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The Research Council of Norway

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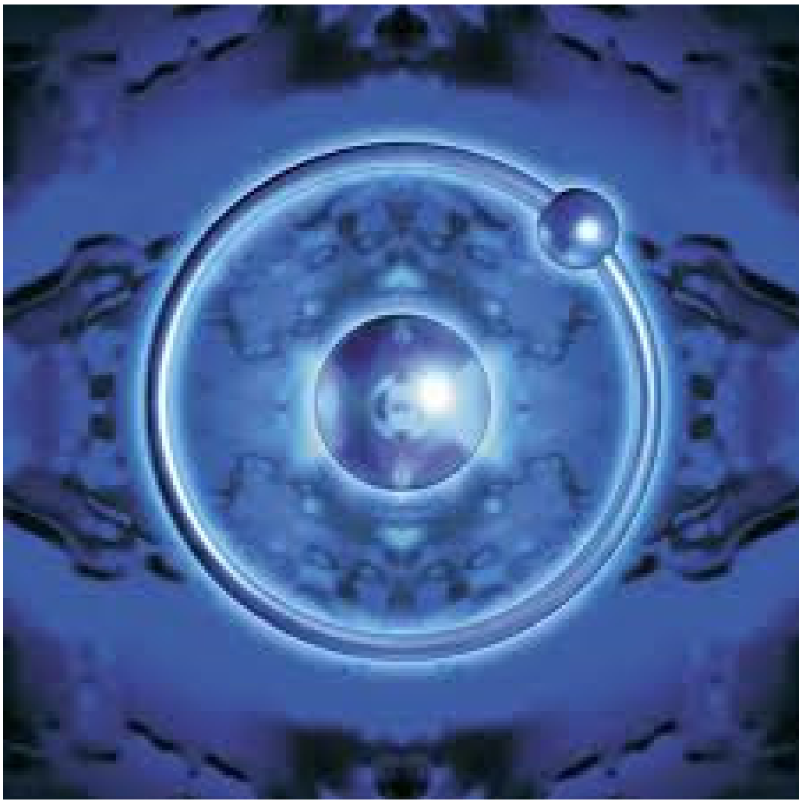
Final report from HyPilot

Survey and recommendations on research infrastructure needs for hydrogen technologies

Authors
Anita Fossdal
Rune Lødeng
Paul Inge Dahl
Steffen Møller-Holst



SINTEF Materials and Chemistry
On behalf of the HyPilot project
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SINTEF Materialer og kjemi
SINTEF Materials and Chemistry

Address:
Postboks 4760 Sluppen
NO-7465 Trondheim
NORWAY

Telephone:+47 73593000
Telefax:+47 22067350

info.mk@sintef.no
www.sintef.no/mk
Enterprise /VAT No:
NO 948007029 MVA

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ABSTRACT

The goal of the HyPilot project was to investigate the need for new research infrastructure (RI) and evaluate concepts for access to and organization of national pilot test infrastructures for hydrogen technologies based on a thorough gap analysis. The initiators of this project were the two largest R&D institutions in the field, NTNU and SINTEF, but all major national stakeholders, both from academia and industry have been involved and have provided input.

The findings of the work, given in this report, point to a clear need among the stakeholders for access to hydrogen research infrastructure and pilot test facilities, both in terms of increased access to existing infrastructure and for new facilities . Due to limitations in the national demand for testing services and the available funding schemes a national hydrogen test center may not be realizable. However it is foreseen that regional, specialized test centers can be established as a part of a virtual infrastructure network, preferably linked to the major R&D institutions. A national research infrastructure network is a feasible outcome, for better utilization of existing infrastructures and promotion of new collaborations. Due to the limited volume of hydrogen activities in Norway, cooperation across the borders, i.e. towards the Nordic/EU countries is essential and should be promoted and supported by the Research Council of Norway.

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1 Introduction

HyPilot is a pre-project funded by the Research Council of Norway. The goal is to identify needs for Research Infrastructure (RI) / test facilities in the field of hydrogen technology and to prepare the ground for better national utilization of this infrastructure based on a thorough gap analysis. The project aims at supporting R&D activities related to hydrogen technologies and to facilitate their application in a sustainable energy and transportation fuel market. The need for hydrogen technology RI is pinpointed in several strategic documents, from the National Hydrogen Council as well as reflected in the involved R&D partners' strategic priorities. Following up on this, an evaluation of the interest in establishment of a national hydrogen technology pilot test research infrastructure, and the nature of such a hypothetical centre is performed within *HyPilot*.

The initiative for the *HyPilot* project was taken by the two largest R&D institutions in the field, NTNU and SINTEF, but the ultimate goal has been to engage and involve all major national stakeholders, both from academia and industry – especially addressing small and medium-sized enterprises (SMEs).

SINTEF conducted a first survey (Survey A), in *HyPilot*, in order to identify current and future needs for research infrastructure for hydrogen and fuel cell technologies. National stakeholders (companies and research institutes) involved in hydrogen technology development were invited to participate, in addition to selected international companies. A total of 42 potential respondents were contacted, of which 10 considered the survey not relevant for their company (mainly due to little or no current activity related to hydrogen). A total of 26 stakeholders (22 industry partners and 4 research institutes) from the 32 relevant partners submitted answers, giving a response rate of 81%, which is considered acceptable. The information supplied in the questionnaires was depersonalized as far as possible without changing the intention of the answer, so that no answer could be traced back to an individual respondent.

In parallel with the survey involving the commercial stakeholders on their experienced needs, another survey (Survey B) was conducted among the educational institutions and research institutes. Survey B has focused on existing research infrastructures as well existing competence and on-going activities in the field of hydrogen technologies. Seven institutions, spread over 20 subdivisions (i.e. institutes, faculties) have given input to Survey B, giving a representative picture of the national hydrogen activities.

While the results of Survey A constitute the main part of the present report, the results of Survey B are presented as an Appendix (B) to the report, giving an overview of the different infrastructures, competences and activities among the involved R&D providers. The dedication to hydrogen technology research in Norway, demonstrated by extensive participation to these two surveys, was confirmed by 26 participants from 15 different institutions attending a national workshop arranged as an integral part of the HyPilot-project in Oslo, 8.12.2011 in order to discuss possibilities for future cooperation on hydrogen research activities and in particular research infrastructure. Following the work of the *HyPilot* project, strategic possibilities for how to proceed are now being considered. Norway has a limited number of active stakeholders and constitutes a rather small market related to pilot-testing needs. Hence, a Nordic collaboration may be a more viable option to pursue as a basis for developing new research infrastructure as well as improved utilization of existing infrastructure.

2 Recommendations to the Research Council of Norway

Based on the thorough assessment carried out in this *HyPilot*-project, it is recommended that the Research Council of Norway (RCN) supports actions to stimulate better coordination of research activities, easier access for external stakeholders to existing Research Infrastructure (RI), establishment of regional specialized test centers linked to major R&D institutions, and actions promoting increased visibility for high utilization of investments. Key issues and comments are as follows:

1) There is a need for better coordination of existing research infrastructures and demonstration test units (both in academia and industry) related to hydrogen technologies. As an example, utilization of opportunities for testing new technologies at the Energy Park in Lillestrøm can be highlighted. Additionally, there is a need for upgrades of existing facilities and investments in new research infrastructure, especially linked to the major R&D-institutions. A national project for realization of research infrastructure is recommended, preferably covering both implementation of new infrastructure for demonstration of new technologies as well as coordination of existing facilities in a virtual test center (network), as a viable alternative to a localized center. The overviews from the *HyPilot* project represent a good starting point for establishment of such project.

2) There is a need for increased RI capacity and potentially a dedicated test center for large fuel cell systems, in the range of 40-120 kW, directed towards the transportation sector. In general for this and all future test centers it is important that they are seen in connection with already existing facilities internationally in order to avoid duplication where this is not desired.

3) There is a need for better coordination of research activities related to hydrogen technologies on a superior level. A unique national networking project should be established in order to create a meeting arena aiming to reduce the existing fragmentation and facilitate new collaborations. An annual or semiannual meeting on RI-issues is suggested for this purpose, preferably combined with the national Hydrogen seminars initially organized annually from 2001 for PhD students in the field of hydrogen technologies. In 2003, 2006 and 2011 these have been extended to Nordic seminars.

4) Active participation in international R&D activities is crucial for Norwegian stakeholders to ensure high quality research. There is, however, a need for a permanent national instrument for co-funding of projects under the FCH JU program and other programs where the funding level from the European Commission is low. It is highly recommended that RCN should further pursue and strengthen their work towards the financing Ministries to ensure implementation of such an instrument to provide top-financing to the accepted EU-projects.

5) It is important for the hydrogen community in Norway to join forces, stand together and be even more visible outwards, towards the public and the international research arenas. RCN financial support for the above recommended projects and initiatives could help facilitate this.

6) Hydrogen and fuel cell technologies are pinpointed as key enabling technologies for realizing the European Strategic Energy Technology (SET) Plan. Substantial support from industry as well as national governments is seen in Europe. Although Norwegian industry engagement in this field is limited, the potential for national value creation in Norway is high, because the market for R&D services as well as products is international. Strong support from RCN for enabling hydrogen technologies and materials research will help secure continuity in the internationally acknowledged Norwegian R&D portfolio in this field.

3 Survey on H_2 infrastructure needs

3.1 Questionnaire

In order to investigate the perceived need for additional hydrogen technology research infrastructure, a questionnaire was developed (see Appendix A). The questionnaire consisted of five parts, briefly summarized in the following:

Question 1: Defining the respondent's overall field of business
- Identification of which areas of hydrogen technology the respondent is involved in, as well as the use of selected hydrogen sources

Question 2: Identification of research infrastructure needs on three levels
- Pilot testing and technology demonstration purposes
- Applied research infrastructure
- Basic research infrastructure

Question 3: Identification of competence and funding needs, as well as the attractiveness of hydrogen-relevant funding sources both currently and within a 5-10 year time frame.

Question 4: Mapping the respondent's preferences for a hydrogen technology test center, including
- Current use of external research resources
- In-house availability of infrastructure that could be included in a virtual test center network
- Experienced need for hydrogen technology test center
- Options for meeting future infrastructure needs
- Important factors for the respondent to use the services of a hydrogen technology test center
- Specific test methods, test conditions, etc. that the respondent would like to see included in a hydrogen technology test center
- Preferences regarding organization of a hydrogen technology test center

Question 5: Opinions on trends in the field of hydrogen technology

Attached to the questionnaire were two appendices:

I: A list of the recipients of the questionnaire

II: Definitions (explaining some key words/phrases in the questionnaire)

3.2 Analysis of answers to questionnaire

Note that answers given in per cent in the text have been rounded to the nearest integer. This is done as a result of the relatively low number of respondents, and the fact that reporting results with several decimals would give an impression of a too high accuracy level. As an example, each respondent constitutes 3.85 %, which is thus rounded to 4 %. As a result of this the sum of percentages listed in the text may vary in the range 99-101 % for questions where only one answer is allowed. For several questions more than one answer is possible, hence the answers do not sum to 100 %.

The answers have not been weighted, meaning that answers from small and large stakeholders have equal impact. For some of the respondents the answers given are specific to one division of a corporation and therefore do not necessarily represent the views of the whole corporation.

3.2.1 Question 1: Your Company's overall field of business

3.2.1.1 Use of hydrogen sources

"Please rank according to importance the Hydrogen sources your company uses". The alternatives were:

- Renewable energy / H_2O splitting
- Natural gas
- Diesel
- Ethanol
- Biomass
- Other (please specify)
- N/A (not applicable)

Each alternative could be given a score from 1 to 6, or left blank. The intension was that a score of 1 would be most important, with decreasing importance for higher scores. However – this was not stated explicitly in the question. Several respondents did not use the full scale, but rather only the extreme values of the scale (i.e. 1 or 6), leading to uncertainty on whether all respondents understood the ranking system in the same manner. It was therefore decided to abandon the ranking system in the analysis of the answers, i.e. summing only whether or not the respondent used or did not use the Hydrogen source in question. The result is shown in Figure 3.1.

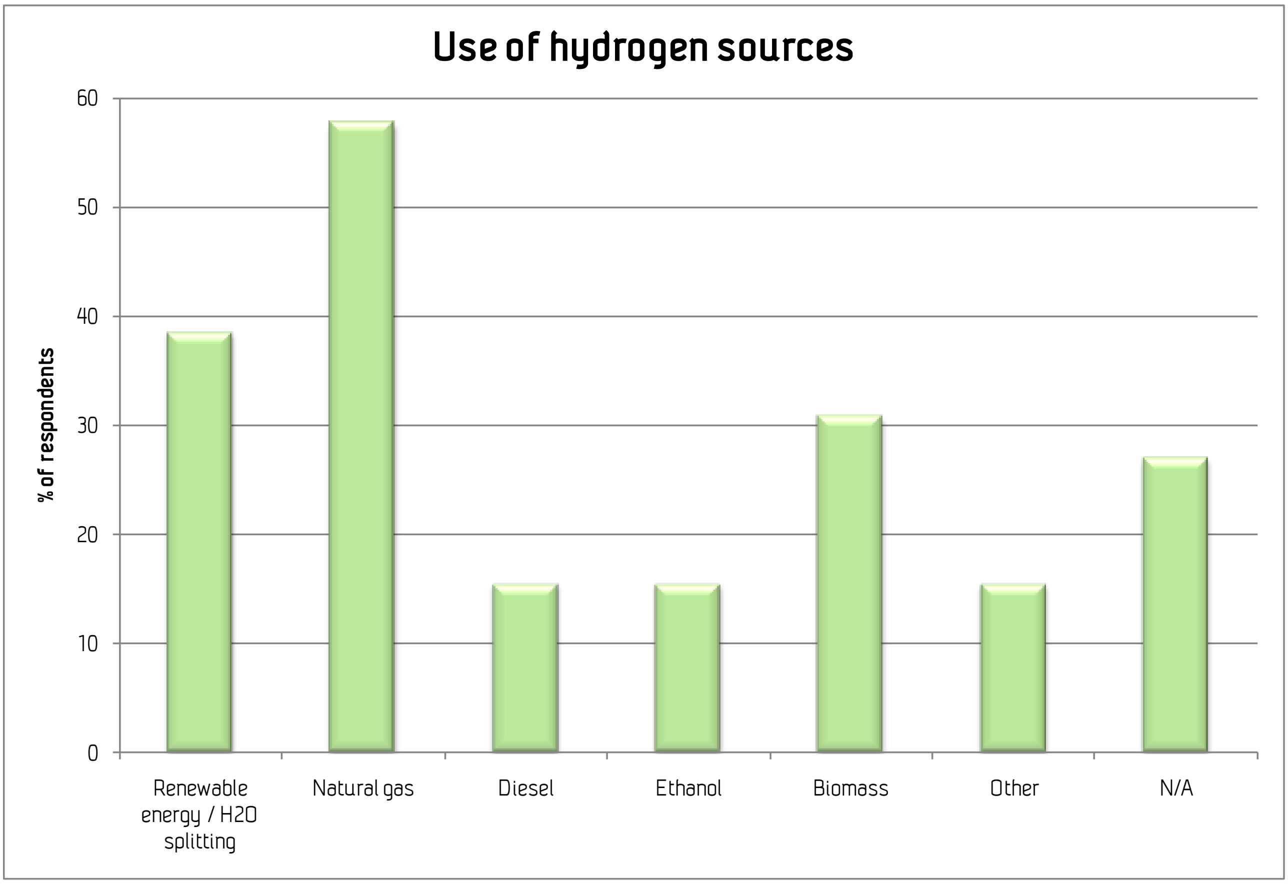


Figure 3.1. Use of specific Hydrogen sources among the respondents. Other: commercial compressed gas, LPG (liquefied petroleum gas) or biogas from waste.

The majority of the respondents (58 %) use natural gas as a Hydrogen source. The second most used is Renewable energy / H_2O splitting (39 %), followed by Biomass (4 %). Diesel, Ethanol and Other (commercial compressed gas, LPG or Biogas from waste) was used by 15 %, whereas 27 % of the respondents did not use hydrogen.

3.2.1.2 Areas of hydrogen technology

"Please indicate all areas of hydrogen technology in which your company is involved". The question comprised of four main areas:

- *Hydrogen production (incl. Purification)*
- *Hydrogen storage and distribution*
- *Hydrogen end-use / systems*
- *Cross-cutting issues*

Several sub-areas were listed under each main category (see also Appendix A). The results are shown in Figure 3.2-Figure 3.5.

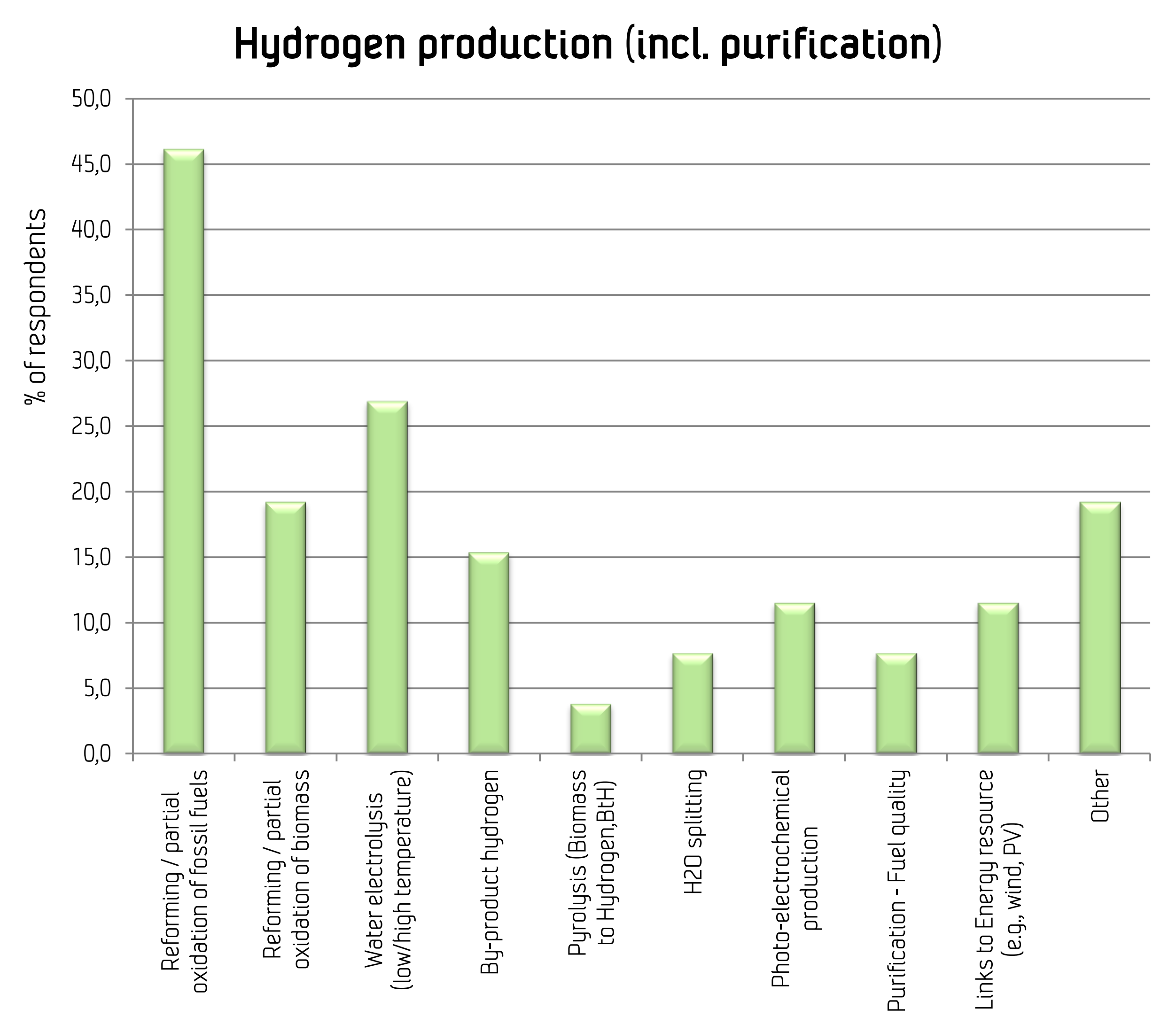


Figure 3.2. Involvement in Hydrogen production (incl. Purification).

