	Hydrogen and Battery safety
USN	Knut Vågsæther	Hydrogen and Battery safety
FFI	Helge Weydahl	Battery safety, fuel cell systems
FFI	Martin Gilljam	Chemical characterization of lithium ion batteries
FFI	Toreif Lian	Thermal stability of lithium ion batteries
FFI	Sissel Forseth	Battery safety
FFI	Susanne Hansen Troøyen	Battery safety
SINTEF	Rune Bredesen	Functional oxides, solid state diffusion/kinetics, membranes, fuel cells and electrolysers
SINTEF	Paul Inge Dahl	Materials synthesis and processing for batteries
SINTEF	Halvor Dalaker	Batteries, Si-anodes
SINTEF	Sigrid Damman	Governance, institutional drivers and barriers
SINTEF	Marie-Laure Fontaine	Composite membranes for PEMFC
SINTEF	Halvorsen Ivar Johan	Diagnostics and control of fuel cells
SINTEF	Ole Edvard Kongstein	PEMFC Bipolar plates and PEMFC systems
SINTEF	Anders Kroksæter	Transport modelling, system development
SINTEF	Magne Lysberg	Model development of electrolyzer cell performance
SINTEF	Olav Kåre Malmin	Transport modelling, system development

SINTEF	Solveig Meland	Social scientific transport research
SINTEF	Edel Sheridan	Batteries, RA1 SINTEF PL
SINTEF	Steffen Møller-Holst	H2-technologies, feasibility studies, policy, strategy (EU)
SINTEF	Roar Norvik	Social scientific transport research
SINTEF	Vibeke Stærkebye Nørstebø	Operations research, economic analysis
SINTEF	Anders Ødegård	PEMFC Bipolar plates and PEMFC systems
SINTEF	Magnus Skinlo Thomassen	RA coordination. PEMWE/PEMFC materials and systems
SINTEF	Unn Karin Thorenfeldt	Transport model development
SINTEF	Julian Richard Tolchard	Functional oxide materials, structural characterisation
SINTEF	Werner Adrian Tobias	Operations research and mathematical programming, economics
SINTEF	Zenith Federico	Fuel cell control, techno-economic analyses
SINTEF	Barnett Alejandro Oyarce	PEMFC and PEMWE testing, BPP, membranes, catalysts and AST protocols
SINTEF	Bjerkan Kristin Ystmark	Social scientific transport research
SINTEF	Anders Brunsvik	Analytical Chemistry
SINTEF	Odd Arne Hjelkrem	Transport and energy modelling
SINTEF	Ingvild Thue Jensen	Catalyst characterization
SINTEF	Ulf Johansen	Operations research, economic analysis
SINTEF	Gerardo A Perez-Valdes	Operations research, economic analysis
SINTEF	Stein Rørvik	Microscopical analysis
SINTEF	Graham Thomas Smith	PEMFC Bipolar plates and PEMFC systems
SINTEF	Martin Fleissner Sunding	Material characterisation by microscopical and spectroscopical techniques
SINTEF	Artur Tron	Batteries Development
SINTEF	Kyrre Sundseth	Techno-economic analyses
SINTEF	Wagner Nils Peter	Li ion batterier utvikling av katoder og anoder
SINTEF	Wang Lu	Batteries, electrode manufacturering, assembly and evaluation
SINTEF	Tor Olav Sunde	Catalyst development
SINTEF	Graff Joachim Seland	Sample characterisation by SEM and EDS
SINTEF	Kvello Jannicke Hatlø	Electrode manufacturing and assembly
SINTEF	Stig Yngve Martinsen	Fuel cell and electrolyzer testing
IFE	Jan Petter Mæhlen	Anode materials development for Li-ion batteries and Data science
IFE	Volodymyr Yartys	Ni-metal hydride batteries. Synchrotron and neutron characterization
IFE	Preben Joakim Svela Vie	Battery lifetime and characterization
IFE	Øystein Ulleberg	Hydrogen systems - fuel cells and electrolyzers
IFE	Fredrik Aarskog	Hydrogen systems - fuel cells
IFE	Ragnhild Hancke	Hydrogen systems - electrolyzers
IFE	Alexey Koposov	Electrochemical characterization and organic chemistry
IFE	Asbjørn Ulvestad	Anode material development, electron microscopy
IFE	Carl Erik Lie Foss	Electrochemical characterization, Graphite electrodes
IFE	Samson Lai	Materials development, Synchrotron and neutron characterization
IFE	Hanne Flåten Andersen	Anode materials development for Li-ion batteries
IFE	Marius Uv Nagell	Battery Laboratory responsible
IFE	Morten Tjelta	Corrosion in alkaline media
IFE	Jon Kvarekvål	Corrosion in alkaline media
IFE	Kari Aa Espegren	Energy system modelling
IFE	Stefano Deledda	Neutron radiography
IFE	Pernille M. S. Seljom	Energy system modelling
IFE	Ida Hugem Lereng	Energy system modelling
TØI	Erik Figenbaum	Electric vehicles, environmental characteristics of vehicles, technology diffusion
TØI	Guri Natalie Jordbakke	Environment, Energy, Technology
TØI	Astrid Helene Amundsen	Environment, Energy, Technology
TØI	Ingrid Sundvor	Environment, Energy, Technology
TØI	Daniel Ruben Pinchasik	Environment, Energy, Technology
TØI	Inger Beate Hovi	Vehicle and demand modelling, SCGE-modelling, cost functions, economic incentives, user needs and obstacles
TØI	Rebecca Thorne	Environment, Energy, Technology
TØI	Lasse Fridstrøm	Vehicle fleet forecasting, vehicle and demand modelling, economic incentives