A total of 46 % of the respondents reported being involved in *reforming/partial oxidation of fossil fuels*, whereas 27 % had activity in *water electrolysis (low or high temperature)*. The third largest of the specific categories was *reforming/partial oxidation of biomass* (19 %), followed by *by-product hydrogen* (15 %). Following this was *photo-electrochemical production* and *links to energy resource (e.g. wind, PV)* with 12 % each. *H_2O splitting* and *Purification – fuel quality* was checked by 8 %, whereas 4 % (one respondent) reported being involved in *pyrolysis*. The *Other* category (19 %) comprised of

- Service provider on risk management
- In general everything that creates a demand for storing or transporting H_2
- Focus on H_2 produced with minimal CO_2-emissions
- Reforming of biogas
- (one unspecified)

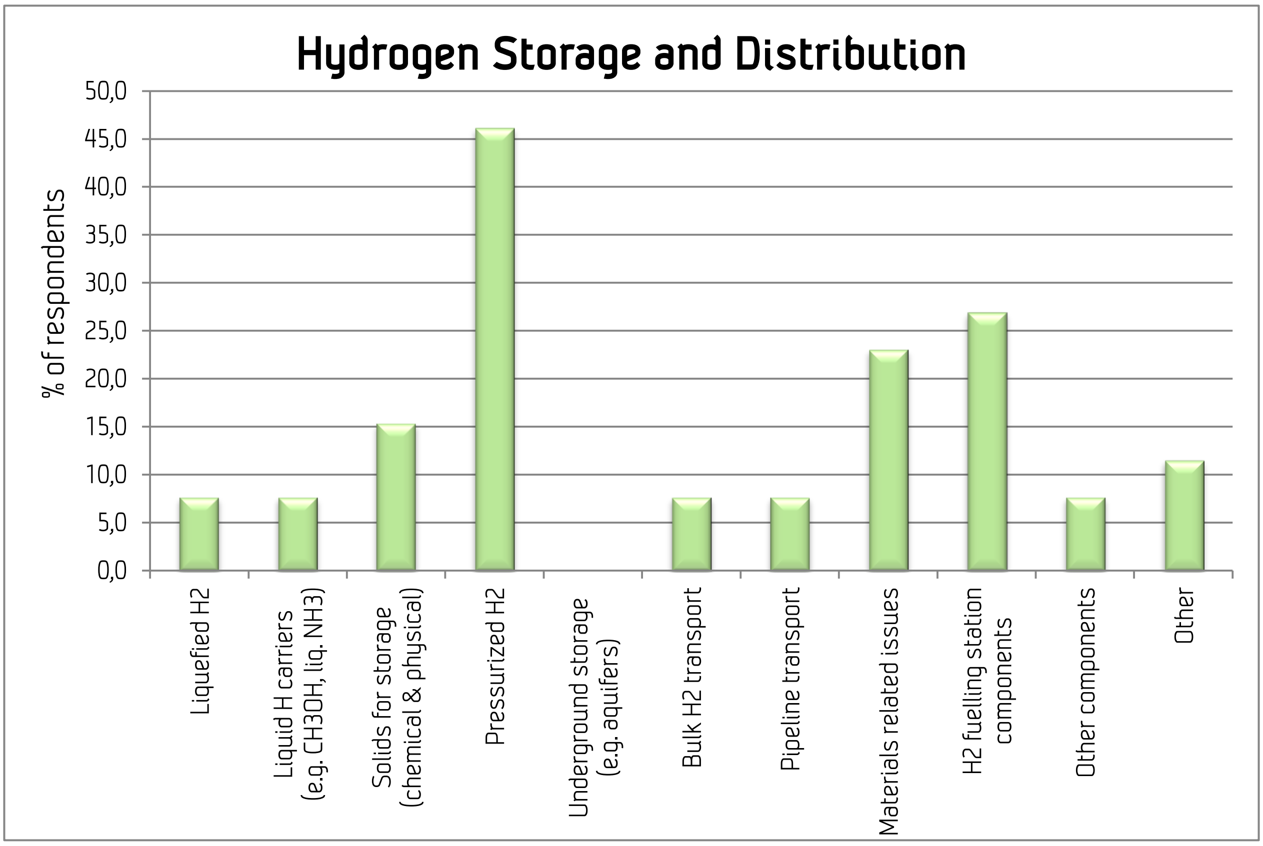


Figure 3.3. Involvement in Hydrogen storage and distribution

46 % of the respondents reported activities related to *pressurized H_2*, whereas the second largest category in the field of Hydrogen storage and distribution was *H_2 Fuelling station components* (27 %). The third largest was *Materials related issues* (23 %) , followed by *Solids for storage (chemical and physical)* with 15 %, *Bulk H_2 transport*, *Liquefied H_2*, *Liquid H_2 carriers*, *Pipeline transport* and *Other components* (all 8 %). The *Other* category (12 %) consisted of:

- a concept to replace storage using existing natural gas distribution
- service provider on risk management
- safety studies (R&D and consulting)

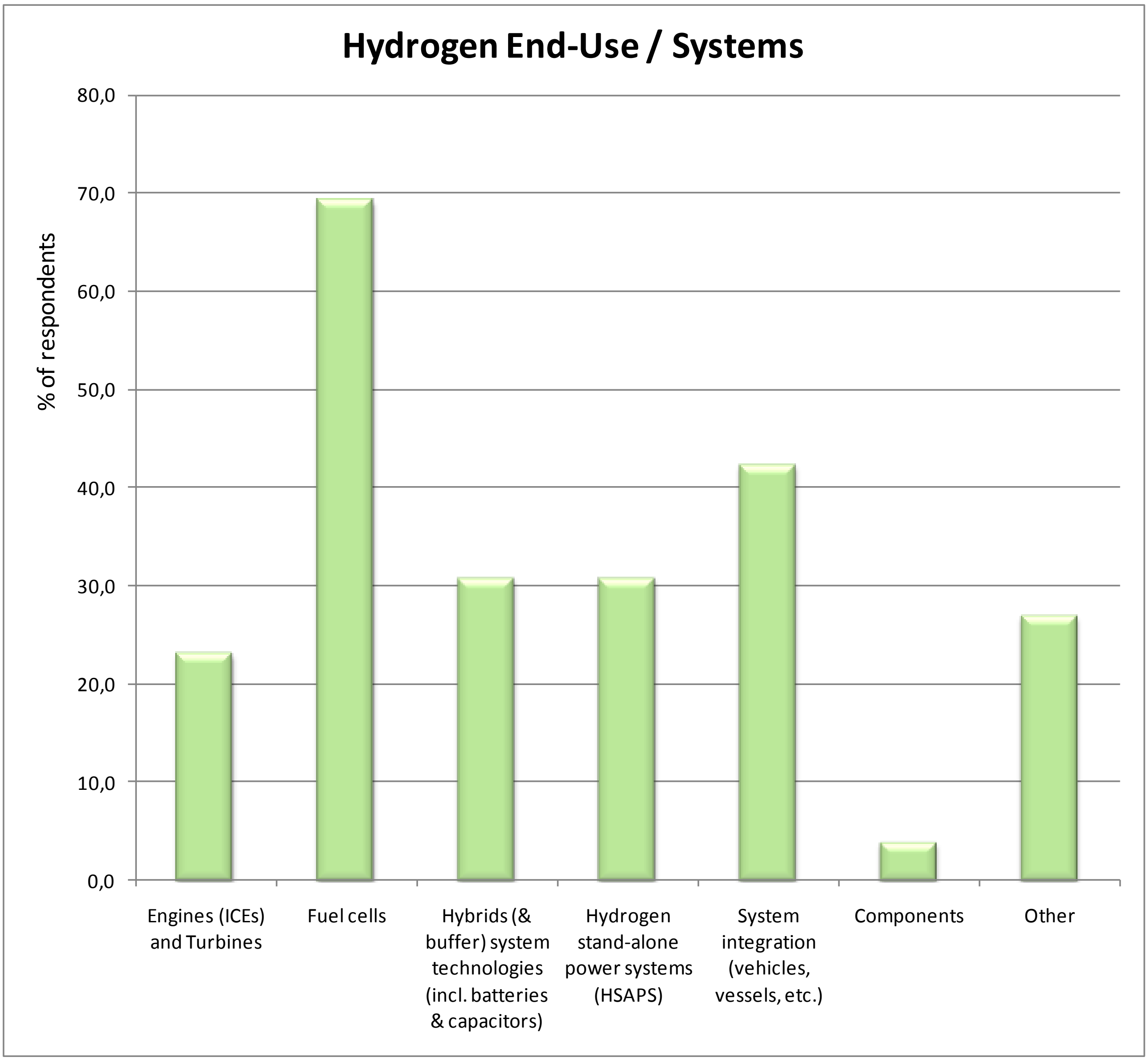


Figure 3.4. Involvement in Hydrogen end-use and/or systems.

66 % of the respondents reported being involved in *Fuel cell* activities, whereas 42 % have activity in *System integration*. The third largest category is *Hydrogen stand-alone power systems* and *Hybrids (& buffer) systems* (31 %) and *Engines and turbines* (23 %). 4 % (1 respondent) report working with *Components*, whereas 27 % have activity in *Other* areas. The respondent's specifications of *Other* include:

- Hybrid systems for electricity and H_2 production
- On-demand H_2 production for filling stations and power systems with CCU (carbon capture and utilization)
- Petrochemical
- Service provider on risk management
- Gas mixers
- Safety studies (R&D and consulting)
- Testing FC-systems for Forklifts

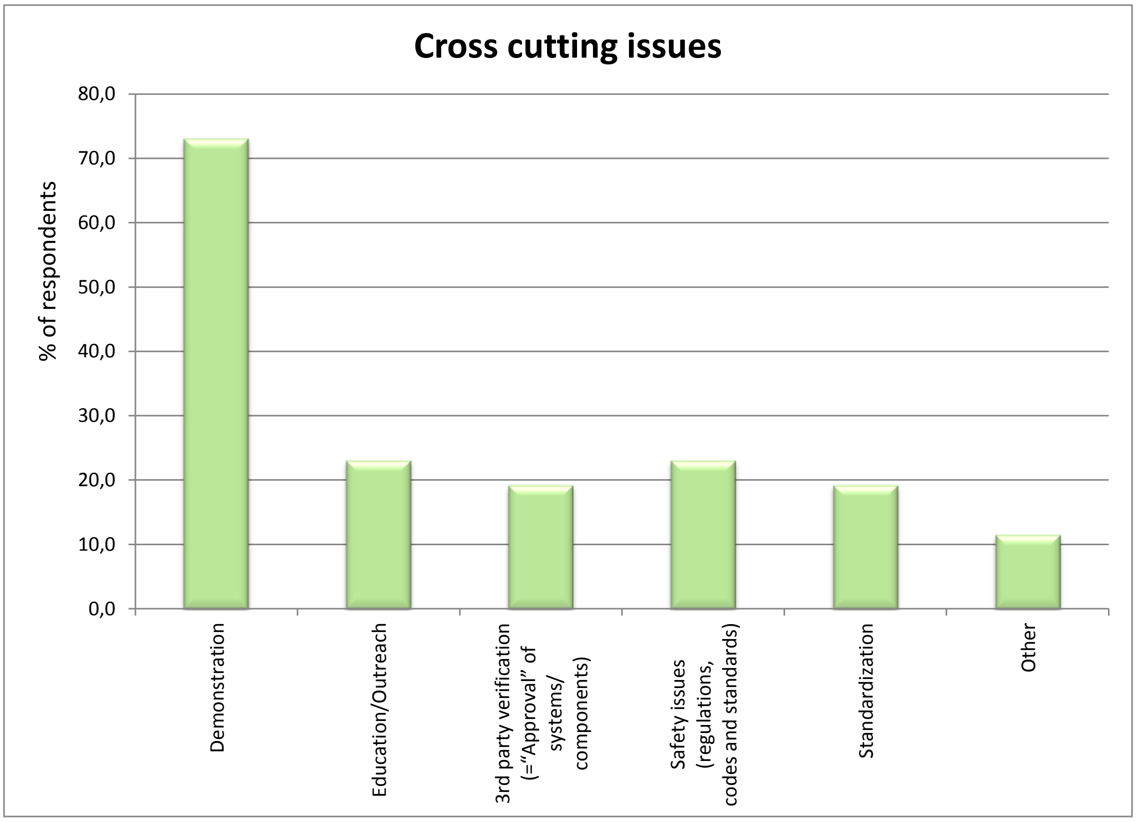


Figure 3.5. Involvement in Cross cutting issues

For Cross cutting issues, *Demonstration* is by far the largest sub-group, with a total of 73 %. Second is *Safety issues* and *Education/Outreach* (both 23 %), followed by *3rd party verification* and *Standardization* (both 19 %). In the *Other* category (12 %) we find:

- Long product validation cycle
- Service provider and offer assistance/services on hydrogen safety and regulations, codes and standards (RCS) matters
- Fuel Quality issues, related to Fuel Cells' tolerance to impurities

3.2.2 Question 2: Identification of research infrastructure needs

"Does your company experience a gap between its needs and the available research infrastructure? If so – what is the nature of this gap? Could external institutions bridge this gap?

Field 1: Infrastructure for pilot testing and technology demonstration purposes
Field 2: Applied research infrastructure (for proof of concept, etc.)
Field 3: Basic research infrastructure (materials synthesis and characterization, etc.)"

3.2.2.1 Infrastructure for pilot testing and technology demonstration purposes

46 % of respondents report experiencing a gap when it comes to infrastructure for pilot testing and demonstration purposes. In Table 3-1, the comments describing the perceived gap are listed along with the respondents' corresponding suggestions for bridging the gap.

Table 3-1. Perceived gap regarding pilot testing and demonstration infrastructure.

Perceived gap (pilot testing and demonstration infrastructure)	**Suggestions for bridging the gap**
Need equipment for testing quality and use of by-product hydrogen and possibly purifying the hydrogen	Relevant equipment available for loan- with competent personnel to aid with setup
Availability of non-specialized / commercial H_2 dispense / fuelling equipment	Investment by fuel providers / OLMs
Need for infrastructure to demonstrate technology	We are bridging the gap by establishing our production plant. This will also give other companies the possibility to demonstrate their technology in our plant.
In Norway, we are lacking a Hydrogen program and National laboratories that could provide infrastructure for pilot testing of new hydrogen technology in general.	A Hydrogen program and at least two National laboratories (e.g., at Kjeller and in Trondheim) that could provide pilot testing infrastructure to SMBs at (non-/) low-cost.
Access to physical infrastructure (indoor or outdoor space) for placement of pilot installations with proximity to Blindern/Forskningsparken/ UiO/SINTEF	Prioritize space for pilot testing and demonstrations when developing Statsbygg "Gaustad Gård" with new chemistry buildings for UiO
Equipment for pilot production of ceramic components for SOFC, with a capacity of > 20 000 pieces a year	Financial support for establishing a line for pilot production of components.
Public money for large scale demo deployment	Money
How could H Based Energy Technologies (HBET) complement existing power sources for the actual needs of diverse telecom networks?	Some sort of feasibility analysis with detailed input vectors from both worlds: - HBET properties - Telecom networks requirements
So far, we have had to finance the pilot testing and technology demonstration with help from NFR. In this phase, when it is impossible to profit from hydrogen production from biogas, this burden is too heavy for small companies.	A national test center with national funding - so private companies can buy - and not develop - hydrogen solutions.
Missing flexible large scale test facilities and demonstration vessels	Local infrastructure for large system level testing

Perceived gap (pilot testing and demonstration infrastructure)	Suggestions for bridging the gap
As H_2-technologies mature the pilot testing needs increase. Especially Fuel Cell System Testing in the 10-50kW range is currently not available in Norway. Also - there is a need to combine technologies (build systems) that otherwise often are tested out independently at ideal conditions (for example reformers and fuel cells). Cross-disciplinary development would improve progress in interrelated dependent fields	A joint effort where various partners can utilize common equipment at a lower cost than if they would have to invest in the testing equipment alone. Laboratory facilities/space available for common use. A test center would be required (best solution) if this type of activity is beyond a certain size

The comments above display a wide range of needs in the field of pilot testing and demonstration infrastructure. Some respondents require *funding* for own development, while others have a higher need for *access to relevant infrastructure* (local or national) for implementation of their technology. It would appear that generic infrastructure (i.e. setups that can be utilized for a wide range of devices in various size regimes, and even portable equipment) would be of highest interest.

One respondent is currently a production plant and open for allowing other actors to demonstrate their own technology in this plant. This plant might therefore contribute to bridging the gap for portable applications, but for applications on a larger scale a local solution is needed.

3.2.2.2 Applied research infrastructure

35 % of respondents report experiencing a gap when it comes to applied research infrastructure. In Table 3-2, the comments describing the perceived gap are listed along with the respondents' corresponding suggestions for bridging the gap.

Table 3-2. Perceived gap regarding applied research infrastructure.

Perceived gap (applied research infrastructure)	Suggestions for bridging the gap
Need equipment for testing quality and use of by-product hydrogen and possibly purifying the hydrogen	Relevant equipment available for loan- with competent personnel to aid with setup
Except for the HyNor-project, there is no applied hydrogen infrastructure in the country. Furthermore, within the HyNor-project, only HyNor Lillestrøm is related to research.	Again, a Hydrogen program is required and earmarked transfers from the national energy (especially oil and gas) incomes in order to build up new energy industry and infrastructure paving the way for Norway to remain an energy nation also in the future.
Research into hydrogen compression and refueling of vehicles	Extensive laboratory equipment in new novel compression technologies and principles
Available financing	Bigger RCN budgets for new grants, or, establishment of an ARPA-E type of organization in Norway

Perceived gap (applied research infrastructure)	Suggestions for bridging the gap
There are several test centers for natural gas and hydrogen technology available. The possible use of these is mainly an economical issue and a practical issue.	
There is a lack of high pressure test capacity on the globe for our core business products (medium to large high pressure cylinders)	Investments. We are looking for partners that are will to co-finance sufficient capacity under our control. If no agreement within short, we will (must) start build up our own test facility in Nebraska. Initial investment calculated to MUSD 3 (2011/2012) with another 2MUSD in 2013
So far, we have had to finance the pilot testing and technology demonstration with help from NFR. In this phase, when it is impossible to profit from hydrogen production from biogas, this burden is too heavy for small companies.	A national test center with national funding - so private companies can buy - and not develop - hydrogen solutions.
Low level of research and testing within compact storage technologies	National research within compact on-board storage technologies
Not as evident as the Perceived gap in Infrastructure for pilot testing (above) but still there are some fundamental activities which eventually lead to the point where Proof of Concept is adequate. Applied research infrastructure facilities are not always available.	

The common denominator for the responses concerning applied research infrastructure is the lack of available funding. Several companies working in this area are small, and investment costs for such infrastructure are too high for one company to carry alone. Suggestions for bridging the gap include a dedicated Hydrogen Program with the Research Council of Norway, as well as the establishment of a nationally funded test center. One respondent feels that test facilities are already available[1], and that the potential use of these facilities depends on economy and practicality. Another respondent is in search of investment partners for co-financing of infrastructure in their control.

[1] *Abroad? Authors note.*

3.2.2.3 Basic research infrastructure

27 % of respondents report experiencing a gap when it comes to basic research infrastructure. In Table 3-3, the comments describing the perceived gap are listed along with the respondents' corresponding suggestions for bridging the gap.

Table 3-3. Perceived gap regarding basic research infrastructure.

Perceived gap (basic research infrastructure)	Suggestions for bridging the gap
At present no gap related to basic research infrastructure. Well-established national collaboration developed during the last 6-8 years using expertise in different institutions in Norway related to research on hydrogen storage materials, and thus giving Norway a strong international position in this area.	Funding for national projects involving collaboration between the key research institutions in Norway: IFE, SINTEF, NTNU and UiO.
(Our company) is in need of infrastructure for materials synthesis in controlled atmosphere and materials treatment (milling, annealing,...) in the several kg range.	Investments in equipment for materials synthesis in controlled atmosphere and materials treatment (milling, annealing,...) in the several kg range. Investments could be made at IFE/Kjeller.
Infrastructure at "lab-scale" level is world class at NTNU/UiO/SINTEF, but Norway has little "demonstration scale" infrastructure for materials synthesis and characterization	Very large grants (above NOK 100 million each) to build materials synthesis and characterization infrastructure on a larger scale. Our interest is primarily functional ceramics.
Closer access to several kinds of standard characterization equipment like XRD, SEM, TEM, TGA, IR-characterization, particle size distribution, BET, mass spectroscopy, Raman spectroscopy, SIMS, etc.	Well-equipped regional laboratories with qualified personnel running and supervising the equipment. The laboratories should typically be localized at the universities.
Test labs have today very limited possibilities to work with hydrogen. In addition comes the amount of hydrogen. Further, the size and high pressure (not necessarily to be Hydrogen only) require larger test facilities than what is available today.	Investments. We are looking for partners that are will to co-finance sufficient capacity under our control. If no agreement within short, we will (must) start build up our own test facility in Nebraska. Initial investment calculated to MUSD 3 (2011/2012) with another 2MUSD in 2013
We believe that the infrastructure is there but it is very fragmented *(did not report gap, auth. note)*	Better integration efforts and sharing of resources, no "reinventing of the wheel"
Missing : efficient conversion systems from sun, compact storage technologies , nano technologies	More resources and facilities and larger programs
Including the shared laboratory infrastructure owned by NTNU the basic research infrastructure is well covered.	

From the comments above, it would appear that the park of basic infrastructure for hydrogen research is sufficient, with the exception of up scaling of material synthesis to small pilot scale/demonstration scale.

A point made by several respondents is the need for collaboration and cooperation between the large actors in the research field. One respondent suggests the establishment of regional laboratories with qualified personnel running and supervising the equipment, typically localized at the universities. To some extent, this is already the case, as contract research organizations like IFE, SINTEF, CMR/Prototech, etc. are well-equipped when it comes to basic research infrastructure (both hydrogen related and generic), and all are located close to universities (UiO, NTNU and UiB, respectively) and collaborate with them. One possibility here could be to formalize collaboration between the universities and research institutions in a virtual network supported by the Research Council of Norway, allowing companies access to relevant infrastructure through this network. This would be in accordance with the comment from another respondent, requesting "better integration efforts and sharing of resources, no "reinventing of the wheel"."

3.2.3 Question 3: Identification of competence and funding needs

"Does your company experience a gap between its needs and the available competence and/or funding? If so – what is the nature of this gap? Could external institutions bridge this gap?

Field 4: Competence
Field 5: Funding"

3.2.3.1 Competence needs

35 % of respondents report experiencing a gap when it comes to competence. In Table 3-4, the comments describing the perceived gap are listed along with the respondents' corresponding suggestions for bridging the gap. In some cases the respondents have commented without experiencing a gap. Such cases are indicated with *(no gap)*.

Table 3-4. Perceived gap regarding competence.

Perceived gap (competence)	**Suggestions for bridging the gap**
General hydrogen competence, cleaning, testing and use in engine/fuel cell	Access to expertise within these areas.
Needed competence is available, however lack of research funding will reduce the future access of essential competence	
Our institute has international top level competence within several hydrogen technologies, however lack of research funding decreases the overall research on hydrogen and could reduce the future access of essential competence	More new projects
Fuel cell expertise is limited in the UK	Broader PhD base

Perceived gap (competence)	Suggestions for bridging the gap
(Our company) is in need of competence from research institutions and highly skilled engineers	Good contact with leading national competence within the field of metal hydrides and their development/implementation
R&D competences on hydrogen compression and refueling	
Fuel cell, Fuel cell systems and fuel reforming	More projects in university related to the applied fuel cell related issues
Competence built up in-house *(no gap)*.	
Our companies need more competence/knowledge of polymers behavior exposed for high pressure hydrogen and variable pressure and quick pressure drops /as happening when a car cylinder is depressurized or a when a hydrogen refueling station is delivering hydrogen to a hydrogen vehicle	To some extent an external institution might be able to support, but this kind of activity cannot be broken up and be studied separated from our core business products.
Outline of the best gap analysis method and the HBET property vector mentioned in Q2	Collaboration with skilled personnel with the competency mentioned above
Efficient and safe solutions to be developed	Solve storage and safety challenges
Handled by international partner *(no apparent gap in Norway)*	
Efficient energy conversion (energy and cost)	Increase competence programs
Some National R&D-groups within H2-techonolgy have very highly qualified personnel. However, most R&D groups in Norway are small. This leads to a gap in certain areas and some projects because each group does not have experts covering all fields.	SINTEF has the broadest competence base in Norway in this field. Still there is a gap which either may be closed by closer collaboration between institutions (exchange of experts) or increasing the size of the research groups.

The need for research expertise within several areas of hydrogen technology is mentioned by several respondents. Increased collaboration with existing research groups in Norway (preferably aided by a financing tool from RCN), combined with competence projects funded by the RCN could be one way of bridging this gap, resulting in education of relevant experts as well as investigating industrially relevant problems that need addressing.

Appendix B to this report (The Guide to Norwegian competence and infrastructure on H_2 research and technology development in the Research and Educational sector) may serve as a tool for identifying relevant research partners for meeting research needs. As an example, a company needing competence and/or infrastructure in a specific field could use the Guide and/or the related infrastructure tables to find relevant information.

3.2.3.2 Funding

50 % of respondents report experiencing a gap when it comes to funding. In Table 3-5, the comments describing the perceived gap are listed along with the respondents' corresponding suggestions for bridging the gap. In some cases the respondents have commented without experiencing a gap. Such cases are indicated with *(no gap)*.

Table 3-5. Perceived gap regarding funding.

Perceived gap (funding)	Suggestions for bridging the gap
The demand for own co-financing for small start-up businesses	Well, can't be changed (EU), but access to infrastructure, equipment and competence for little or very low cost would aid to narrow the gap.
Lack of national industrial interest and support to hydrogen research projects	Long term governmental support for projects and technology development
UK Government funding focused at fundamental scientific level, limited funding for "on the ground" demo projects	Increase prominence of real world projects and fund to promote work
More private and public funding is needed	More money, but probably a visible and profiled demonstration of the potential of the technology so that private investors are willing to invest
The main challenge in co-operation with Norwegian competence/research institutions is the high cost related to their services	A Hydrogen program supporting the fledgeling hydrogen industry should be established. Furthermore, at least Norwegian research institutes should get more basic funding in order to be able to offer their services to Norwegian SMBs at a lower rate.
Universities sometimes have to co-finance and thus will not always participate in projects.	100% funding for universities + R&D organizations
Funding for small projects below 10 mill NOK is good, but little funding for larger demonstration with costs above 100 mill NOK	Large scale funding for demonstration projects with budgets above 100 mill NOK
More governmental money for projects product development, that takes research from idea to an object	Money for start-up or high risk projects in small companies
Currently too few participants in HyNor phase 2 Stavanger	More end users participating
Currently not possible to get sufficient funding to make it possible to participate in / keep up previous H2 related RCS activities, safety network activities etc.	Better funding of cross cutting activities (safety, RCS), and selected international networks as IPHE, IEA H2 activities. Lack of funding leads to reduced activity. It is still difficult to find a short term commercial justification for these activities
Start-up companies in Norway have too limited	Have better conditions for small companies in the

Perceived gap (funding)	Suggestions for bridging the gap
economy to enter KMB or BIP projects - they are too expensive (compare e.g. with EU projects which are not so tough on small companies, rather supportive). In Norway it is important not to let SME prosper from research, in Europe it is the opposite :-)	research council. Make them survive!
NFR provides relevant public funding. Private funding hardly available in Norway	
Storing of compressed hydrogen has not been given priority or challenges not been understood or addressed correctly in the past. There are technology gaps that are still deep black holes in technologies, which must be closed a.s.a.p. (3-5Y)	Competence and a lot of R&D
Prohibitively high cost of fuel cells and associated equipment, and also lack of access to H_2 (&-filling stations)	Increased subsidies, grants etc. to hydrogen technology might increase implementation
So far, we have had to finance the pilot testing and technology demonstration with help from NFR. In this phase, when it is impossible to profit from hydrogen production from biogas, this burden is too heavy for small companies.	More national funding for test projects that gains "everyone".
Funding on hydrogen issues seems to be decreasing	More funding
Handled by international partner *(no apparent gap in Norway)*	
(Our company)'s activities within hydrogen have been reduced the last years. H_2 is still regarded as a potential fuel for the future, but not in a short time perspective. *(no gap)*	
Practically no available funding to build large scale infrastructure	10 years program as i.e. South Korea has done
1) National funding to R&D is limited and distributed over a wide range of H_2-technologies, leaving (with few exceptions) sub-critical budgets for each area for reaching technology breakthroughs and internationally acknowledged research groups. 2) Low funding level in EU-program FCH JU. 3) Sub-critical funding of research groups working with key H_2 technologies periodically leads to non-continuous activity in the field, making development, competence maintenance, and satisfactory progress in the field difficult.	The main challenge for national R&D activities is the absence of large industrial companies which in turn could provide the co-funding required on the Research Council of Norway (RCN). On the European arena (FCH JU) the funding is typically 30-45%. Top financing of the FCH JU-projects from RCN up to at least 75% should be established as a permanent instrument

Several aspects related to funding needs are addressed in the comments to this question. Comments generally fall into one or more of these categories:

1) *Small companies:* Many hydrogen-related businesses are small and often in a start-up phase, and thus have limited funds for investment in equipment or as own-financing for the RCN-supported KMB or BIP projects. The cost of the services of research institutes is often too high for small companies. Also: Need for more funding for start-op or high risk projects in small companies.

2) National funding is decreasing, while the need for funding for hydrogen research is still high.

3) Lack of industrial interest and support to hydrogen research projects.

4) Little funding for demonstration and large scale infrastructure, and lack of access to infrastructure

5) Available national funding is distributed over a broad range of H_2 technologies, leaving many areas sub-critical.

6) Low funding level for projects (e.g. 30-45 % in FCH JU) and no permanent tool for top financing by RCN.

3.2.3.3 Attractiveness of funding sources

"Input for shaping of future calls for project proposals: Which funding sources do you find attractive /unattractive for financing research projects, and why? Currently and Future (5-10 years)"

The listed funding sources were:

- EU: Capacities
- EU: FCH-JU
- EU: Other
- Competence projects
- Innovation projects
- Researcher projects
- Own financing
- Other (please specify)

The respondents were given the following choices for ranking the attractiveness of each funding source

- Very attractive
- Attractive
- Neutral
- Unattractive
- (blank)

In Figure 3.6 and Figure 3.7 the results from this question are displayed. In the figures, only the "Very attractive", "Attractive" and "Unattractive" answers are shown. Neutral and blank answers were considered to be of little significant difference, and constitute the difference between the results in the figures and 100% for each category.

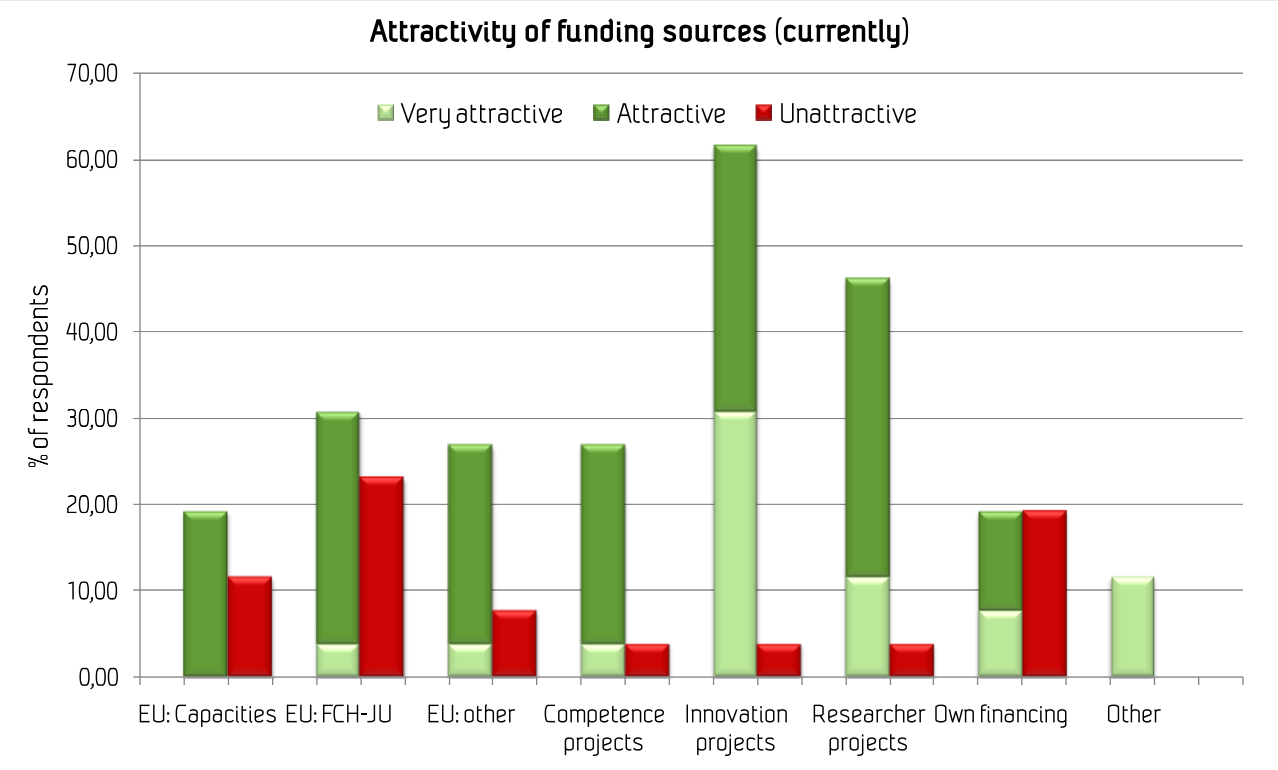


Figure 3.6. Perceived attractiveness of typical funding sources at present.

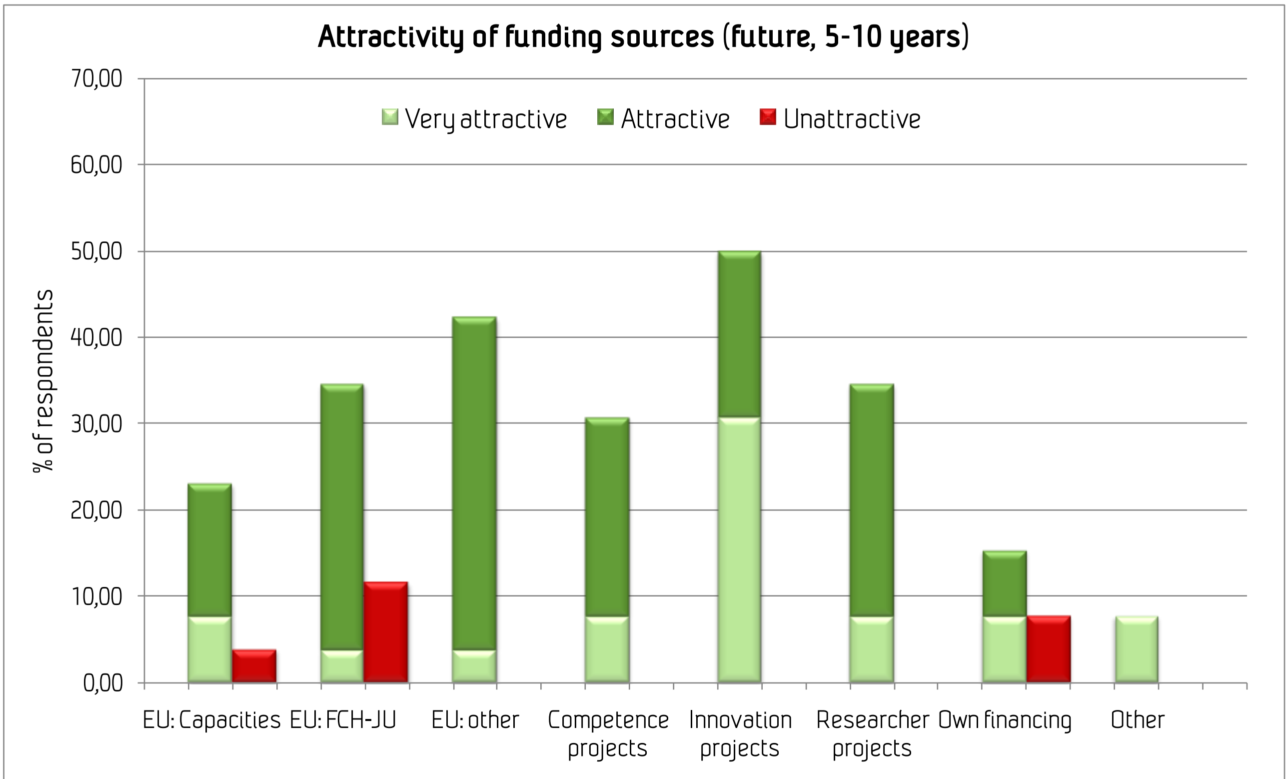


Figure 3.7. Perceived future (time scale 5-10 years) attractiveness of typical funding sources.

Table 3-6, 3-7 and 3-8 show comparisons for the "Attractive + Very attractive", "Neutral + blank" and "Unattractive" categories in a current and future time perspective.

Table 3-6. Comparison of the "Attractive + Very attractive" category in a future and current time perspective.

Attractive / Very attractive	Currently	Future	Difference
EU: Capacities	19	23	4
EU: FCH-JU	31	35	4
EU: other	27	42	15
Competence projects	27	31	4
Innovation projects	62	50	-12
Researcher projects	46	35	-12
Own financing	19	15	-4
Other	12	8	-4

Table 3-7. Comparison of the "Neutral + blank" category in a future and current time perspective.

Attractive / Very attractive	Currently	Future	Difference
EU: Capacities	69	73	4
EU: FCH-JU	46	54	8
EU: other	65	58	-8
Competence projects	69	69	0
Innovation projects	35	50	15
Researcher projects	50	65	15
Own financing	62	77	15
Other	88	92	4

Table 3-8. Comparison of the "Unattractive" category in a future and current time perspective.

Attractive / Very attractive	Currently	Future	Difference
EU: Capacities	12	4	-8
EU: FCH-JU	23	12	-12
EU: other	8	0	-8
Competence projects	4	0	-4
Innovation projects	4	0	-4
Researcher projects	4	0	-4
Own financing	19	8	-12
Other	0	0	0

Table 3-9 lists the comments given regarding the attractiveness of funding sources.

Table 3-9. Comments given by respondents regarding the attractiveness of funding sources

Comment
For a small development/startup company EU projects are not necessarily interesting, both due to IPR questions and due to the workload to get these projects.
EU-funding attractive for international collaboration, as projects within FCH-JU, infrastructure projects (Capacities) and other (like Energy or NMP). Research projects are important for basic research issues and to develop own competence. Competence and innovation projects links the research issues to Norwegian industry.
Except for EuroStars, EU proposals are too comprehensive for SMBs
Except for the FCH-JU, I do not have sufficient detailed knowledge to comment on how attractive these might be, but the funding regime would be a deciding factor. In general opportunities for full or nearly full funding are very rare. This while some other nations appear to find ways of funding cross cutting activities.
Let SMEs have money-neutral projects
Not relevant
We use most of these funding sources with variable emphasis depending on work context, timing etc.
FCH-JU programs are unattractive without top financing from RCN, however attractive if the additional financing is there.

The most popular funding source, both currently and in the future, is the Innovation project, which 62 % find attractive or very attractive at the moment and 50 % feel the same for the future. Researcher projects come second in attractiveness with 46% / 35 % in a current / future perspective. These two funding schemes also exhibit the largest drop in attractiveness with time, with a drop of 12 percentage points.

EU projects other than Capacities and FCH-JU show the highest increase in attractiveness with time, rising from 27 % currently to 42 % in a future perspective, an increase of 15 percentage points.

In general, few funding sources are seen as unattractive. The least attractive funding sources are FCH-JU with currently 23 % (likely to be related to the low funding rate of projects combined with the high effort needed to apply for projects under this scheme), followed by Capacities (23%) and Own financing (19%). This corresponds well with the comments made by the respondents earlier in the questionnaire, where higher levels of funding and less own financing is sought after. For all funding sources, the number of respondents that find them unattractive drops when extending the time horizon from current to future view.

A very high percentage of answers fall in the neutral and blank category. This may reflect an indifference to funding source (possibly having more focus on the relevance of the call rather than the funding principle), a low level of knowledge regarding the funding tools or simply that it is not relevant for the respondent. However, as the questionnaire did not specify the difference between "neutral" and "blank", it would be over interpreting the data to separate these answers in two categories.

3.2.4 Question 4: Preferences for a hydrogen technology test center

3.2.4.1 Current use of external resources

"*Does your company currently use external research resources, e.g. by sending own employees to use infrastructure elsewhere or by outsourcing tasks?*"

Alternatives:

- *Often*
- *Regularly*
- *Sometimes*
- *Rarely*
- *Never*
- *(Blank)*

Figure 3.8 summarizes the answers given by the respondents to the above question, and

Table 3-10 lists the comments given regarding use of external research sources.

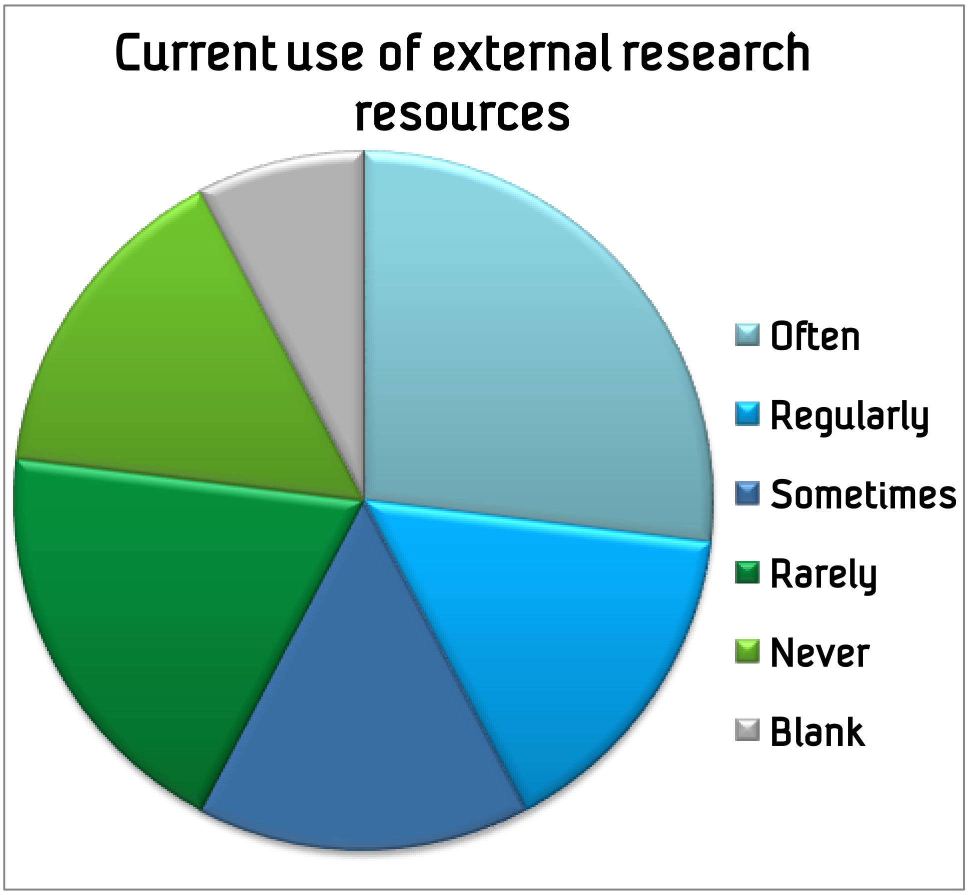


Figure 3.8. Use of external resources, either by sending own employees to use infrastructure elsewhere or by outsourcing tasks.

The results here show a relatively homogeneous distribution between the alternatives, with *Often* as the most frequent (27 %), followed by *Rarely* (19 %) and *Regularly*, *Sometimes* and *Never* (all 15 %). 8 % gave no answer.

Table 3-10. Comments given by respondents regarding use of external research sources

Comment
Current academic partner's laboratory facilities + contract-based testing abroad.
(We have) test equipment localised at Risavika Gas Center
Strong national collaboration. Use of European large-scale facility infrastructure, for example the ESRF in Grenoble
Involved in doctorate training center (BHAM) and Supergen, use as directed research resource
The company does not have own employees
(Our company) co-operates tightly with IFE/Kjeller and depend strongly on their infrastructure
Outsourcing tasks. Some smaller tasks to SINTEF/NTNU, but with larger tasks assigned to American suppliers
We use the facilities of UiB for material characterisation. We also use Risavika Gas Center and BKKs facilities at Kollsnes for pilot testing of fuel cell systems. Short travelling time is essential for such use.
Outsourcing of material characterisation at suppliers or research partners
Research work and competence contributions are performed by external research resources in our hydrogen projects.
We have not used this in the past due to non-availability of personnel and good choices but this can be an option in the future
Not at the moment (within H_2)
Large companies need their own infrastructure to do basic testing. Special research tasks and new technology validation to be done elsewhere
Not high need for use of external infrastructure due to wide range of in-house competence and resource base

In general, the comments in Table 3-10 and the results shown in Figure 3.8 indicate that the larger companies and research institutes are largely self-sufficient (either in-house or through collaboration with relevant partners) when it comes to general instrumentation. More specialized tasks are however often outsourced to research institutes in Norway or to international research facilities. Smaller companies are likely to have less in-house instrumentation and thus a higher need for outsourcing tasks. However, the cost of using purchasing external research resources can be too high for SMEs (ref. e.g. paragraph 3.2.3.2 concerning funding).

3.2.4.2 Infrastructure that could be included in a delocalized center?

"Does your company currently have infrastructure that could be included as a part of a virtual (distributed) test center network, i.e. infrastructure that you could make available to other parties (either by allowing external users to use the infrastructure or by performing selected tasks for such users)?"

Alternatives:

- *Yes, to external users*
- *Yes, internal users*
- *No*
- *(Blank)*

Figure 3.9 summarizes the answers given by the respondents to the above question, and Table 3-11 lists the comments on available research infrastructure for potential inclusion in a virtual hydrogen test center.

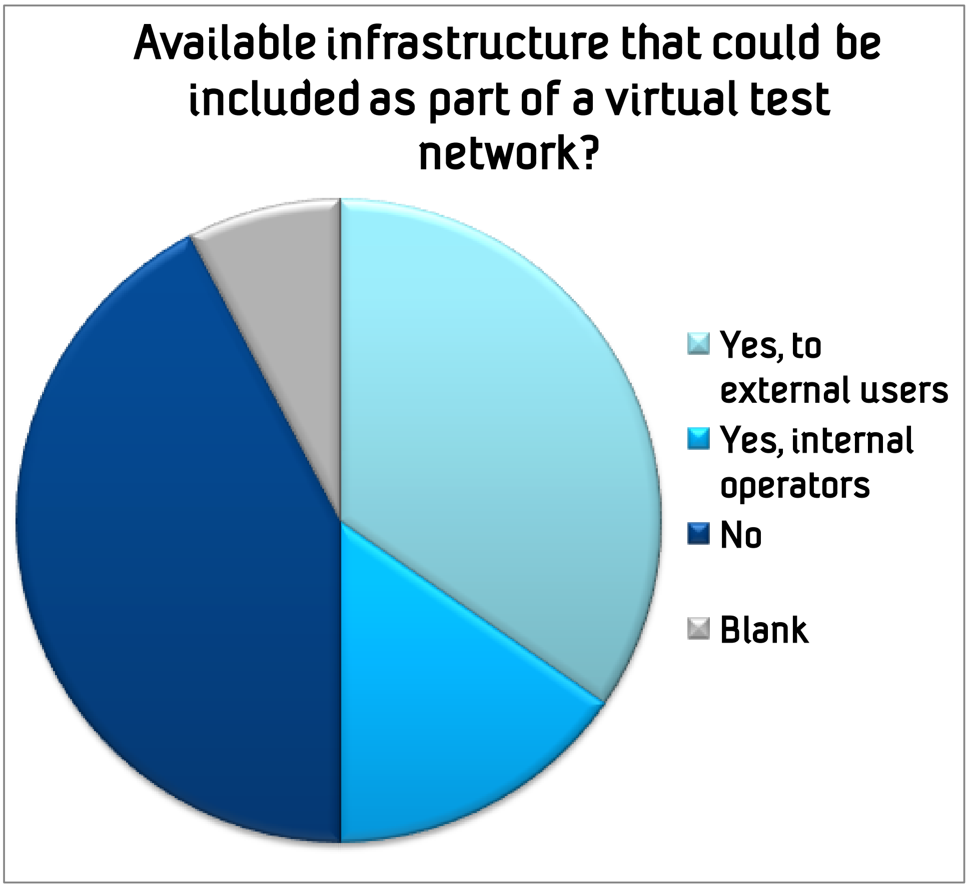


Figure 3.9. Availability of infrastructure that could be included as part of a virtual (distributed) test center network.