PhD students working on projects in the Center with financial support from other sources					
Institution	Name	Nationality	Period	Sex M/F	Topic
UiO	Rasmus Vester Thøgersen	Norway	2018-2022	M	High-end catamaterials
UiO	Frida Hempel	Norway	2018-2021	F	Solid electrolytes
UiO	Xinyu Li	China	2018-2019	F	Solid electrolytes
NTNU/ TØI	Vegard Østli	Norway	2018-2022	M	Vehicle and demand modelling
NTNU/ IFE	Ika Dewi Wijayanti	Indonesia	2017-2019	F	Ni-metal hydride batteries

Postdoctoral Researchers working on projects in the Center with financial support from other sources					
Institution	Name	Nationality	Period	Sex M/F	Topic
NTNU	Sepideh Jafarzadeh	Iran	2016-2018	F	System design guidelines for H2 FC ships
UiO	Julia Wind	Austria	2018-2020	F	Solid electrolytes

Master degrees			
Institution	Name	Sex M/F	Topic
NTNU	Steinar Åsmund Fagervold	M	NMC katodematerialer
NTNU	Silje Nordnes Bryntesen	F	NMC katodematerialer
NTNU	Philip Keck	M	Solid state electrolytes
NTNU	Live Mølmen	F	Metallhydrid batterier
USN	Christian Eide Stueland	M	Change in flame front area over time with premixed combustion across an obstacle
USN	Henrik Hovrud	M	Simulating gas dispersion and explosion with OpenFOAM

Appendix 2: Statement of Accounts

Funding	Amount
The Research Council	15 406
The Host Institution (IFE)	1 875
Research Partners	7 098
Industry partners	4 892
Public partners	2 673
Total funding	**31 944**

Costs	Amount
The Host Institution (IFE)	6 779
Research Partners	20 190
Industry partners	4 013
Public partners	873
Equipment	89
Total costs	**31 944**

(All figures are given in kNOK)