A total of 42 % of the respondents do not have infrastructure that could be included in a virtual hydrogen technology test center, whereas 35 % (9 respondents) have infrastructure that could be made available to external users and 15 % (4 respondents) have infrastructure that could be made available, with the condition of internal operators. 8 % gave no answer.

Table 3-11. Comments given by respondents regarding availability of infrastructure for potential inclusion in a virtual hydrogen technology test center.

Comment
Infrastructure will be built in a hydrogen test center planned at Energiparken, Lillestrøm
JEEP II at IFE is an excellent tool for basic material research, and is very attractive for international projects within hydrogen storage.
(Our company) co-operates tightly with IFE/Kjeller and depend strongly on their infrastructure
Mobile test unit ($36m^2$, 2+2 shipping containers) for integrated hydrogen separation membrane applications. Currently set up with capacity to produce liquid aromatics from natural gas with ultrapure hydrogen as by-product. Adaptable to other hydrogen separation applications
We have a large hydrogen / fuel cell capacity
(Our company) is a third party test center
We are more of a service provider, although we have lab infrastructure that cover other activities I do not think this is relevant for us at the moment
We are too small for letting people use our lab. But we can make/sell tests for people/institutes/industry on specialised services, often in collaboration with UiO.
The degree of interference from external users will have to be discussed in each case.
Medium-scale and lab-scale testing facilities (both equipment e.g. fuel cells and flammable gases e.g. hydrogen can be tested)
(Our company uses) Linde Hydrogen Center in Munich
(Our company) has over the last years built up R&D infrastructure within renewable energy and hydrogen (Energy Park and H_2 station in Porsgrunn). One possible future activity at this site could include making it available to external users. This opportunity has not yet been thoroughly investigated.
We are working with alternatives for regional test infrastructures within a wide area of technologies
We have recently received funding for a European infrastructure collaboration networking activity entitled H2FC European Research Infrastructure

Half of the respondents (13 companies / research institutes) have infrastructure that could be made available to others under certain conditions. Of particular interest might be the planned hydrogen demonstration facilities at Energiparken in Lillestrøm, where there will be opportunities to test new technologies. Several other companies / research institutes also have highly relevant infrastructure (see e.g. the infrastructure Guide in Appendix B), hence an exploration of a virtual infrastructure network for hydrogen technology seems to be pertinent. Several organizational approaches are possible for such a network, including (by no means exhaustive)

- Formalized network with strict application procedures and a common public interface
- Formalized network with informal application procedures. Less visible to the public.
- Information on available infrastructure is made public (like e.g. in the appended Guide). Bilateral agreements between relevant parties regarding use of infrastructure and/or research resources

3.2.4.3 Perceived need for a hydrogen technology test center

"Do you feel there is/might be a need for a hydrogen technology test center?"

Alternatives:
- *Yes, current need*
- *Yes, future need*
- *No, don't foresee need*
- *Undecided*
- *(blank)*

Figure 3.10 summarizes the answers given by the respondents to the above question, and comments are listed in Table 3-12

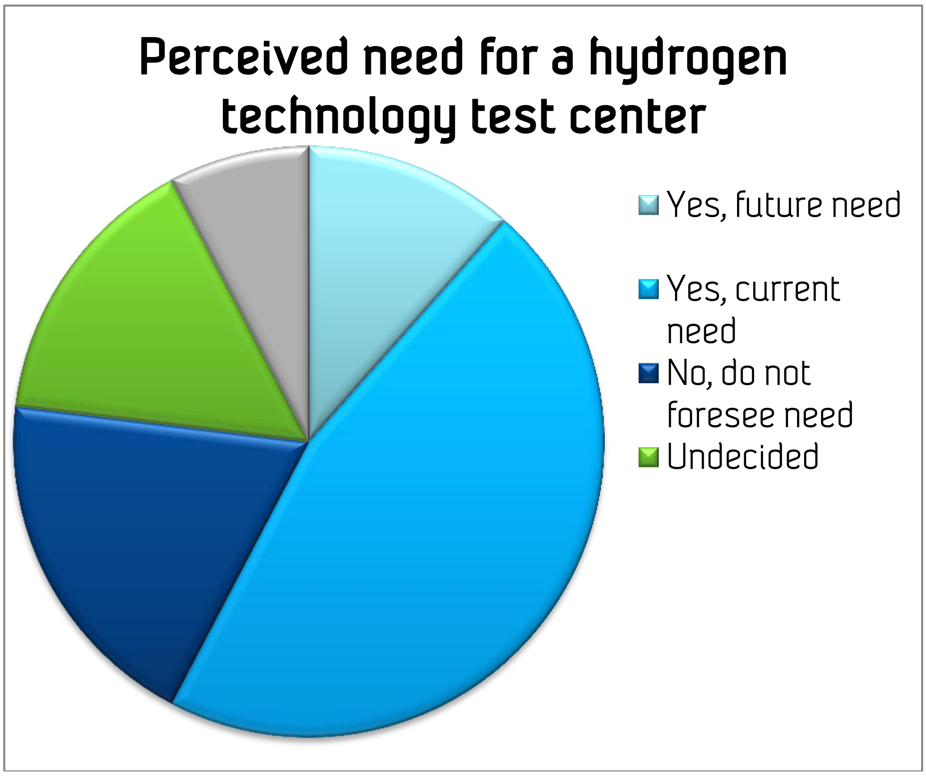


Figure 3.10. Perceived need (or lack thereof) for a hydrogen technology test center.

Of the respondents 46 % answered that they experience a current need for a hydrogen technology test center, whereas 12 % expected a future need. 19 % reported foreseeing no need for such a test center, whereas 15 % were undecided. 8 % gave no answer.

Table 3-12. Comments regarding the felt need (or lack thereof) for a hydrogen technology test center.

Comments
In principle this sounds like a good idea if it is done right as it could contribute to improved national cooperation and joining forces giving valuable synergies and facilitate technology development.

3.2.4.4 Meeting of future infrastructure needs

"How does your company envision meeting its infrastructure needs in the future? (Check all that apply)"

Alternatives were:
- *In-house infrastructure*
- *Infrastructure owned by industrial partners*
- *Infrastructure owned by research partners (universities / research institutes)*
- *Hydrogen technology test center (new)*
- *Existing national / international research infrastructure*

Figure 3.11 summarizes the answers given by the respondents to the above question.

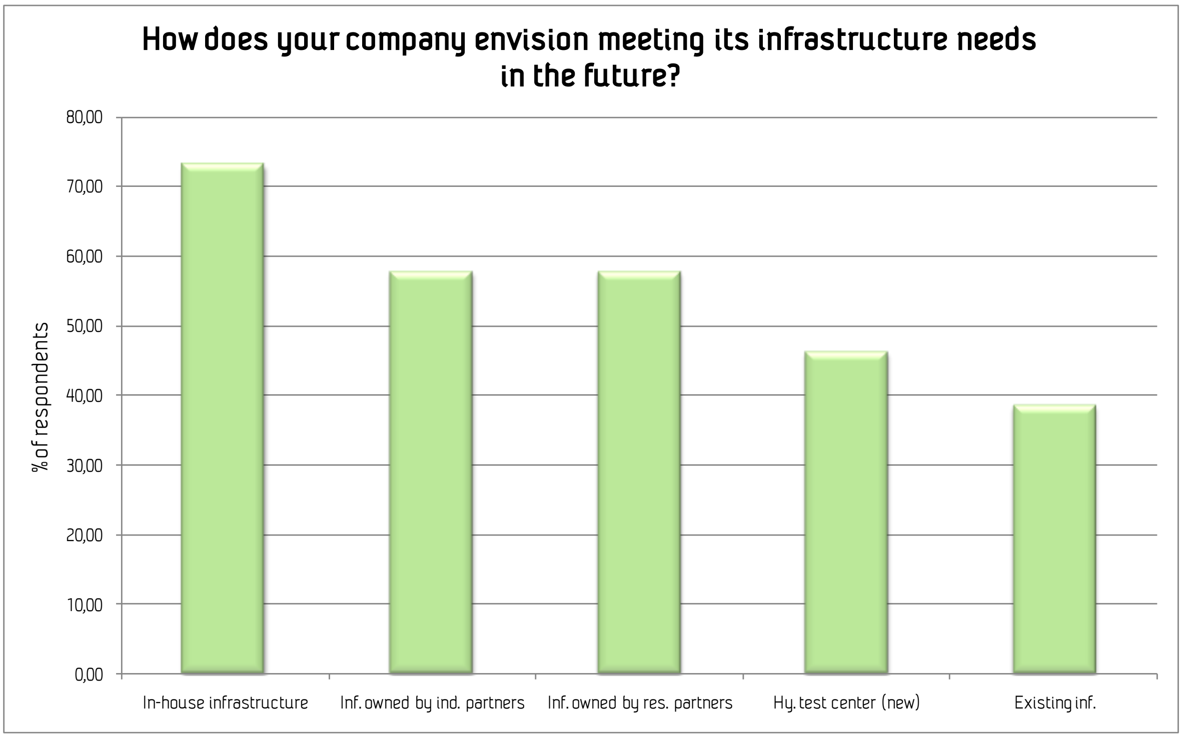


Figure 3.11. Foreseen ways of meeting future infrastructure needs (more than one answer possible).

73 % of the respondents envision meeting their future infrastructure needs with *in-house infrastructure*, whereas 58 % will *use infrastructure owned by industrial or research partners*. 46 % answer that they could use a *new hydrogen technology test center*, and 38 % will use *existing national or international infrastructure*. 8 % (two respondents) did not tick any of the alternatives, most likely due to lack of relevance.

Table 3-13 lists the comments given by the respondents to this part of the questionnaire.

Table 3-13. Comments on meeting future infrastructure needs.

Comments
For larger scale demonstrations: Infrastructure provided for demonstration purposes by international oil & gas, petrochemical companies
Close localization and short travel time is essential for efficient utilization
For the coming 3-5 years *(we)* have enough internal capacity for its own needs
Hydrogen production to be started at *(our company)* in 2011. It is anticipated that application on new technology is related to turbines and motors provided by industry.
(Research partner:) UiO
Challenging to reply adequately to the question, because if one alternative is realized, then the need for others is not that prominent. With *(our company)*'s broad and growing activity in the field, we foresee that all the above alternatives may be(come) relevant.

3.2.4.5 Important factors for using a hydrogen technology test center

"What would be important factors for you to utilize the service(s) of a hydrogen technology test center (check all that apply)."

Alternatives:

- *Location (please specify)*
- *Proximity / link to competence institutions*
- *Financing / cost*
- *Uniqueness of infrastructure*
- *R & D support personnel*
- *Certification / verification possibilities*
- *Health, safety and environment (HSE) issues*
- *Education of industry personnel*
- *Seminars / work shops*
- *Development of testing protocols*
- *Basic research infrastructure*
- *Applied research infrastructure*
- *Lab scale testing facilities*
- *Pilot scale testing facilities*
- *High pressure testing capabilities*
- *High / low temperature testing capabilities*
- *Materials testing*
- *Component testing*
- *Prototype testing*
- *Other (please specify)*

Figure 3.12 summarizes the answers given by the respondents to the above question.

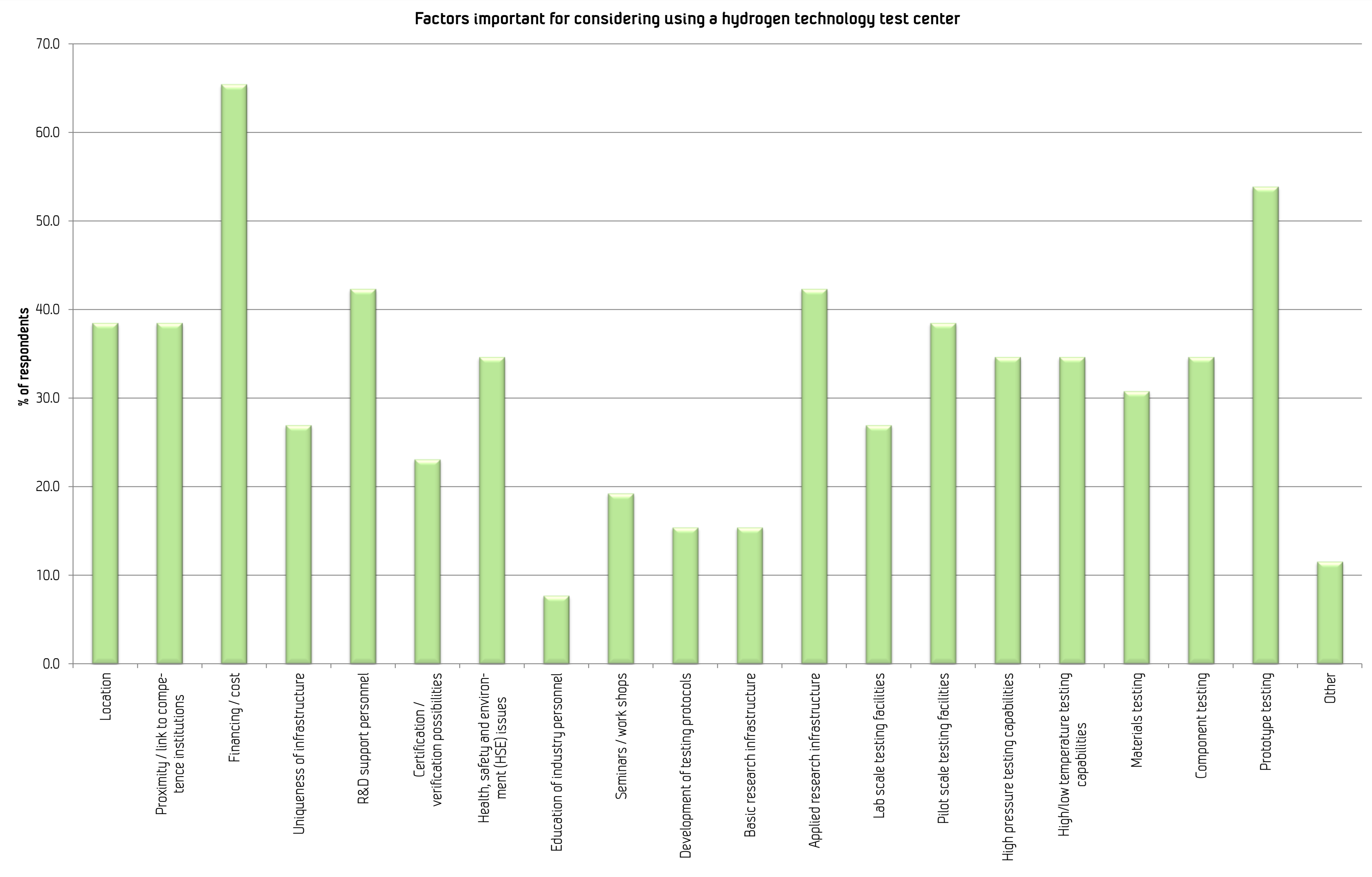


Figure 3.12. Factors important for considering using a hydrogen technology test center.

The by far most important factor for the respondents to consider using a hydrogen technology test center is Financing / cost, as a total of 65 % checked this alternative. Second most important was *Prototype testing*, with 54 %. *R & D support personnel* and *Applied research infrastructure* are both selected by 42%. In the range 30-40 %, we find *Location*, *Proximity / link to competence institutions*, *Pilot scale testing facilities*, *HSE issues*, *High pressure and high/low temperature testing capabilities*, *Component testing* and *Materials testing*. Between 20-30 % of the respondents checked *Uniqueness of infrastructure*, *Lab scale testing facilities* and *Certification / verification possibilities*, whereas 10-20 % felt that *Seminars / workshops*, *Development of testing procedures*, *Basic research infrastructure* and *Other* were important. 8 % could be interested in *Education of industry personnel*.

One respondent reported seeing no need for a hydrogen technology test center.

Even though 39 % (10 respondents) considered *Location* to be important, only 6 chose to specify a desired location. Of these, two preferred the Lillestrøm/Kjeller area (one specified that relevant infrastructure is already in the process of being established there). Oslo, Trondheim, Gothenburg (Sweden) and Lincoln (Nebraska, USA) were specified by one respondent each.

In the *Other* category, these comments were given:

- Lending of equipment + expert assistance
- Linde test center in Munich (Germany)
- Benchmarking

3.2.4.6 Desired content of hydrogen technology test center

"Are there any specific test methods, services, pressure / temperature ranges, etc. you could like to see included in a hydrogen technology test center? Please specify".

Table 3-14 lists the comments given by the respondents to this part of the questionnaire.

Table 3-14. Comments on desired content of a hypothetical hydrogen technology test center.

Comments
Lending of equipment + expert assistance
Environmental chamber facilities capable of running large > 20kW fc engines
Materials characterization: scientific analysis techniques, such as pressure-composition-temperature (PCT) isotherm measurements, thermal desorption spectroscopy (TDS), stability/cycling tests with respect to gas impurities, safety (pyrophoric etc.) tests, XRD, SEM, and TEM. Temperature range: 15-300 °C. Pressure range: 0-1 kbar.
1000 bar hydrogen compression
High temperature (400-1100°C)
Freeze capability of sub-systems or complete systems
30 bar, 1200°C
No particular comment. Safe handling and efficient production and storage important.
Long term automated (fuel cell) testing + Climate chamber with operation between -30 (or -40) °C and up to +50°C.

3.2.4.7 Organization of hydrogen technology test center

"How would you have liked a hydrogen technology test center to be organized? (Check all that apply)"

The alternatives were:

- *Open access, where external users can come to the center to use the infrastructure (etc.). Basic supporting personnel available (project based)*
- *Test center with research personnel performing defined and standardized tests for customers (project based)*
- *A centralized hydrogen technology test center physically located in _____ (fill in)*
- *A main hydrogen technology test center physically located in ___ (fill in) with infrastructure "satellites" located with industry/universities/research institutes*
- *A network of existing and new research infrastructure*
- *Other (please specify)*

Figure 3.13 summarizes the answers given by the respondents to the above question.

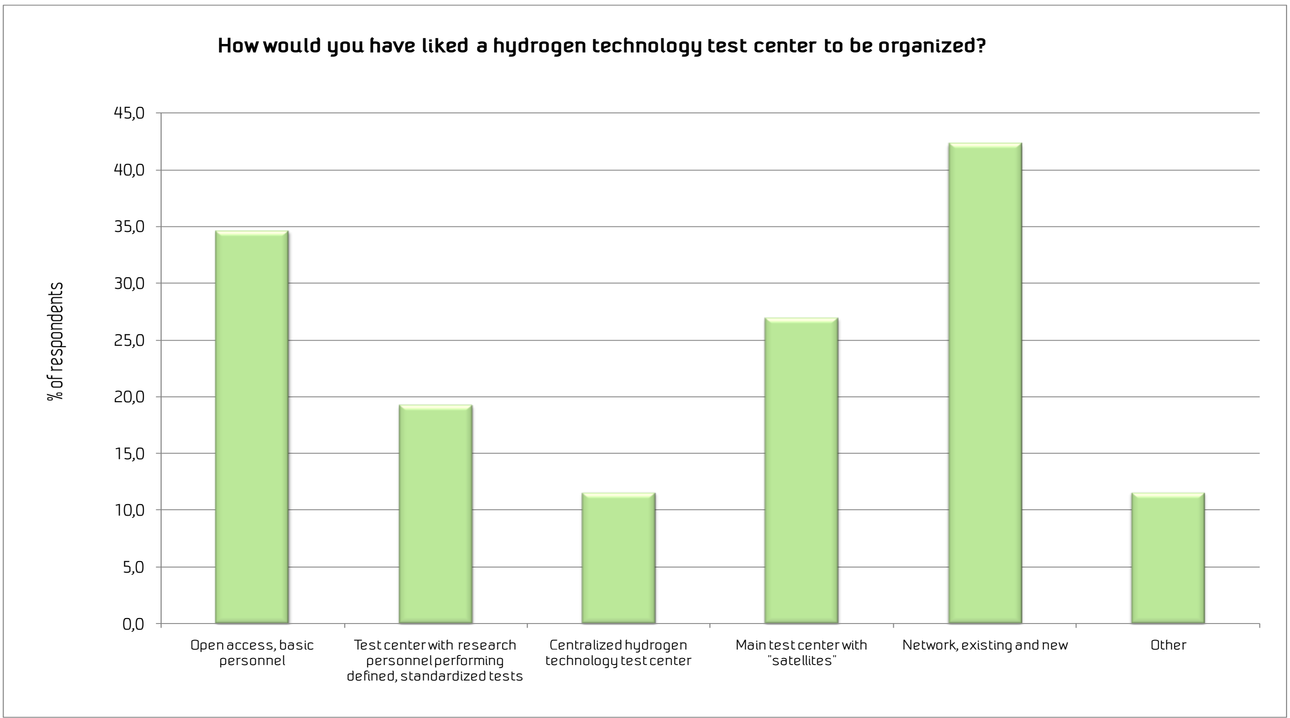


Figure 3.13. Preferences for organization of a hypothetical hydrogen technology test center.

When it comes to localization of a hypothetical hydrogen technology test center, the preferred alternative, checked by 42% is a *Network of existing and new infrastructure*. Slightly less attractive (27 %) is a *Main test center with "satellites"*. Oslo (or the Oslo region) was specified by 3 respondents, Trondheim by 2 and Bergen and Gothenburg were mentioned once. Two respondents did not specify a location. A *Centralized hydrogen technology test center* is viewed as least attractive of the given alternatives, with only 12 % (3 respondents). Of these 3, one preferred the Bergen region, one Kjeller and one did not specify a location.

Regarding organization, a center with *Open access and basic personnel available* was selected by 35 %. 19% checked *Test center with research personnel performing defined, standardized tests*.

Comments under Other are shown in Table 3-15 below.

Table 3-15. Comments on organization and localization of a hypothetical hydrogen technology test center.

Comments
Depending on budget and partners. Preferred would be annual budget above 200 million NOK and major oil and gas companies as partners (Shell, ExxonMobile, Statoil)
I assume that the most realistic is to build on what already exists, including existing competence and facilities, and fund the best ones.
We are in doubt about what role a centralized test center can do for us, except for standardized testing for product qualification (type approval and lot sample control)
Not relevant to us
Many different aspects to study and widespread competence in Norway. Therefore wrong to make one centralized test center.
N/A

3.2.5 Question 5: Opinion on trends in H_2-related areas

3.2.5.1 Hydrogen as an energy carrier

"Please give your opinion on trends in the following H_2-related areas:

- *National public opinion (acceptance)*
- *National use*
- *International public opinion (acceptance)*
- *International use"*

Alternatives for national/international public opinion:
- *More positive*
- *Status Quo*
- *More negative*
- *No opinion*
- *(blank)*

Alternatives for national/international use:
- *Growing*
- *Status Quo*
- *Declining*
- *No opinion*
- *(blank)*

Figure 3.14 and Figure 3.15 summarize the answers given by the respondents to the above question. The No opinion and (blank) categories are displayed together, as they were considered to be of little significant difference.

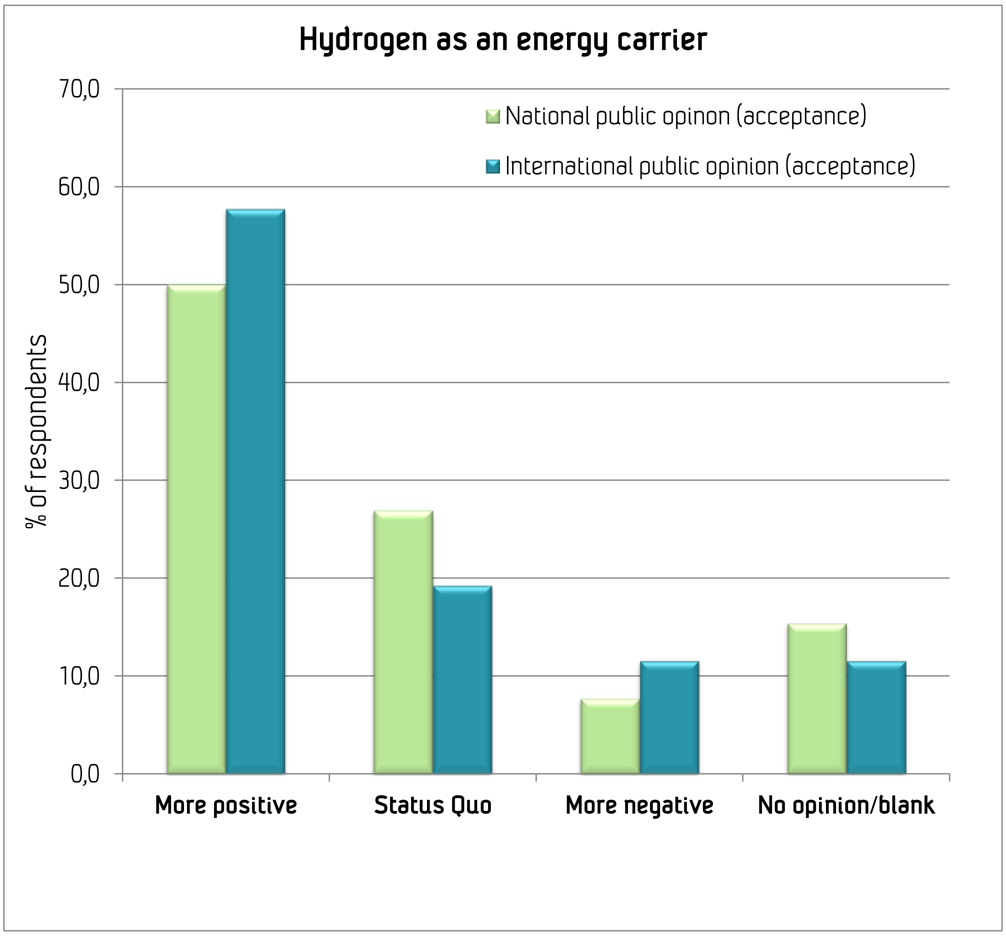


Figure 3.14. Opinions on national and international trends in public opinion on hydrogen as an energy carrier.

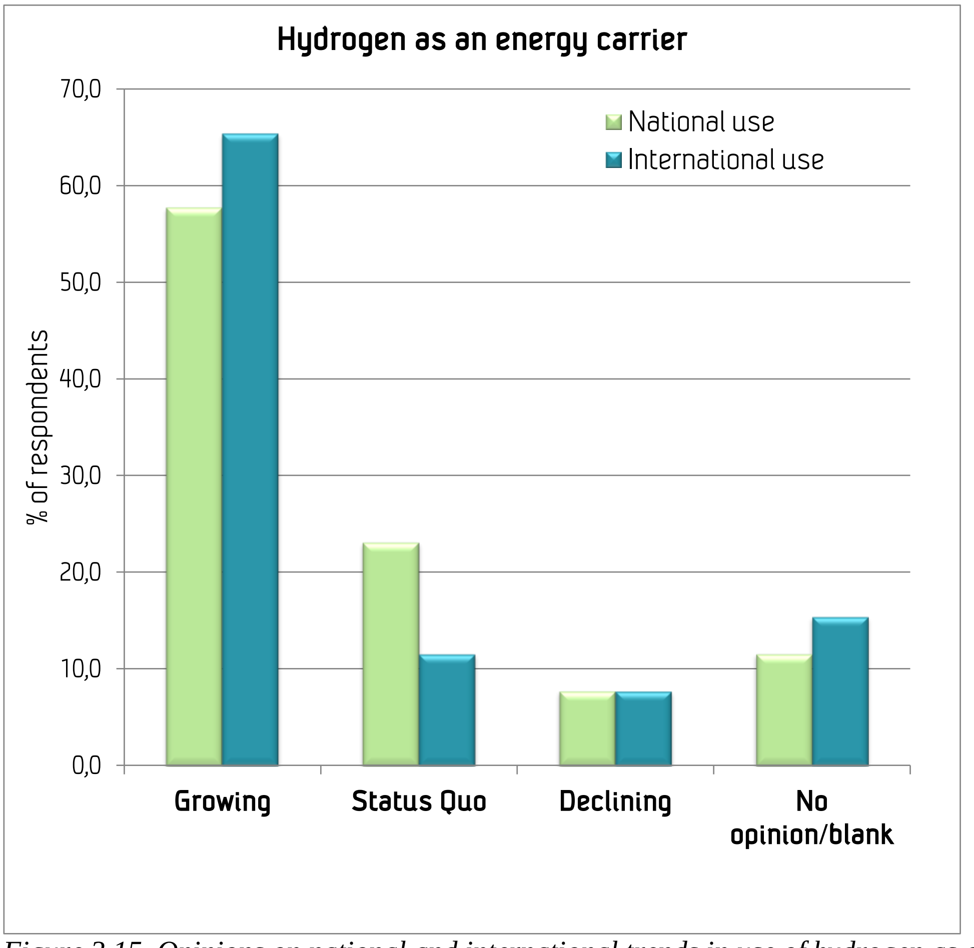


Figure 3.15. Opinions on national and international trends in use of hydrogen as an energy carrier.

The graphs show that the respondents are generally very positive to both national and international hydrogen trends, slightly more positive for the international opinion and use.

Regarding hydrogen as an energy carrier, 50% expect the national public opinion to be more positive in the future, whereas 58% are positive when it comes to the international public opinion. A total of 27 % / 19 % expect the national / international public opinion to remain at status quo, whereas 8 % / 11 % expect a negative trend for the national and international public opinion, respectively. 15 % / 12 % gave no opinion or a blank answer.

The same trend can be seen for the respondents' assessment of the use of hydrogen as an energy carrier in the future. 58 % expect the national market for use of hydrogen to grow in the future, and an even higher number of respondents (65 %) feel the same for the international market. 23 % / 12 % expect status quo for national / international hydrogen usage, whereas 8 % expect a decline in use. 12 % / 15 % gave no opinion or a blank answer.

One of the respondents that gave no answer to this point, commented: “Depends on too many non-technical factors to have an opinion about”. No other comments were made.

3.2.5.2 Market for hydrogen technologies

"Please give your opinion on trends in the following H_2-related areas:

- *National market*
- *International market"*

Alternatives:

- *Growing*
- *Status Quo*
- *Declining*
- *No opinion*
- *(blank)*

Figure 3.16 summarizes the answers given by the respondents to the above question. The No opinion and (blank) categories are displayed together, as they were considered to be of little significant difference.

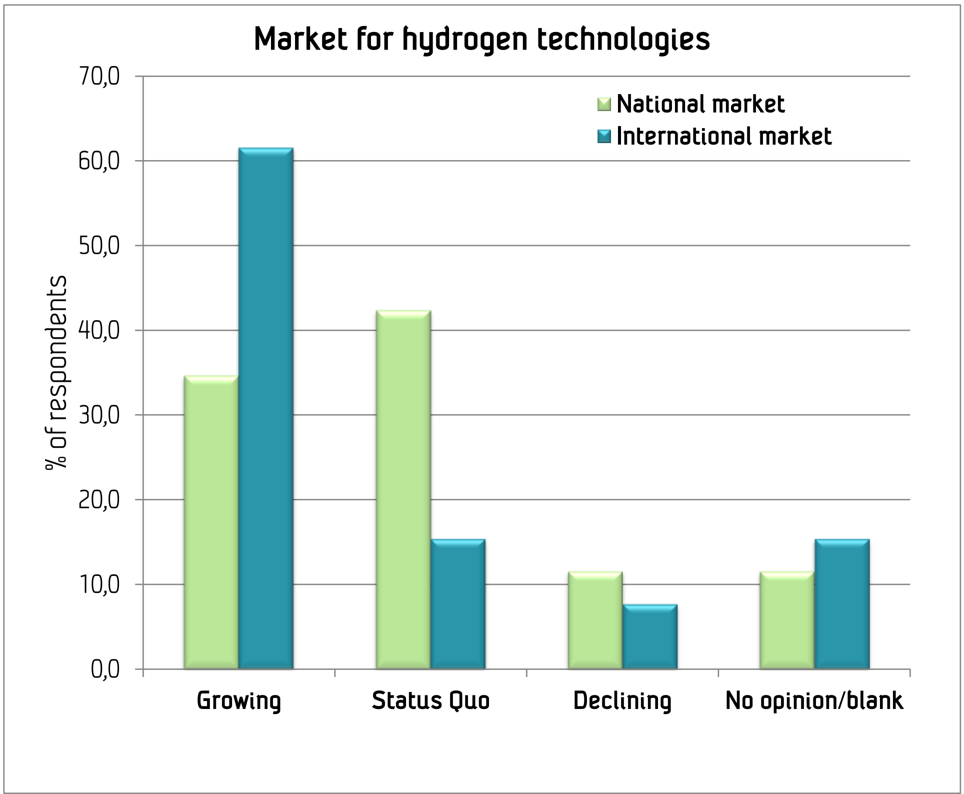


Figure 3.16. Opinions on national and international trends on the market for hydrogen technologies.

The optimism is high for the international market for hydrogen technologies, which 62 % feels is growing, while only 35 % feel the same for the national market. 42 % expect status quo for the national market, whereas only 15 % expect the international market to remain unchanged. 12 % / 8 % expect a decline in the national / international market for hydrogen technologies, whereas 12 % / 8 % gave no opinion or a blank answer.

Comments to this point are shown in Table 3-16 below.

Table 3-16. Comments trends in the market for hydrogen technologies.

Comments
But it takes time, and reaching commercial break-through is a challenge! *(Respondent indicated Growing for both national and international markets, auth. comment).*
Depends on too many non-technical factors to have an opinion about *(Respondent answered (blank), auth. comm.)*
High activity internationally, especially in Germany. In Norway we are missing an actor to fill the gap between R&D and consumer.

3.2.5.3 Market drivers

"Which are, in your opinion, presently the most important market drivers for hydrogen technology?"

The responses to the above question are shown in Table 3-17 below.

Table 3-17. Opinions on important market drivers for hydrogen technology

Comments
Passenger cars
Politicians
Local environment issues, efficient use of energy and accumulating/storing and transport of energy
Military niche products and cars.
Too early to say. A real market has not been launched yet.
Hydrogen for transport purposes
Environmental issues. Nuclear industry (but may be questionable after Fukushima)
Clean energy
Local pollution in cities. High fuel costs. Economic incentives favouring zero emission vehicles. In the future, with high penetration of renewable energy in the electricity grid, energy storage will become an issue.
Energy storage for balancing renewable energy and the whole transportation industry emission targets. New technology development within nanostructures
Global warming scenarios, depletion of crude oil resources and the need for higher end user efficiency (e.g., substitution of Internal Combustion Engines with Fuel Cells in vehicles).

3.2.5.4 Major bottlenecks

"What are the major bottlenecks that your company encounters regarding initiating and/or running research projects? Examples: IPR, financing, networking, competence, capacity, risk of project denial (hampering long-term planning, Norwegian Research Council research program guidelines, etc. Please elaborate."

The responses to the above question are shown in Table 3-18 below.

Table 3-18. Opinions on major bottlenecks for initiating and/or running research projects

Comments
Capacity
We see ourselves as frontrunners in our field of technology. Lack of relevant competence in general as well as lack of adequate suppliers.
IPR and financing. Our further product development need a lot of up front investments and strong(er) political commitments both on a national, regional and continental level, before a company like ours will take all the risks associated with an early (too early) investment
Project bottlenecks (as well as enablers) are results of company internal assessment and priorities based on a.o. all factors mentioned.
Financing and project manager capacity. Our hydrogen projects are large in terms of investments, but small when it comes to expected profit. Hence, PM for our hydrogen projects is also involved in many other projects unrelated to hydrogen.
Lack of efficient storage solutions and cost-efficient safe handling limits the big push / momentum within hydrogen energy
Financing, capacity
Political decisions, regulations and price mechanism for emissions.
1) The lack of national industry is a bottleneck limiting the nationally funded project portfolio significantly over the last years. 2) the level of funding (financing) of European projects within the FCH JU-program. The uncertainty when taking new European initiatives is substantial, not knowing if there will be national top-financing for the FCH JU-projects from RCN. 3) There are limited funding possibilities through researcher projects, which could be used more actively by the NRC as a tool to counteract against fluctuations in industrial participation

3.3 Conclusions from questionnaire

The survey on hydrogen research infrastructure needs has confirmed the existence of a wide range of hydrogen-related activities in Norway. In principle all defined disciplines within the four main areas are covered; *1) Production* – dominated by reforming/partial oxidation of fossil fuels, *2) Storage and distribution* – dominated by pressurized hydrogen, *3) End use* – dominated by fuel cells and *4)Cross-cutting issues* – dominated by demonstration activities. The most common hydrogen source used by the participants of the survey is natural gas. Renewable energy/H_2O splitting and biomass are also stated as important (second and third most used, respectively) hydrogen sources.

There is evidence of gaps between existing and needed infrastructures, in particular for demo/pilot testing, were 46% of the respondents experience a gap. For applied and basic research infrastructures 35% and 27%, respectively, experience a gap. Most of the respondents to this survey are industry representatives and a more realistic picture, if all R&D actors (i.e. Universities) were included, would most likely indicate a larger gap between existing and needed applied and basic research infrastructures.

As much as 58% of the respondents indicate a perceived need for a hydrogen test center. Such a test center may contribute to improved national cooperation and create valuable synergies from joint forces within the Norwegian hydrogen community, and hence, facilitate the technology development. The planned Energy Park in Lillestrøm may cover some of this need especially in the Oslo region, but a national hydrogen test center may not be realizable in the near future. However – it is foreseen that regional, specialized test centers, preferably linked to the major R&D institutions, should be established as parts of a virtual infrastructure network. The defined needs for advanced, unique test facilities could be covered (at least to some extent) by coordination of the existing infrastructures in an organized network. This idea is amplified by the fact that 50% of the partners in *Survey A* indicate that their company possess research infrastructure that could be made accessible for such a network, either in form of direct access for external partner or through internal operators.

The major obstacles for development of a national hydrogen test center are defined by the Norwegian hydrogen market and the available funding schemes. The need for additional funding in order to take hydrogen technology to the next level and consequently to market is evident, and pointed out by 50% of the survey participants. Several actors in the field are small, and hence have limited financial resources for investment in specialized infrastructure. Use of external research institutes is also financially restricted and the limited funds available inhibit initiation of new hydrogen activities. Funding from the Research Council of Norway (RCN) in form of Innovation Projects and Researcher Projects are found most attractive, however, there is a growing interest in the EU funding schemes as well. The Fuel Cell and Hydrogen Joint Undertaking program is interesting, however, with the low funding level (now increasing) there is an immediate need for a permanent tool for top financing by RCN for projects under this program.

It is also noted that 35% of the respondents indicated a gap between existing and needed competence, hence there is likely room for a better coordination of the hydrogen related educational programs. More involvement from the industrial partners may be needed for pointing out relevant directions for the academia to consider in the education of new students.

The Norwegian market in the field of hydrogen technology is currently quite limited with little involvement from the large industrial companies. It is therefore important that the Norwegian research activities are somewhat coordinated, not only on national level, but also internationally. This is highlighted in the next chapter of this report where some actions taken to facilitate increased collaboration and sharing of infrastructures are suggested.

4 Nordic / international collaboration

The first survey (Survey A), discussed in the previous chapters, unveiled a clear need for increased access to research infrastructures while available funding for realizing such infrastructure are currently insufficient. It is therefore apparent that better coordination of already existing infrastructures is a good starting point that should be pursued before considering realization of a larger national hydrogen test center. A natural step will include establishment of regional, specialized test center(s) linked to the major R&D institutions. Norway is a small country with limited activity in the field of hydrogen technology research and the bulk part of the engaged industrial partners consists of SMEs. From a broader perspective it is highly recommended to coordinate the on-going national hydrogen activities with other countries – the Nordic countries being an obvious possibility that deserves more attention. Through the *HyPilot* project activity SINTEF has established a close connection with partners in Sweden, Denmark and Finland (Chalmers, Risøe/DTU and VTT, respectively) with a confirmed commitment to cooperate on establishing test capacity for hydrogen and fuel cell technologies in the Nordic countries. The initiative is not limited to the partners involved, and each partner of this group will act as a national representative for the individual countries.

For further extension outside the Nordic countries it should be mentioned that IFE and SINTEF are partners in a European Initiative, the *H2FC project*, established to integrate the European R&D community around rare and/or unique infrastructural elements that will facilitate and significantly enhance the R&D outcome. In this project leading European R&D institutions in the hydrogen field are gathered with those of the fuel cell community, covering the entire energy-chain, i.e. hydrogen production, storage, distribution, and final use in fuel cells. In addition to networking and joint research activities the project strongly focuses on transnational access for the *H2FC* R&D communities to advanced infrastructures. Such access is not limited (however not unrestricted) to the partners of the consortium access. IFE and SINTEF should act as representatives for the Norwegian hydrogen and fuel cell community as a whole, and inform of the possibilities within the *H2FC project*.

5 Mapping of existing infrastructure and competence (Survey B)

In parallel to the Survey A, involving the commercial stakeholders investigating their experienced needs, another survey (Survey B) was conducted among the educational institutions and research institutes. The aim of Survey B was to establish the basis for being able to draw conclusions in the *HyPilot* project (See Why).

Why

1) To establish the required information needed to identify the gap (existing minus needed) with respect to research infrastructure and need for a hydrogen technology test center.
2) To identify active groups / (present) stakeholders.
3) To provide an overview of the present situation, who – what – where - in hydrogen research in Norway, in one report.

What and Where

1) Available competence, including selected relevant publications
2) Recent and on-going research activities (project list)
3) Available infrastructures

How

Organizations known to be active in the field were asked to fill in a questionnaire and provide information (fill in questionnaire) according to predetermined headings (See Appendix B), to ensure that information from the contributors was consistent, and in accordance with needed information. Seven institutions, spread over 20 subdivisions (i.e. institutes, faculties), contributed to the survey, giving a good representation of the different hydrogen activities on national basis.

Survey results

The complete results from Survey B are presented in Appendix B (The Guide to Norwegian competence and infrastructure on H_2 research and technology development in the Research and Educational sector, a.k.a. "The Guide"), including some statistics based on the answers obtained. Competence and infrastructure is explicitly listed by contributor (as obtained by the individual respondents). In addition a list of recent project activities is given (considered to be comprehensive enough to give an introduction to identify most of the major fields of interest). It should be noted that the list is not exhaustive. In addition, infrastructure information was also compiled in a database in order to simplify finding relevant information in the Guide. The database was used to sort the infrastructure data according to selected criteria. Three tables with different structuring of the data are presented at the end of the Guide.

6 Overall summary / discussion

Although still with relatively low market penetration in Norway, technology based on hydrogen as an energy carrier is an important research field. It is envisioned that hydrogen technology will play a central role in the energy landscape in the not so distant future. This is confirmed through the European Strategic Energy Technology (SET)-plan, in which these technologies are pinpointed as crucial enabling technologies to reach the long term goals set out for Europe. The *HyPilot* project has aimed to investigate the need for and – if applicable – the nature of a national pilot test center for hydrogen technologies. A thorough gap analysis was performed based on two questionnaires developed within the project and the corresponding input from the stakeholders.

The perceived needs for research infrastructure and test facilities among 26 industrial partners (including 3 research institutes) active in the hydrogen field were investigated in a first survey (Survey A). Based on the responses given, there is definitively an uncovered need for improved coordination of R&D and Demonstration services within the Norwegian commercial H_2 technology community, aimed at bringing technology to the market. The Norwegian hydrogen industrial community consists primarily of small and medium-sized enterprises (SMEs) in terms of involvement, whereas the large industrial companies have had limited engagement over the last 5 years. By their nature, the SMEs do not have the financial resources to establish and operate infrastructure beyond the laboratory scale. In fact, 46% of the respondents to the survey reported experiencing a gap when it came to access to pilot- and demonstration scale infrastructure. The perceived need for infrastructure in SMEs is however not limited to the pilot and demo scale. Whereas large industrial companies often have in-house access to basic characterization equipment, some smaller companies lack these capabilities and therefore need to purchase external services. However, for many small companies, the cost of external services is perceived as too high. A majority of the national actors in this field point to "funding and funding tools" as major obstacles limiting the progress in their current research and development activity. Although not a primary conclusion of this work, it was noted, within the survey, a question was posed concerning the attractiveness of various funding sources. It is apparent from this that due to the low level of funding in the European FCH JU-program many SMEs do not find this funding scheme attractive. The level of funding from this program is currently increasing somewhat and will therefore become more attractive in the future, however, significant co-funding is still be needed, especially for SMEs and research institutes with low basic funding.