Appendix 3: Publications

THE ACTIVITIES IN THE CENTER HAVE RESULTED IN THE FOLLOWING PUBLICATIONS IN 2018

Publications in refereed journals

1 Figenbaum, E., Can battery electric light commercial vehicles work for craftsmen and service enterprises? Energy Policy, 2018. 120: p. 58-72.
2 Henriksen, M., A.V. Gaathaug, and J. Lundberg, Determination of underexpanded hydrogen jet flame length with a complex nozzle geometry. International journal of hydrogen energy, 2018: p. 1-9.
3 Jafarzadeh, S. and I. Schjølberg, Operational profiles of ships in Norwegian waters: An activity-based approach to assess the benefits of hybrid and electric propulsion. Transportation Research Part D: Transport and Environment, 2018. 65: p. 500-523.
4 Sun, X., K. Xu, C. Fleischer, X. Liu, M. Grandcolas, R. Strandbakke, T.S. Bjørheim, T.E. Norby, and A.E. Chatzitakis, Earth-Abundant Electrocatalysts in Proton Exchange Membrane Electrolyzers. Catalysts, 2018. 8(12): p. 41.
5 Ulvestad, A., H.F. Andersen, I.J.T. Jensen, T. Mongstad, J.P. Mæhlen, Ø. Prytz, and M. Kirkengen, Substoichiometric Silicon Nitride – An Anode Material for Li-ion Batteries Promising High Stability and High Capacity. Scientific Reports, 2018. 8: p. 13.
6 Vatani, M., P.J.S. Vie, and Ø. Ulleberg, Cycling Lifetime Prediction Model for Lithium-ion Batteries Based on Artificial Neural Networks. IEEE PES Innovative Smart Grid Technologies Conference Europe, 2018: p. 6.
7 Vågsæther, K., A.V. Gaathaug, and D. Bjerketvedt, PIV-measurements of reactant flow in hydrogen-air explosions. International journal of hydrogen energy, 2018: p. 8.

Published reports

1 Fridstrøm, Lasse; Tomasgard, Asgeir; Eskeland, Gunnar; Espegren, Kari Aamodt; Rosenberg, Eva; Helgesen, Per Ivar; Lind, Arne; Ryghaug, Marianne; Berg, Heidi Bull; Walnum, Hans Jakob; Ellingsen, Linda Ager-Wick; Graabak, Ingeborg. Decarbonization of transport; A position paper prepared by FME MOZEES and FME CenSES: FME CenSES og MoZEES 2018 (ISBN 978-82-93198-25-3) 51 s. IFE NHH NTNU SINTEF TØI UiO VF
2 Fridstrøm, Lasse; Tomasgard, Asgeir; Eskeland, Gunnar; Espegren, Kari Aamodt; Rosenberg, Eva; Helgesen, Per Ivar; Lind, Arne; Ryghaug, Marianne; Berg, Heidi Bull; Walnum, Hans Jakob; Ellingsen, Linda Ager-Wick; Graabak, Ingeborg. Decarbonization of transport; Short version of a position paper prepared by FME MoZEES and FME CenSES. : FME CenSES og MoZEES 2018 31 s. IFE NHH NTNU SINTEF TØI UiO VF
3 Jordbakke, G.N., A.H. Amundsen, I. Sundvor, E. Figenbaum, and I.B. Hovi, Technological maturity level and market introduction timeline of zero-emission heavy-duty vehicles. 2018, Transportøkonomisk institutt. p. 64.

Monographs

1 Eide Stueland, C., A.V. Gaathaug, and K. Vågsæther, Change in flame front area over time with premixed combustion across an obstacle. 2018, Universitetet i Sørøst-Norge. p. 54.
2 Hovrud, H., A.V. Gaathaug, and K. Vågsæther, Simulating gas dispersion and explosion with OpenFOAM. 2018, Universitetet i Sørøst-Norge. p. 68.
3 Gilljam, M., H. Weydahl, P.J.S. Vie, S. Forseth, and T. Lian, Effect of Electrical Energy and Aging on Cell Safety, in Electrochemical Power Sources: Fundamentals, Systems, and Applications - Li-Battery Safety. 2018, Elsevier. p. 670.

MoZEES
Mobility Zero Emission Energy Systems

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