HyPilot was initiated as a pre-project to map the need for a hydrogen test center initiative were one envisioned a localized national center for multiple test possibilities. The majority (58%) of the respondents to the survey reported a perceived need for a hydrogen technology test center, either currently or in the future. The nature of the national commercial market related to size, stability, and funding availability, is likely not sufficient to give a nation-wide localized center model a stable customer basis over time at present. A localized national center for pilot testing of H_2 technologies may not address the needs of the H_2 research community for a variety of reasons discussed in this document, including accessibility, financing, etc. However, there is a significant requirement for access both to test facilities and to more generic research infrastructure, some of which already exist. A regional approach may therefore be a better suited with testing facilities for specific technologies and concepts. The regional test center(s) should preferably be linked to the major R&D institutions deeply involved in development of hydrogen and fuel cell technologies. This will increase the potential for value creation linked to the investments. Cooperation in the R&D community on establishing virtual centers on specialized fields could be a short-term solution until the commercial market grows to a more robust size. Half of the respondents reported having infrastructure (some with restrictions on operator affiliation) that could be made available for such a virtual network.

Existing R&D and Demonstration needs can be better covered today by coordination of existing resources, and as a stimulus knowledge of existing national infrastructure and competence should be made more available. A first attempt of this is provided in this report via Appendix B, covering a survey of the current situation in the educational institutions and research institutes. This survey covers mapping of available research infrastructure, competence and on-going activities based on contributions from 7 institutions, spread over 20 subdivisions (i.e. institutes, faculties). The extensive overview is gathered in the guide document presented in Appendix B of the present report. This initiative should be followed up, i.e. to prepare an update and open for addition of missing information and input from new actors in the field of hydrogen technology. The guide is a valuable tool that could promote new collaborations and be used as a basis to initiate a national network providing access to needed test facilities in the future. Establishment of robust and stable financial instuments for upgrades of existing infrastructure and new investments will be essential for a successful the national needs for test facilities could be covered through a coordinated network.

In order to increase the customer base for a hydrogen test center network and thereby ensuring high utilization of investments, international cooperation is crucial, for example through participation in a Nordic or European research infrastructure community. A Nordic cooperation agreement is under development for establishing common test capacity for hydrogen and fuel cell technologies. On a European level a project with focus on transnational access for the hydrogen and fuel cell communities to advanced infrastructures has already been established (H2FC). The Norwegian partners in these Nordic and European alliances should assure good communication with the rest of the national hydrogen and fuel cell community in order to facilitate fruitful collaborations on both national and international levels.

Acknowledgement

The authors would like to thank all the hydrogen stakeholders from industry, research institutes and universities for responding to the distributed questionnaires, and hence, providing the essential input for completing this project. The conclusions are drawn and recommendations provided upon these invaluable inputs. Special thanks go to Dr. Ulrich Bünger, Prof.II at NTNU and Prof. Hilde Johnsen Venvik at NTNU for their contribution to the work. The project could not have been completed without the financing from the Research Council of Norway, under the auspice of project number 197713/V30.

Technology for a better society

Appendix A

Welcome to HyPilot

A survey on infrastructure needs for hydrogen technologies

Name of Company:

Location (city, country)

Contact person

Name:

e-mail:

Telephone no.:

Forskningsrådet | NTNU – Trondheim Norwegian University of Science and Technology | SINTEF

Q1: Your company's overall field of business

Q1a: Please rank according to importance the Hydrogen sources your company uses

- ☐ Renewable energy/H_2O splitting
- ☐ Natural gas
- ☐ Diesel
- ☐ Ethanol
- ☐ Biomass
- ☐ Other (please specify)
- ☐ N/A

Q1b: Please indicate all areas of hydrogen technology in which your company is involved:

Hydrogen Production (incl. purification)

- ☐ Reforming / partial oxidation of fossil fuels
- ☐ Reforming / partial oxidation of biomass
- ☐ Water electrolysis (low/high temperature)
- ☐ By-product hydrogen
- ☐ Pyrolysis (Biomass to Hydrogen,BtH)
- ☐ H_2O splitting
- ☐ Photo-electrochemical production
- ☐ Purification - Fuel quality
- ☐ Links to Energy resource (e.g., wind, PV)
- ☐ Other (please specify)

Hydrogen Storage and Distribution

- ☐ Liquefied H_2
- ☐ Liquid H carriers (e.g. CH_3OH, liq. NH_3)
- ☐ Solids for storage (chemical & physical)
- ☐ Pressurized H_2
- ☐ Underground storage (e.g. aquifers)
- ☐ Bulk H_2 transport
- ☐ Pipeline transport
- ☐ Materials related issues
- ☐ H_2 fuelling station components
- ☐ Other components (please specify)
- ☐ Other (please specify)

Hydrogen End-Use / Systems

- ☐ Engines (ICEs) and Turbines
- ☐ Fuel cells
- ☐ Hybrids (& buffer) system technologies (incl. batteries & capacitors)
- ☐ Hydrogen stand-alone power systems (HSAPS)
- ☐ System integration (vehicles, vessels, etc.)
- ☐ Components (please specify)
- ☐ Other (please specify)

Cross cutting issues

- ☐ Demonstration
- ☐ Education/Outreach
- ☐ 3rd party verification (="Approval" of systems/components)
- ☐ Safety issues (regulations, codes and standards)
- ☐ Standardization
- ☐ Other (please specify)

Q2: Identification of research infrastructure needs
Does your company experience a gap between its needs and the available research infrastructure[i]? If so - what is the nature of this gap? Could external institutions[1] bridge this gap?
☐ **Field 1)** Infrastructure for pilot testing and technology demonstration purposes
Perceived gap:
What is required to bridge the gap?
☐ **Field 2)** Applied research infrastructure (for proof of concept, etc.)
Perceived gap:
What is required to bridge the gap?
☐ **Field 3)** Basic research infrastructure (materials synthesis and characterization, etc.)
Perceived gap:
What is required to bridge the gap?

[1] e.g. universities, research institutes or a hydrogen technology test center

***Q3:** Identification of competence and funding needs*

Does your company experience a gap between its needs and available competence[ii] and/or funding[iii]? If so - what is the nature of this gap? Could external institutions[2] contribute to bridging this gap?

☐ **Field 4)** Competence

Perceived gap:

What is required to bridge the gap?

☐ **Field 5)** Funding

Perceived gap:

What is required to bridge the gap?

Input for shaping of future calls for project proposals: Which funding sources[iv] do you find attractive/unattractive for financing research projects, and why?

	Currently	Future (5-10 years)
EU: Capacities		
EU: FCH-JU		
EU: other		
Competence projects		
Innovation projects		
Researcher projects		
Own financing		
Other (please specify)		

Comments:

[2] e.g. universities, research institutes or a hydrogen technology test center

Q4: Mapping your company's preferences for a hydrogen technology test center[v]
Q4a: Does your company currently use external research resources, e.g. by sending own employees to use infrastructure elsewhere or by outsourcing tasks? Comment:
Q4b: Does your company currently have infrastructure that could be included as a part of a virtual (distributed) test center network, i.e. infrastructure that you could make available to other parties (either by allowing external users to use the infrastructure or by performing selected tasks for such users)? Comment:
Q4c: Do you feel there is/might be a need for a hydrogen technology test center?
Q4d: How does your company envision meeting its infrastructure needs in the future? (Check all that apply). ☐ In-house infrastructure ☐ Infrastructure owned by industrial partners ☐ Infrastructure owned by research partners (universities / research institutes) ☐ Hydrogen technology test center (new) ☐ Existing national / international research infrastructure Please specify if possible:

(question continued on the next page)

Q4e: What would be important factors for you to utilize the service(s) of a hydrogen technology test center (Check all that apply)

- ☐ Location (please specify)
- ☐ Proximity / link to competence institutions
- ☐ Financing / cost
- ☐ Uniqueness of infrastructure
- ☐ R&D support personnel
- ☐ Certification / verification possibilities
- ☐ Health, safety and environment (HSE) issues
- ☐ Education of industry personnel
- ☐ Seminars / work shops
- ☐ Development of testing protocols
- ☐ Basic research infrastructure
- ☐ Applied research infrastructure
- ☐ Lab scale testing facilities
- ☐ Pilot scale testing facilities
- ☐ High pressure testing capabilities
- ☐ High/low temperature testing capabilities
- ☐ Materials testing
- ☐ Component testing
- ☐ Prototype testing
- ☐ Other (please specify):

Q4f: Are there any specific test methods, services, pressure/temperature ranges, etc. you would like to see included in a hydrogen technology test center? Please specify:

Q4g: How would you have liked a hydrogen technology test center to be organized? (Check all that apply)

- ☐ Open access, where external users can come to the center to use the infrastructure (etc). Basic supporting personnel available (project based)
- ☐ Test center with research personnel performing defined and standardized tests for customers (project based)
- ☐ A centralized hydrogen technology test center physically located in:
- ☐ A main hydrogen technology test center physically located in: with infrastructure "satellites" located with industry/universities/research institutes
- ☐ A network[3] of existing and new research infrastructure
- ☐ Other (please specify):

[3] virtual (distributed) network, where companies and institutions make their infrastructure available to external operators, alternatively provide services for external clients using internal operators

We would like to have your opinion on trends and future (5-10 years) perspectives in the field of hydrogen technology. Your answers may be used as input to the process of shaping calls for project proposals in the future.
***Q5:** Please give your opinion on trends in the following H_2-related areas:*

Q5a: Hydrogen as an energy carrier

National public opinion (acceptance)	
National use	
International public opinion (acceptance)	
International use	

Comment:

Q5b: Market for hydrogen technologies

National market	
International market	

Comment:

Q5c: Which are, in your opinion, presently the most important market drivers for hydrogen technology?

Q5d: What are the major bottlenecks that your company encounters regarding initiating and/or running research projects? Examples: IPR, financing, networking, competence, capacity, risk of project denial (hampering long-term planning), Norwegian Research Council research program guidelines etc. Please elaborate.

Thank you for your contribution!

Appendix I: Recipients of the questionnaire[4]

- Aetek
- AGA AS
- Buskerud University college
- Carbontech Holding AS
- Cenergie Corp. Nordic AS
- Christian Michelsen Research AS
- Det Norske Veritas
- Eidesvik Off-shore ASA
- Energiparken AS
- Energy Development AS
- Energy Norway
- FFI
- Fremo AS
- Gasnor AS
- GasPlas
- GexCon AS
- Hydrogen Technologies
- HyNor Lillestrøm
- Hystorsys
- IFE
- Nordic Power Systems
- NorECS
- n-Tec AS
- Protia
- Prototech
- Raufoss Fuel Systems
- Risavika Gas Centre
- Siemens
- SINTEF
- Statkraft
- Statoil
- Tel-Tek/GassTEK
- Wärtsilä
- ZEG Power AS

- H2 logic (DK)
- Hydrogen Link (DK)
- Powercell (SE)
- Vätgass Sverige (SE)
- Intelligent Energy (GB)
- NedStack (NL)

[4] A few international stakeholders are also invited to join this survey as an initial investigation into the international interest in a Norwegian-based Hydrogen technology test center.

Appendix II: Definitions

[i] Research infrastructure in this context has a wide scope, including (but not limited to) "hard and soft" equipment, including systems, centers, networks, etc. ranging from lab scale research to demonstration scale testing, software development, control system development, design tools, verification and certification facilities, etc.

[ii] Knowledge and know-how, both in personnel and industrial core competence. Availability and capacity of personnel with the right competence (in-house or externally, nationally and internationally), including production of an adequate number of Masters and PhDs in the right areas.

[iii] Level and type of funding from various sources (e.g. the Research Council of Norway and EU), as well as the relevance and scope of research programs, etc.

[iv] Links to information on relevant funding sources for research projects in Norway and Europe:

Financing scheme	See description and requirements here:
Competence project	http://www.forskningsradet.no/en/Knowledgebuilding_project_for_the_business_sector/1253963988225
Innovation project	http://www.forskningsradet.no/en/Innovation_project_in_the_business_sector/1253963988186
Researcher project	http://www.forskningsradet.no/en/Researcher_project/1195592882768
EU (general)	http://cordis.europa.eu
EU (Capacities)	http://cordis.europa.eu/fp7/capacities/home_en.html
EU (FCH-JU)	http://ec.europa.eu/research/fch/index_en.cfm

[v] A tool to facilitate the introduction of H_2 technologies in the market. The market needs in terms of the hydrogen technology test center nature, content (research infrastructure), location (including whether it should be localized or virtual) and type (research, development, verification, demonstration profile, etc.) is to be investigated through this questionnaire.

Appendix B

The Guide to Norwegian competence and infrastructure on H_2 research and technology development in the Research and Educational sector

The HyPilot project, 2010 - 2011

Contents

1. Introduction

1.1 Information key (organization - infrastructure - competence)

Tables 1 – 3 provide information about the organizational units included in the survey, their respective field of research, as well as the page number for further information about either infrastructure or competence.

- **P** = Production
- **S-D** = Storage and Distribution
- **E** = End-use
- **C** = Cross-cutting issues

Table 1. SINTEF – information key

Org. Units	Gemini Center	Category	Competence (see page)	Infrastructure (see page)
SINTEF Materials and Chemistry				
Applied mechanics and Corrosion		S-D	8	52
Energy conversion and materials	Materials & Energy	P , E, C	12	54
Process Chemistry	KinCat, CatMat	P , S-D	15	55
Synthesis and Properties		P, S-D, C	20	57
SINTEF Energy				
Energy processes		E, S-D	23	58
Energy systems		P, E, C	60	60
SINTEF IKT				
Applied Cybernetics		P, C	26	61
SINTEF Marintek		S-D, E	65	65

Table 2. NTNU – information key

Org. Units	Gemini Center	Category	Competence (see page no.)	Infrastructure (see page no.)
NTNU, Fac. of Nat. Science and Techn.				
Chemical Engineering	KinCat	P, S-D	15	55
Material Science and Engineering	Materials & Energy	P, E	29	63
NTNU, Fac. of Eng. Science and Techn.				
Engineering Design and Materials			32	62
Energy and Process Engineering		E, S-D	23	58
Marine Technology		E	65	65

Table 3. CMR-Prototech / IFE / HiT / UiB / UiO – information key

Org. Units	Gemini Centers	Category	Competence (see page no.)	Infrastructure (see page no.)
CMR - Prototech		P, S-D, E,C	34	68
Institute for Energy Technology (IFE)				
Physics		S-D	36	69
Environmental technology		P	39	70
Telemark Univ. College, Fac. of Techn.				
Combustion, Explosion and Process Safety		C	43	71
Gas Processing		E	46	72
University in Bergen (UiB), Phys. & Techn.				
Group multiphase systems		E	48	73
University in Oslo (UiO)				
Chemistry	CatMat	P, E, C	50	74

1.2 Contact information

Tables 4 – 6 provides contact information for the relevant organizational units.

Table 4. Contact information; SINTEF

Org. Units	Contacts	Email addresses	Phone
SINTEF Materials and Chemistry			
Applied mechanics and Corrosion	Vigdis Olden	Vigdis.Olden@sintef.no	47 98230434
Energy conversion and materials	Steffen Møller-Holst	Steffen.Moller-Holst@sintef.no	47 92604534
Process Chemistry	Rune Lødeng	Rune.Lodeng@sintef.no	47 98243476
Synthesis and Properties	Ragnar Fagerberg	Ragnar.Fagerberg@sintef.no	47 93059309
SINTEF Energy			
Energy processes	Petter Neksa	Petter.Neksa@sintef.no	47 92606519
	Marie Bysveen	Marie.Bysveen@sintef.no	47 92286113
Energy systems	Magnus Korpås	Magnus.Korpas@sintef.no	47 73597229
	Nils Arild Ringheim	Nils.A.Ringheim@sintef.no	47 92802990
SINTEF IKT			
Applied Cybernetics	Ingrid Schjølberg	Ingerid.Schjolberg@sintef.no	47 93066355
	Frederico Zenith	Frederico.Zenith@sintef.no	47 93053023
SINTEF Marintek			

Table 5. Contact information; NTNU

Org. Units	Contacts	Email addresses	Phone
NTNU, Fac. of Nat. Science and Techn.			
Chemical Engineering	Hilde J. Venvik	Hilde.Venvik@chemeng.ntnu.no	47 92808787
Material Science and Engineering	Svein Sunde	Svein.Sunde@material.ntnu.no	47 73594051
	Frode Seland	Frode.Seland@material.ntnu.no	47 91320529
NTNU, Fac. of Eng. Science and Techn.			
Engineering Design and Materials	Andreas Echtermeyer	Andreas.Echtermeyer@ntnu.no	47 97123217
Energy and Process Engineering	Erling Næss	Erling.Nass@ntnu.no	47 91897970
Marine Technology	Harald Valland	Harald.Valland@ntnu.no	47 73595517

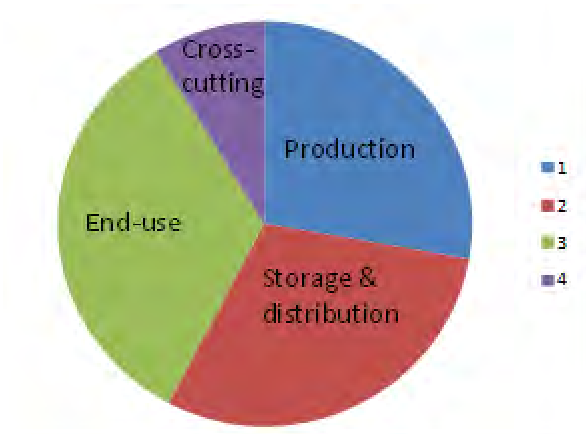
Table 6. Contact information; CMR-Prototech / IFE / HiT / UiB / UiO

Org. Units	Contacts	Email addresses	Phone
CMR - Prototech			
	Ivar Wærnhus	Ivar.Warnhus@prototech.no	47 91157913
	Arild Vik	Arild.vik@prototech.no	47 90893012
Institute for Energy Technology (IFE)			
Physics	Bjørn C .Hauback	Bjorn.Hauback@ife.no	47 22856422
Environmental technology	Julien Meyer	Julien.Meyer@ife.no	47 99460895
Telemark Univ. College, Fac. of Techn.			
Combustion, Explosion and Process Safety	Dag Bjerketvedt	Dag.Bjerketvedt@hit.no	47 35575232
	Knut Vågsæther	Knut.Vagsather@hit.no	47 41683542
Gas Processing	Klaus J. Jens	Klaus.J.Jens@hit.no	47 35575193
Univ. Bergen (UiB), Phys. & Techn.			
Group multiphase systems	Alex C. Hoffmann	Alex.hoffmann@ift.uib.no	47 55582876
University in Oslo (UiO)			
Chemistry	Truls Norby	T.E.Norby@kjemi.uio.no	47 99257611

2. Results

2.1 Major statistical data

A total of 90 projects (activities) were reported. Budget figures were reported for 55 projects. For 26 of the projects the budget was reported as divided by running year. A total budget of 406 millions NOK was reported for the 55 projects. The type of project, i.e. category, was according to the chart in Figure 1. The distribution of total budgets by year, as received for 26 of the 90 projects, is shown on Figure 2.



ategory (Basis = 90 projects); 1: H_2 production, 2: Storage and Distribution, 3: End-use, 4: Cross-cutting issues

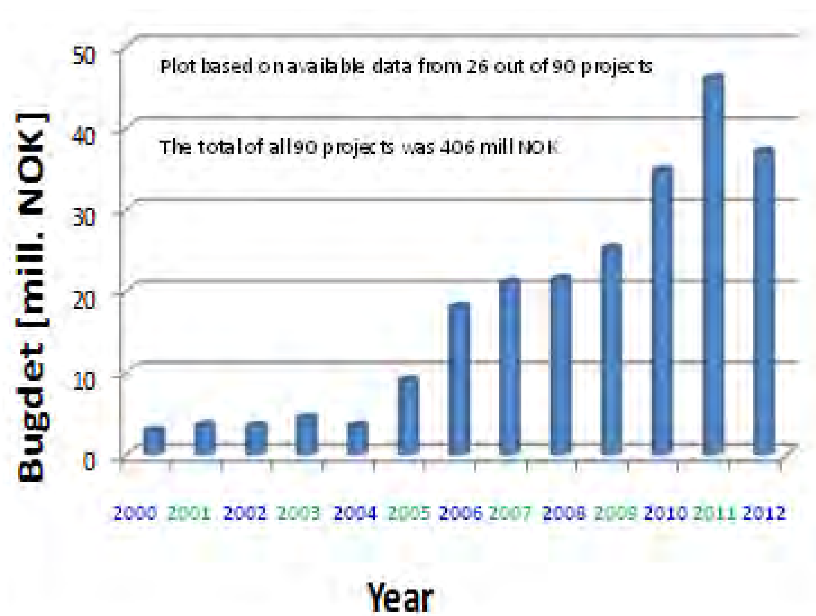


Figure 2: Distribution of total budgets on year (basis = 26 out of 90 projects)

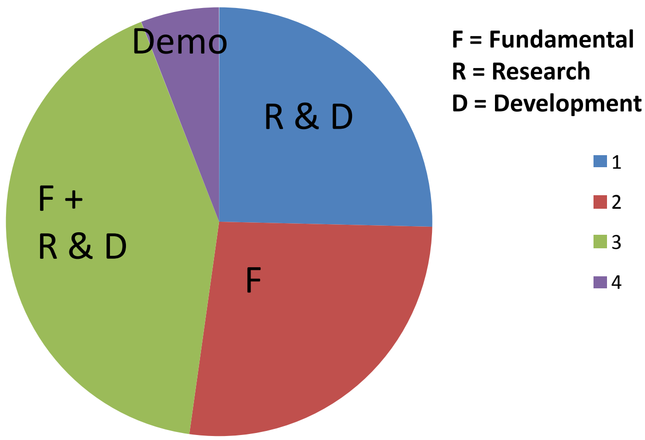


Figure 3: Projects divided by nature (Total basis = 66 projects)

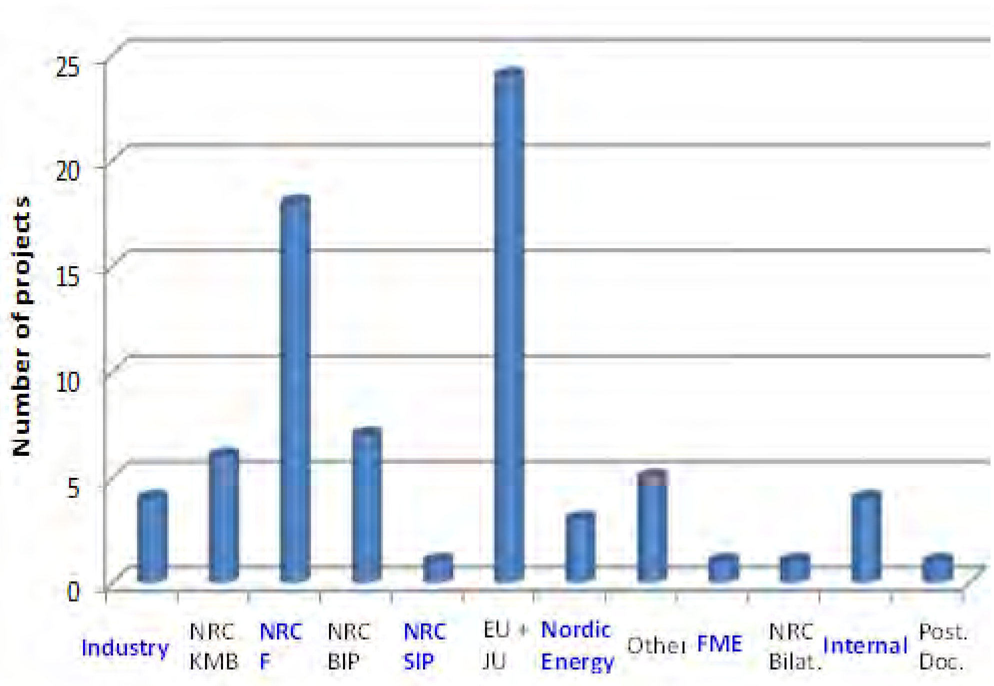


Figure 4; Projects divided by funding type (Total basis = 75 projects).

2.2 Competence by organization

SINTEF MC – Dept. Applied Mechanics and Corrosion

Contact:

Vigdis Olden, Vigdis.Olden@sintef.no

Relevant superior H_2 disciplines (EU 7. FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Distribution
- Cross-cutting

Subjects and disciplines:

- Hydrogen diffusion
- Mechanical and micro mechanical properties
- Degradation mechanisms
- Fracture mechanics
- FE-based material and fracture modeling
- Running fracture in pressurized pipelines

Core competence - H_2 related chemistry and processes:

- Hydrogen diffusion in metals
- Hydrogen influence on micro mechanical degradation (embrittlement) mechanisms in metals.
- Hydrogen influence on tensile fracture mechanics properties of steel.
- Large scale crack arrest testing of hydrogen transporting pipelines

Core competence - H_2 relevant materials:

- Structural CMn Steel
- Martensitic stainless steel
- Duplex stainless steel
- Austenitic stainless steel
- Aluminum

Core competence - System (meaning "combining technologies or functions"):

- Combining hydrogen charging and diffusion with influence on micro mechanical and fracture mechanical properties
- Numerical modeling of running ductile fracture in pressurized pipelines (fluid-structure interaction)

Experimental versus theoretical competence:

Experimental as well as numerical simulations are performed. Theoretical competence of SINTEF researchers are developed in JIPs and industry projects. Close cooperation with NTNU (IPM and Materials technology) on project, Master and PhD level.

Method competence ("How we do it"):

- Testing and characterization
- Small scale and large scale testing
- Testing after charging with hydrogen and in hydrogen containing environment
- FE modeling and simulation
- Close cooperation with NTNU in industry projects, MSc and PhD education and in use of laboratories and test equipment.

Special conditions competence:

- Combined experimental and FE modeling competence are the departments strong point
- Materials testing for practical industrial application and development as well as for input to and verification of finite element models.
- Nature of activities; Alternatives: Basic, applied, development, demonstration

Other H_2 relevant (generic) fields:

- General materials testing and structural finite element analyses competence at all length scales from meso to macro.
- Chemical analyses
- Microstructural and fractographic characterization. Knowledge of steel microstructures and fracture surfaces using
- Optical microscopy and Scanning Electron Microscope (SEM).
- Welding technology (hyperbaric welding)

- Standardized and tailor made testing for Stress Corrosion Cracking (SCC): Four point bend (4PB) , Constant load (CL) (uniaxial tensile type), C-ring (CR), Slow strain rate (SSR)

Strategic cooperation partners - externally:

Established European consortium in previous EU project proposal on multiscale modeling of hydrogen embrittlement: ARMINES Saint-Etienne, France, Universität des Saarlandes, Germany, BMS Steel A.S.. Norway, Institute Prime (UPR CNRS Université de Poitiers ENSMA), France,GKSS-Forschungszentrum, Germany, OCAS N.V - ArcelorMittal Global R&D Gent, Belgium., In large scale testing of hydrogen containing pipes: The university of Tokyo

Selected publications

1) Olden,V., Thaulow, C., Johnsen, R., Østby, E., “Cohesive zone modeling of hydrogen-induced stress cracking in 25% Cr duplex stainless steel” Scripta Materialia 57, 2007, p. 615-618.
2) Olden V., Thaulow C., Johnsen R., Østby E., Berstad T. “Influence of hydrogen from CP on the fracture susceptibility of 25%Cr duplex stainless steel – constant load SENT testing and FE modeling using hydrogen influenced cohesive zone elements”,
3) Eng. Fracture Mech. 76, 2009, p. 827-844 A. Smirnova, R. Johnsen, K. Nisancioglu. “Influence of temperature and hydrostatic pressure on hydrogen diffusivity and permeability in 13% Cr super martensitic stainless steel under cathodic protection”, NACE Corrosion’2010, paper no. 10292, San Antonio, USA (2010)
4) S. Aihara, E Østby, H Lange, K Misawa, Y Imai, C Thaulow, "Burst test for high pressure hydrogen gas line pipe", proceedings IPC 2008, 7th Int. Pipeline Conf., Sept Oct 2008, Calgary Canada, ASME IPC 2008-64166
5) S. Aihara, H Lange, K Misawa, Y Imai, Y Sedei, E Østby, C Thaulow, "Full scale Burst test of hydrogen gas X65 pipeline", proceedings IPC 2010, 8th Int. Pipeline Conf., Sept Oct 2010, Calgary Canada, ASME IPC 2010-31235
6) Berstad T., Dørum C., Jakobsen J. P., Kragset S., Li H., Lund H., Morin A., Munkejord S. T., Mølnvik M. J., Nordhagen H. O., Østby E. (2010). CO2 pipeline integrity: A new evaluation methodology. International Conference on Greenhouse Gas Technologies (GHGT-10), Amsterdam, Sept. 19 - 23

Relevant PhDs

1) FE modeling of hydrogen induced stress cracking in 25% duplex stainless steel, V. Olden, NTNU 2008:129
2) Hydrogen permeation in 13% Cr supermartensitic stainless steel and API X70 pipeline steel, A. Smirnova, NTNU 2010:208
3) A. Alvaro, Modeling of Hydrogen Embrittlement in X70 steel welds, DEEPIT project, Thesis defence at NTNU in 2013

SINTEF MC – Dept. Energy Conversion and Materials

Contact:

Research manager Steffen Møller-Holst, steffen.moller-holst@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End-use
- Cross-cutting issues

Subjects and disciplines:

- Electro chemistry
- Inorganic chemistry
- Material science

Core competence - H_2 related chemistry and processes:

- Electrocatalysis and photo-electrocatalysis
- Water electrolysis
- Methane Steam Reforming (MSR) and Water Gas Shift (WGS) membrane reactors
- Hydrogen separation by membranes
- Low temperature PEM and alkaline fuel cells
- High temperature fuel cells (SOFC and PCFC)

Core competence - H_2 relevant materials:

- Pd-based membranes
- High temperature dense ceramic membranes (mixed oxides)
- Ceramic electrolyte materials
- Ceramic and metallic electrode materials and interconnects
- Pt/Ir/Ru-based catalyst
- C/nano fiber/ATO-based catalyst supports

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

Method competence ("How we do it"):

Patented routes for fabrication of thin Pd-based membranes on porous supports
Ceramic forming and coating methods: extrusion, slip-/tape-/centrifugal casting, spin-/spray-/dip-coating

Special conditions competence:

Membrane and material testing in high pressure/high temperature conditions in various gas mixtures

Nature of activities; Alternatives: Basic, applied, development, demonstration

Basic and applied

Other H_2 relevant (generic) fields:

- Cleanroom for preparation of Pd membranes
- Ceramics lab & extrusion lab for fabrication of ceramic membranes/fuel cells

Strategic cooperation partners - internally

- SINTEF Energy Research
- SINTEF Materials and Chemistry, Dept. of

Strategic cooperation partners - externally:

- NTNU and UiO
- EU Networks (European Membrane House, NanoMemPro Network of Excellence,…..)
- CIRIMAT, France

Selected publications

1) Helge Weydahl , Thomassen Magnus Skinlo , Børre T. Børresen , Møller-Holst Steffen, Response of a proton exchange membrane fuel cell to a sinusoidal current load, Journal of Applied Electrochemistry 40, 4, 809-819 (2010)
2) "Stiller Christoph, Svensson Ann Mari , Rosenberg, Eva , Møller-Holst Steffen , Bunger Ulrich, Building a Hydrogen Infrastructure in Norway, , World Electric Vehicle Journal 3, 1-10 (2009)"
3) Stiller Christoph , Bunger Ulrich , Møller-Holst Steffen , Svensson Ann Mari , Espegren, Kari , Nowak, Mathias, Pathways to a Hydrogen Infrastructure in Norway, International Journal of Hydrogen Energy 24, 1, 234 (2009)

4) Mejdell Astrid, Chen De, Peters Thijs, Bredesen Rune, Venvik Hilde, The effect of heat treatment in air on CO inhibition of a ~3 µm Pd-Ag (23 wt. %) membrane, Journal of Membrane Science, Volume 350, Issues 1-2, 15 March 2010, Pages 371-377

5) Peters Thijs, Stange Marit Synnøve Sæverud, Klette Hallgeir, Bredesen Rune (2008). High pressure performance of thin Pd-23%Ag/Stainless Steel composite membranes in Water Gas Sift gas mixtures; influence of dilution, mass transfer and surface effects on the hydrogen flux. Journal of Membrane Science 316 (1-2), 119-127

6) Fontaine, Marie-Laure, Larring Yngve, Smith Ivar Eskerud, Ræder, Henrik, Andersen, Ø.S., Einarsrud, M.-A., Wiik, K., Bredesen Rune (2009). Shaping of advanced asymmetric structures of proton conducting ceramic materials for SOFC and membrane-based process applications, Journal of the European Ceramic Society 29 (5), 931-935.

SINTEF MC – Dept. Process Chemistry
NTNU – Faculty of Natural Sciences and Technology, Dept. Chem. Eng.

Contacts (KinCat Gemini Center):

SINTEF; Senior Scientist Rune Lødeng, Rune.Lodeng@sintef.no
NTNU; Professor Hilde J. Venvik, Hilde.Venvik@chemeng.ntnu.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, Storage and distribution, End use, Cross-cutting issues

- Production (of H_2)
- Storage ("Liquid hydrogen carriers", as well as CNF)

Subjects and disciplines:

- Heterogeneous catalysis
- Reaction kinetics
- Process technology and chemical engineering
- Surface science

Core competence - H_2 related chemistry and processes:

- Natural gas conversion (industrial and emerging processes)
- Reforming (steam, dry, autothermal, sorption enhanced)
- Water-Gas Shift, PROX (Selective oxidation of CO in H_2 rich gas), methanation
- Dehydrogenation (dominantly $C_3H_8 = C_3H_6 + H_2$)
- Catalytic synthesis of H-carriers (CH_3OH, DME, Diesel, wax) from natural gas
- Biomass utilization (reforming of model compounds to syngas/H_2, syngas chemistry)
- Catalyst deactivation
- Micro kinetic modeling
- Core competence - H_2 relevant materials:
- Catalyst development
- Porous materials
- Carriers (ceramics, gauzes, foams, etc.) and catalysts
- Oxides (single oxides, mixed oxides, hydrotalcites, spinels, etc.)
- Absorbents (for CO_2); Silicates, Carbonates
- Carbon NanoFibres (CNF)

Core competence - System (meaning "combining technologies or functions"):

- Combining reforming reactions and membrane separation (Pd-based)
- Combining reforming reactions and CO_2 adsorption

Experimental versus theoretical competence:

- Practical studies are emphasized
- Evaluation of technologies (including techno-economic pre-studies with NTNU)

Method competence ("How we do it"):

- Laboratory scale processes (test rigs with controlled flows (gas + liq.), pressure, temp.)
- Reactor design and construction (quartz and special alloys)
- Catalyst preparation
- Testing and characterization
- Analysis (gas chromatograph (GC), mass spectrometer (MS), spectroscopy (IR, UV, etc.)
- Characterization (bulk, surface, … surface science)
- Modeling (global kinetics and micro kinetics, some reactor modeling)

Special conditions competence:

Performing practical studies at industrial pressures and temperatures

Nature of activities; Alternatives: Basic, applied, development, demonstration

- Basic and applied (often combined as (contract) research project
- Educational; PhD and Post doctors

Other H_2 relevant (generic) fields:

- Hydrotreatment; Cleaning and upgrading of fossil oils (environment, quality)
- Upgrading of bio-oils (deoxygenation)
- Hydro (cracking, isomerization), hydrogenation, hydrogenolysis
- Methanisation (synthetic natural gas)
- Decomposition of light alkanes and alkenes to Carbon Nano Fibres (CNF) and H_2
- Pyrolysis of natural gas to olefins, acetylene, benzene and H_2

Strategic cooperation partners - internally:

- "KinCat" Gemini center; SINTEF MK Hydrocarbon Process Chemistry - Catalysis - together with IKP (NTNU) / Sharing laboratories, equipment and personnel resources
- SINTEF MK - Synthesis and properties (standard and advanced characterization)

Strategic cooperation partners - externally:

- Forschungszentrum Karlsruhe (supplier of micro structured reactors)
- NTNU university network (professors network)
- EU networks (Network Industrial Catalysis Europe, NICE)
- CATMAT gemini center, SINTEF MK Hydrocarbon Process Chemistry together with catalysis group at UiO (Prof. Unni Olsbye and others)

Selected publications

1) Bjørn Christian Enger, J. Walmsley, R. Lødeng, E. Bjørgum, Peter Pfeifer, Klaus Schubert, H. J. Venvik, A. Holmen, Reactor performance and SEM characterization of Rh impregnated micro channel reaction in the catalytic partial oxidation of methane and propane, Chem. Eng. J. 144, 489-501 (2008)
2) De Chen, Rune Lødeng, Kjersti Omdahl, Arne Anundskås, Ola Olsvik, Anders Holmen, "A model for reforming on Ni catalyst with carbon formation and deactivation", ISCD, Lexington, USA – october 2001. Stud. Surf. Sci. Catal., (Eds. Spivey, Roberts, Davis), Vol. 139, 93 –100 (2001)
3) Esther Ochoa-Fernandez, Claudia Lacalle-Vila, Kjersti O. Christensen, John C. Walmsley, Manus Rønning, Anders Holmen, De Chen, Ni catalysts for sorption enhanced steam methane reforming, Topics in Catalysis, vol. 45, nos 1-3 (3-8) 2007
4) Ingrid Aartun, Hilde J. Venvik, Anders Holmen, Peter Pfeifer, Oliver Görke, Klaus Schubert, Temperature profiles and residence time effects during catalytic partial oxidation and oxidative steam reforming of propane in metallic microchannel reactors, Catalysis Today 110, 98 - 107 (2005)
5) K.O. Christensen, D. Chen, R. Lødeng, A. Holmen, Effects of supports and Ni crystal size on carbon formation and sintering during steam methane reforming, Applied Catalysis A: General 314 (2006) 9-22
6) Vidar Frøseth, Sølvi Storsæter, Øyvind Borg, Edd A. Blekkan, Magnus Rønning, Anders Holmen, Steady-state isotopic transient kinetic analysis (SSITKA) of CO hydrogenation on different Co catalysts, Appl. Catal., A: General 289 (2005) 10-15

Relevant PhDs

1) Hamidreza Bakhtiary-Davijany, Performance assessment of a packed-bed microstructured reactor – heat exchanger for methanol synthesis from syngas, PhD dissertation at NTNU 2010: 205
2) Sara Boullosa Eiras, Comparative study of selected catalysts for methane partial oxidation, PhD thesis NTNU 2010: 186

3) Li He, Sorption Enhanced Steam Reforming of Biomass-derived compounds: Process and Materials, PhD thesis NTNU, 2010: 2
4) Astrid Lervik Mejdell, Properties and application of 1-5 micrometer Pd/Ag 23 wt% membranes for hydrogen separation, PhD thesis NTNU 2009: 76
5) Hilde Meland, Preparation and characterization of Cu- and Pt-based water-gas shift catalysts, PhD thesis NTNU 2008: 123
6) Bjørn Christian Enger, Hydrogen production by catalytic partial oxidation of methane, PhD thesis NTNU 2008:327
7) Silje Fosse Håkonsen, Oxidative dehydrogenation of ethane at short contact times, PhD thesis NTNU 2008: 188
8) Nina Hammer, Au-TiO2 catalysts supported on carbon nanostructures for CO removal reactions, PhD thesis NTNU 2008: 269
9) Øyvind Borg, Role of alumina support in Cobalt Fischer-Tropsch synthesis, PhD thesis NTNU 2007: 56
10) Hilde Dyrbeck, Selective catalytic oxidation of hydrogen and oxygen-assisted conversion of propane, PhD thesis NTNU, 2007: 194
11) Esther Ochoa-Fernandez, CO2 acceptors for sorption enhanced steam methane reforming, PhD thesis NTNU, 2007: 130
12) Vidar Frøseth, A steady-state isotopic transient kinetic study of Co catalysts on different supports, PhD thesis NTNU, 2006: 102
13) Kjersti Omdahl Christensen, Steam reforming of methane on different nickel catalysts, PhD thesis NTNU 2005: 46
14) Ingrid Aartun, Microstructured reactors for hydrogen production, PhD thesis NTNU 2005: 131
15) Florian Huber, Nanocrystalline copper-based mixed oxide catalysts for water-gas shift, PhD thesis 2006: 148
16) Erlend Bjørgum, Methane conversion over mixed metal oxides, PhD thesis NTNU 2005: 222
17) Christian Aaserud, Model studies of secondary hydrogenation in Fischer-Tropsch synthesis studied by cobalt catalysts, PhD thesis NTNU 2003: 29
18) Bozena Silberova, Oxidative dehydrogenation of ethane and propane at short contact time, PhD thesis NTNU, 2003: 4
19) Lucie Bednarova, Study of supported Pt-Sn catalysts for Propane Dehydrogenation, PhD thesis 2002: 47
20) Sten Viggo Lundbo, Hydrogenation of carbon monoxide over zirconia and modified zirconia catalysts, PhD thesis NTNU, 2002: 71
21) Thomas Sperle, Steam reforming of hydrocarbons to synthesis gas, PhD thesis NTNU, 2001: 105

22) Marcus Fathi, Catalytic partial oxidation of methane to synthesis gas, PhD thesis NTNU, 2000: 79

23) Ketil Firing Hansen, Cobalt Fischer-Tropsch catalysts studied by steady-state and transient kinetic methods, PhD thesis NTNU 1999: 97

More information in:

Competence fact sheet "Hydrocarbon Process Chemistry" - Hydrogen production and storage"
http://www.sintef.no/Materialer-og-kjemi/Prosesskjemi/faktaark-Prosesskjemi/

SINTEF MC – Dept. Synthesis and Properties

Contact:

Research Manager Ragnar Fagerberg, ragnar.fagerberg@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Storage: Polymer composites for liquid hydrogen storage
- Storage: ab-initio modeling of materials for hydrogen storage
- Production and end use: Materials synthesis (cryo-milling, thin films and nanostructures) for e.g. fuel cells and photocatalysis
- Cross-cutting issues: Surface/interface science
- Cross-cutting issues: Structural and chemical characterization SEM/TEM, electron spectroscopy, sample preparations

Subjects and disciplines:

See above

Core competence - H_2 related chemistry and processes:

~~None~~

Core competence - H_2 relevant materials:

- Metal hydrides
- Oxides, perovskites
- Hydrogen membranes

Core competence - System (meaning "combining technologies or functions"):

None

Experimental versus theoretical competence:

Both are important

Method competence ("How we do it"):

- We generally work with strong interactions between the materials synthesis and the materials characterization. Our abilities to do in situ characterizations are improving (XPS, XRD)
- We have competence on measuring permeability of liquids and gases through polymer matrices.
- We are emphasizing an integrated approach with modeling, synthesis and characterization.
- Many of our techniques are generic, and can be used within a variety of fields

Special conditions competence:

Certain (near) in situ (temperature, gas) regimes can be addressed by XRD/XPS

Nature of activities; Alternatives: Basic, applied, development, demonstration

Basic/applied

Other H_2 relevant (generic) fields:

Strategic cooperation partners - internally:

Strategic cooperation partners - externally:

Selected key publications describing typical activity

1) C.M. Andrei, J.C. Walmsley, H.W. Brinks, R. Holmestad, C.M. Jensen, and B.C. Hauback, 2004, Electron microscopy studies of NaAlH4 with TiF3 additive: Hydrogen Cycling Effects, Applied Physics A-Materials Science & processing 80, (4), 709-715.
2) B. Silberova, H.J. Venvik, J. Walmsley, A. Holmen, 2005, Small-scale hydrogen production from propane, Catalysis Today 100, 457-462.
3) O. M. Løvvik, Viable storage of hydrogen in materials with off-board recharging using high-temperature electrolysis, Int. J. Hydrogen Energy 34 (2009) 2679-2683.
4) C. Qiu, S. M. Opalka, O. M. Løvvik, G. B. Olson, Thermodynamic Modeling of Ti-hydride and Ti Dissolution in Sodium Alanates, Calphad 32 (2008) 624-636.
5) A. Marashdeh, R. A. Olsen, O. M. Løvvik, G.-J. Kroes, A density functional theory study of the TiH_2 interaction with a NaAlH4 cluster, J. Phys. Chem. C 112 (2008) 15759–15764.
6) O. M. Løvvik, S. M. Opalka, Reversed surface segregation in palladium-silver alloys due to hydrogen adsorption, Surf. Sci. 602 (2008) 2840–2844.

7) S. Diplas, J. Lehrmann, S. Jørgensen T. Våland, J. F., Watts and J. Taftø, 2005, "On the development of Ni-B amorphous catalysts used for the hydrogen evolution reaction: Characterisation with XPS and SIMS", Surface and Interface Analysis, 37, 459-465.

8) I.J.T. Jensen, S. Diplas, O.M. Løvvik, J. Watts, S. Hinder, H. Schreuders, B. Dam, X-ray photoelectron spectroscopy study of MgH2 thin films grown by reactive sputtering, Surf. Interf. Anal. 42 (2010) 1140–1143.

9) T. A. T. Seip, R. A. Olsen, O. M. Løvvik, Slab and cluster calculations of the complex hydride $Mg(NH_2)_2$, J. Phys. Chem. C 113 (2009) 21648–21656.

10) S. M. Opalka, O. M. Løvvik, S. C. Emerson, Y. She, T. H. Vanderspurt, Electronic Origins for Sulfur Interactions with Palladium Alloys for Hydrogen-Selective Membranes, J. Membr. Sci. (2011, Accepted)

Relevant PhDs

1) Kianoosh Hadidi, 2008– . UiO. Title: Band-structure density functional calculation on surfaces and electrodes of proton conducting oxides.

2) Ingvild Julie Thue Jensen, 2007– . UiO. Title: Surface studies of hydrogen storage materials

3) Simone Casolo, 2007–2010. UiO, in collaboration with University of Milano (Dr. Rocco Martinazzo). Title: Hydrogen interacting with advanced carbon materials.

SINTEF Energy - Energy processes

NTNU - Energy and Process engineering

Contacts:

SINTEF; Senior Research Scientist, Prof. II, Petter Nekså Petter.Neksa@sintef.no
NTNU; Professor Erling Næss Erling.Nass@ntnu.no
SINTEF; Senior Research Scientist, Marie Bysveen (Marie.Bysveen@sintef.no)

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Storage and distribution
- End-us; H_2 combustion

Subjects and disciplines:

- Liquefaction of hydrogen, processes and components, as well as concepts for distribution chains from production, to filling stations and end use
- Heat and mass transfer aspects of hydrogen storage in ad- and absorptive media. Heat exchanger technology.
- H_2 combustion, especially related to use of H2 as fuel in gas turbines for power generation in IGCC processes

Core competence - H_2 related chemistry and processes:

- Liquefaction processes.
- Chemical kinetics in H_2 combustion
- Aerodynamics, fuel injection, mixing and combustion performance in H2 combustion
- Emissions in H_2 combustion

Core competence - H_2 relevant materials:

Core competence - System (meaning "combining technologies or functions"):

Well-to-end user analysis

Experimental versus theoretical competence:

Experimental as well as theoretical

Method competence ("How we do it"):

Our work is well balanced between theoretical, modeling/simulations and experimental activity, as well as chain analysis.

Special conditions competence:

- Performing practical studies at relevant pressures and temperatures (down to LH2 temperatures)
- Combustion of H_2 at high temperatures and pressures as encountered in gas turbines
- Nature of activities; Alternatives: Basic, applied, development, demonstration
- Applied, as well as development and demonstration

Other H_2 relevant (generic) fields:

Strategic cooperation partners - internally:

- Gemini center Applied Refrigeration Engineering
- NTNU

Strategic cooperation partners - externally:

- Shell Hydrogen, NL
- Linde Kryotechnik, Switzerland
- TU Dresden, Germany
- Max Planck Institute, Stuttgart, Germany
- Sandia National Laboratories (California, USA)
- Deutsche Luft und Raumfahrt, DLR (Stuttgart, Germany)
- Technische Universität München, TUM
- University of California Berkeley

Selected publications

1) Berstad, D., Stang, J. and Nekså, P. (2009): Comparison Criteria for Large-Scale Hydrogen Liquefaction Processes, Int. J of Hydrogen Energy, ISSN 0360-3199, Vol 34 (3), 2009 1560 – 1568

2) Berstad, D., Stang, J. and Nekså, P. (2010): Large-Scale Hydrogen Liquefier Utilizing Mixed Refrigerant Pre-cooling, Int. J. of Hydrogen Energy ISSN 0360-3199, Vol. 35 (10), pp 4512-4523,

3) Jensen, S. and Næss,E. (2009): Sensitivity Analysis of Parameters Related to the Modeling of Adsorption-Type Hydrogen Storage Tanks, Heat Transfer Research, v.40, no. 2, pp.143-164

4) Aleksic, P., Næss, E. and Bünger, U. (2010): Influence of Thermal Effects During Fast Filling Operations on Adsorption Capacity in a Hydrogen Cryo-Adsorption Storage Tank, Proc. 14th Int. Heat Transfer Conf., Washington D.C., USA
5) Aleksic, P., Næss, E. and Bünger, U. (2010): An Experimental Investigation on Thermal Effects During Discharging Operations in a Hydrogen Cryo-Adsorption Storage System, 7th Int. Conf. On Heat Transfer, Fluid Mechanics and Thermodynamics, 19-21 July, Antalya, Turkey
6) Førde, T, Næss, E. and Yartys, V.A. (2009): Modeling and experimental results of heat transfer in a metal hydride store during hydrogen charge and discharge, Int. J. of Hydrogen Energy, v.34, no.12, pp. 5121-5130.
7) A. GRUBER, R. SANKARAN, E. R. HAWKES AND J. H. CHEN. Turbulent flame–wall interaction: a direct numerical simulation study. J. Fluid Mech. (2010), vol. 658, pp. 5–32.
8) R.W. Grout, A. Gruber, C.S. Yoo, J.H. Chen. Direct numerical simulation of flame stabilization downstream of a transverse fuel jet in cross-flow, Proceedings of the Combustion Institute 33 (2011) 1629–1637.

SINTEF IKT – Dept. Applied Cybernetics

Contacts:
Ingrid.Schjolberg@sintef.no
Federico.Zenith@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- Cross cutting issues

Subjects and disciplines:

- Reforming
- Safety, codes and standards
- Fuel cells

Core competence - H_2 related chemistry and processes:

- Small scale reforming (steam, autothermal)
- Natural gas conversion (methanol production)
- Methanol Fuel Cells
- Polymer Fuel cells
- DMFC

Core competence - H_2 relevant materials:

Core competence - System (meaning "combining technologies or functions"):

- Control system design
- Control of small scale reformers
- Safety refueling infrastructure
- ISO/ASME/IEC standards reformer components
- Control of fuel cells
- Experimental versus theoretical competence:
- Experimental and theoretical competence

Method competence ("How we do it"):

- Analysis
- Verification by experiments (mainly related to control of fuel cells)
- Surveys and studies

Special conditions competence:

Nature of activities; Alternatives: Basic, applied, development, demonstration

Applied and development

Other H_2 relevant (generic) fields:

- LNG production
- Compressor control
- Mathematical modeling for control purposes
- Bio coal production
- Small scale reformer design

Strategic cooperation partners - internally:

SINTEF MK

Strategic cooperation partners - externally:

Tokyo Gas, Haldor Topsøe, HyGear, Mahler AGS, Catator, SGC, ENEA, Tübitak, Statoil, GdSuez Max Planck

Selected key publications describing typical activity

https://docs.google.com/viewer?a=v&pid=explorer&chrome=true&srcid=0B_X4z9R5grkBNDNmMDAxZDItNzVlNy00MTJiLWJiZjUtYTg1NTY5N2ExZDhm&hl=en&authkey=CISi_OoG

2) Federico Zenith, Frode Seland, Ole Edvard Kongstein, Børre Børresen, Reidar Tunold, and Sigurd Skogestad. Control-oriented modeling and experimental study of the transient response of a high-temperature polymer fuel cell. Journal of Power Sources, 162:215–227, 2006.

3) Federico Zenith and Sigurd Skogestad. Control of fuel-cell power output. Journal of Process Control, 17:333–347, 2007.

4) Federico Zenith and Sigurd Skogestad. Control of the mass and energy dynamics of polybenzimidazole-membrane fuel cells. Journal of Process Control, 19(3):415–432, March 2009.

5) Federico Zenith and Ulrike Krewer. A simple and reliable model for estimation of methanol cross-over in direct methanol fuel cells and its application to methanol-concentration control. Energy and Environmental Science, 4(2):519–527, 2011.

6) Federico Zenith, Christine Weinzierl, and Ulrike Krewer. Model-based analysis of the feasibility envelope for autonomous operation of a portable direct methanol fuel-cell system. Chemical Engineering Science, 65(15):4411–4419,August 2010.

7) Federico Zenith and Ulrike Krewer. Modeling, dynamics and control of a portable DMFC system. Journal of Process Control, 20(5):630–642, June 2010.

8) Federico Zenith and Ulrike Krewer. Dynamics and control of a portable DMFC system. In Proceedings of the 7th Fuel Cell Science, Engineering and Technology Conference, Newport Beach, California, USA, June 2009.

9) Finn A. Michelsen, Ingrid Schjølberg, Berit F. Lund, 'Dynamic system analysis of a small scale hydrogen production plant', IFAC DyCops, September 2007.

10) Ingrid Schjølberg, Anne B. Østdahl, 'Security and tolerable risk for hydrogen service stations', Technology in Society, 30(1), p.64-70, January 2008

11) Ingrid Schjølberg, Morten Hyllseth, Gunleiv Skofteland, Håvard Nordhus, 'Dynamic analysis of compressor trips in the Snøhvit LNG refrigerant circuits'. ASME Paper no GT2008-51235, Turbo Expo, Berlin, 2008.

12) I. Schjølberg, B.T. Børresen, A.M. Hansen, C. Nelsson, I. Yasuda, 'IEA-HIA Activities on small scale reformers for on-site hydrogen supply', 17th World Hydrogen Energy Conference, WHEC 2008, Brisbane, 15-19 June

13) I. Schjølberg, 'Safety functions for hydrogen service stations', 17th World Hydrogen Energy Conference, WHEC 2008, Brisbane, Australia,15-19 June

14) I. Schjølberg, E.O-Fernandez, C. Nelsson, I. Yasuda, 'IEA-HIA Activities on small scale reformers for on-site hydrogen supply', WHEC, Essen, Germany, 2010.

List of relevant PhDs

1) Federico Zenith. Control of Fuel Cells. PhD thesis, Norwegian University of Science and Technology, Trondheim, Norway, June 2007.

NTNU, Faculty of Natural Sciences and Technology
Department of Material Science and Engineering

Contact:

Svein Sunde (+47 73594051, Svein.Sunde@material.ntnu.no)
Frode Seland (+ 47 73594042, frodesel@material.ntnu.no)

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End-use

Subjects and disciplines:

- Electrocatalysis
- Electrochemical and in-situ characterisation

Core competence - H_2 related chemistry and processes:

- Electrocatalysis
- Characterisation (impedance, AFM-STM etc.)
- Colloidal synthesis

Core competence - H_2 relevant materials:

- Electrocatalysts (metal and bimetallic nanoparticles, core-shell nanoparticles, nanostructured conducting oxides, semiconducting oxides)
- Supports (carbon, to some extent oxides)

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

Strong competence in combining theory and experimental work, in particular impedance

Method competence ("How we do it"):

- Impedance
- General electrochemical characterisation
- Colloidal synthesis

- AFM-STM
- Thermoelectrochemistry

Special conditions competence:

- High-temperature PEM
- Oxidation of small organic molecules
- Nature of activities; Alternatives: Basic, applied, development, demonstration
- Basic and applied

Other H_2 relevant (generic) fields:

Strategic cooperation partners - internally:

- Process Engineering, NTNU
- Inorganic chemistry, NTNU
- Department of Chemistry, NTNU

Strategic cooperation partners - externally:

- SINTEF
- DTU (DK), ICTP Prague (CZ), Danish Power Systems (DK)
- Univ. Newcastle (UK), Univ Montpellier (FR)
- Univ. of Victoria (Canada)
- Univ. Maryland (US)

Selected publications

1) Piotr Ochal, Jose Luis Gomez de la Fuente, Mikhail Tsypkin, Navaneethan Muthuswamy, Magnus Rønning, De Chen, Sergio Garcia, Selim Alayoglu, Bryan Eichhorn, Frode Seland, Svein Sunde, " CO-stripping at Ru@Pt core-shell electrocatalysts", J. Electroanal. Chem., In press (2011)
2) D. Bokach, J.L.G. de la Fuente, M. Tsypkin, P. Ochal, I.C. Endsjø, R. Tunold, S. Sunde and F. Seland, "High-Temperature Electrochemical Characterization of Ru Core pt Shell Fuel Cell Catalyst", accepted for publication in Fuel Cell (2011).
3) Lars-Erik Owe, Ingrid Anne Lervik, Mikhail Tsypkin, Marie Vardenær Syre, and Svein Sunde, "Electrochemical behaviour of iridium oxide films in trifluoromethanesulfonic acid", J. Electrochem. Soc., 157 (2010) B1719

4) A. B. Ofstad, M. S. Thomassen, J. L. Gomez, F. Seland, S. Møller-Holst, and S. Sunde, "Assessment of platinum dissolution from Pt/C fuel cell catalyst: An electrochemical quartz crystal microbalance study", J. Electrochem. Soc., 157 (2010) B621
5) I. A. Lervik M. Tsypkin, L.-E. Owe, S. Sunde, "Electronic structure versus electrocatalytic activity of iridium oxide", J. Electroanal. Chem. 645 (2010) 135
6) S. Sunde, I. A. Lervik, L.-E. Owe, and M. Tsypkin, "Impedance analysis of nano-structured iridium oxide electrocatalysts", Electrochimica Acta, 55 (2010) 7751
7) F. Seland, R. Tunold, D.A. Harrington, "Activating and deactivating mass transport effects in methanol and formic acid oxidation on platinum electrodes", Electrochim. Acta, 55 (2010) 3384-3391
8) F. Seland, C.E.L. Foss, R. Tunold, D.A. Harrington, "Increasing and Decreasing Mass Transport Effects in the Oxidation of Small Organic Molecules", ECS Transactions, 28 (2010) 203-210.
9) S. Sunde, I. A. Lervik, L.-E. Owe, and M. Tsypkin, "An Impedance Model for a Porous Intercalation Electrode with Mixed Conductivity", J. Electrochem. Soc., 156 (2009) B927
10) H. Weydahl, A. M. Svensson, and S. Sunde, "Transient Model of an Alkaline Fuel Cell Cathode", J. Electrochem. Soc., 156 (2009) A225
11) A. B. Ofstad, J. R. Davey, S. Sunde, and R. L. Borup, "Carbon corrosion of a PEMFC during Shut-down/Start-up", ECS Transactions, 16 (2008) 1301
12) A. T. Marshall, S. Sunde, M. Tsypkin, and R. Tunold, "Performance of a PEM water electrolysis cell using $IrxRuyTazO_2$ electrocatalysts for the oxygen evolution electrode", International Journal of Hydrogen Energy, 32 (2007) 2320
13) I., Kvande, S. T. Briskeby, M. Tsypkin, M. Rønning, S. Sunde, R. Tunold, and D. Chen, "On the preparation methods for carbon nanofiber-supported Pt catalysts", Topics in Catalysis, 45 (2007) 81
14) A. Marshall, B. Børresen, G. Hagen, M. Tsypkin, S. Sunde, and R. Tunold,"Iridium oxide based particles as oxygen evolution electrocatalysts", Elektrokhimiya (Russian Journal of Electrochemistry) 42 (2006) 1134

NTNU, Faculty of Engineering Science and Technology
Department of Engineering Design and Materials

Contact:
Andreas Echtermeyer

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

Subjects and disciplines:

Core competence - H_2 related chemistry and processes:
~~none~~

Core competence - H_2 relevant materials:
- Composite and polymers
- Structural integrity of composite pressure vessels for H2 storage and transport
- Design code development

Core competence - System (meaning "combining technologies or functions"):
Composite/polymers/steel interface properties

Experimental versus theoretical competence:
- Structural analysis
- Building of pressure vessels
- Development of test programs and testing for qualification

Method competence ("How we do it"):

Special conditions competence:

Nature of activities; Alternatives: Basic, applied, development, demonstration

Other H_2 relevant (generic) fields:

- Composite pressure vessels
- Liner materials

Strategic cooperation partners - internally:

Sintef H_2 group

Strategic cooperation partners - externally:

DNV on code development

Selected publications

DNV rules for ships, composite pressure vessels for CNG transport
all other things are unfortunately confidential
General composite publications: many

List of relevant PhDs

Impact properties of composites (FE analysis and testing) Sintef Compact project
Combination of fatigue and creep of polymers (liner materials) NTNU internal project

CMR-Prototech

Contact:

Ivar Wærnhus Ivar.warnhus@prototech.no

Subjects and disciplines:

H_2 production:

- Reforming / partial oxidation of biofuels and biomass
- Water electrolysis
- Pyrolysis
- Links to energy resources (wind)

H_2 storage and distribution:

- Solids for storage (metal hydrides)
- Hydrogen compressors

H_2 end use / Systems:

- Fuel cells (SOFC, PEM, HTPEM)
- Hybrids and buffer system technologies
- System integration (vehicles, heat and power generation systems)

Cross cutting issues:

- Demonstration

Strategic cooperation partners:

ESA, NFR, ZEF-Power (CMR + IFE), HYSTORSYS (with IFE) for commercialization of metal hydride technology, Center of Research and Technology, Greece (CERTH) for reversible SOFC, Kerafol (Germany) and ENRG (US) for SOFC materials..

Selected publications:

1. Ho, T.X., Kosinski, P., Hoffmann, A.C. and Vik, A. Effects of heat sources on the performance of a planar solid oxide fuel cell International Journal of Hydrogen Energy 35 (2010), 4276-4284
2. Suciu, C.S., Hoffmann, A.C. and Wærnhus, I. A flexible, cost-effective production method for high-quality nanoparticles Proceedings WCPT6, 26-29 April (2010), Nuremberg, Germany, paper H H 1 0 00260
3. Ho, T.X., Kosinski, P., Hoffmann, A.C. and Vik, A. Transport, chemical and electrochemical processes in a planar SOFC: Detailed three-dimensional modeling Journal of Power Sources 195 (2010) 6764-6773.
4. Tikkanen, H., Suciu, C., Wærnhus, I. and Hoffmann, A.C. Examination of the co-sintering process of thin 8YSZ films obtained by dip-coating on in-house produced NiO-YSZ Journal of the European Ceramic Society 31 (2011), pp. 1733-1739
5. Ivar Wærnhus, Arild Vik, Crina Silva Ilea, and Sonia Faaland, Development of an All Ceramic SOFC, ECS Transactions, Volume 35, Issue Title: Solid Oxide Fuel Cells 12 (SOFC-XII), The Electrochemical Society (2011) 403 – 407
6. H. Tikkanen, C. Suciu, I. Wærnhus, A. C. Hoffmann, Dip-coating of 8YSZ nano-powder for SOFC applications, Ceramics International (2011), DOI: 10.1016/j.ceramint.2011.05.006.

Institute for energy technology (IFE), Dept. Physics

Contact:

Professor/Head of Department Bjørn C. Hauback, bjorn.hauback@ife.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

Storage: Hydrogen storage in solid compounds

Subjects and disciplines:

- Hydrogen storage in solid compounds
- Metal hydrides
- Hydrogen storage properties, thermodynamics and kinetics
- Crystal structures of metal hydrides
- Catalysts for hydrogen storage

Core competence - H_2 related chemistry and processes:

- Condensed matter physics
- Materials science
- Nano science
- Crystallography
- Inorganic chemistry
- Mechanochemical synthesis methods

Core competence - H_2 relevant materials:

- Metal hydrides
- Catalysts in metal hydrides
- Crystal structures of metal hydrides
- Thermodynamics and kinetics of metal hydrides

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

- Experimental-based activities
- Theoretical methods available via collaboration, in particular with University of Oslo

Method competence ("How we do it"):

- Synthesis of novel metal hydrides by mechanochemical methods (ball milling techniques)
- Characterization of hydrogen storage materials including thermodynamics, kinetics properties and crystal structures
- Catalyst development for metal hydrides

Special conditions competence:

Nature of activities; Alternatives: Basic, applied, development, demonstration

Basic

Other H_2 relevant (generic) fields:

- Condensed matter physics
- Crystallography
- Materials and nano science

Strategic cooperation partners - internally:

ENSYS department, IFE

Strategic cooperation partners - externally:

- National: Chemistry Dept., University of Oslo; Dept. of Physics, NTNU and SINTEF Materials and Chemistry
- International: Stockholm University, Sweden, Aarhus University, Denmark, Risø National Laboratory, Denmark, HZG, Germany, KIT, Germany, CNRS, France, Salford University, UK, EMPA, Switzerland, ESRF, France, University of Torino, Italy, NCSR, Greece, Delft University of Technology, University of Hawaii, USA, SRNL, USA, United Technologies, USA, Brookhaven National Laboratory, USA, Griffith University, Australia, Curtin University, Australia, Tohuko University, Japan, AIST, Japan, Hiroshima University, Japan, UQTR, Canada

Selected publications

1) Riktor, M.D., Filinchuk, Y., Vajeeston, P., Bardaji, E.G., Fichtner, M., Fjellvåg, H., Sørby, M.H., Hauback, B.C.: The crystal structure of a novel borohydride borate, Ca3(BD4)3(BO3). In press J. Mater. Chem. (2011).

2) Sartori, S., Knudsen, K. D., Zhao-Karger, Z., Gil Bardaji, E., Muller, J., Fichtner, M., Hauback, B. C.: SANS and SAXS on nano-confined Mg-borohydride. J. Phys. Chem. C (2010) 114, 18785-18789
3) Sartori, S., Istad-Lem, A., Brinks, H.. W., Hauback, B. C.: Mechanochemical synthesis of alanes. Int. J. Hydrogen Energy (2009) 34, 6350-6356
4) Deledda, S., Hauback, B. C.: Formation mechanism and structural characterization of the mixed transition-metal complex hydride Mg2(FeH6)0.5(CoH5)0.5 obtained by reactive milling. Nanotechnology (2009) 20, 204010 (7pp).
5) Hauback, B. C.: Structures of aluminium-based light weight hydrides. Z. Kristallogr. (2008) 223, 636-648
6) Pitt, M. H., Vullum, P. E., Sørby, M. H., Sulic, M. P., Jensen, C. M., Walmsley, J. C., Holmestad, R.,
7) Hauback, B. C: Structural properties of the nanoscopic Al85Ti15 solid solution observed in the hydrogen cycled NaAlH4 + 0.1 TiCl3 system. Acta Mater. (2008) 56, 4691-4701

Relevant PhDs

1) Marit Dalseth Riktor: Experimental investigations of Ca(BH4)2 and its decomposition products. PhD thesis UiO 2011 No 1048
2) Magnus H. Sørby: Average and local structure of selected metal deuterides. PhD thesis UiO 2004
3) Jan Petter Mæhlen: Hydrogen storage properties of carbon nanomaterials and carbon containing metal hydrides. PhD thesis UiO 2003
4) Matylda Guzik: Studies of hydrogen atom configurations in selected metal hydrides in view of repulsive interactions. PhD Thesis University of Geneva 2010

Institute for energy technology (IFE), Dept. Environmental Technology

Contact: Research Scientist, Julien Meyer

Department Head Trond Bøe, trond.boe@ife.no

Relevant superior H_2 disciplines (EU FP7):

Subject and disciplines:

- H_2 production from natural gas with integrated CO_2-capture
- Sorption-enhanced steam reforming and water gas shift processes
- Gas-solid reactions
- Reactor design
- Fluidized bed technology
- High temperature CO_2 sorbents
- Reforming catalysts
- Multi functional high temperature materials

Core competence- H_2 related chemistry and processes:

- Material science
- Thermodynamics
- Inorganic chemistry
- Nano science
- Crystallography
- Microscopy
- Thermo-gravimetry
- Kinetics of reactions
- Chemical synthesis
- Particle agglomeration
- Surface characterization
- Mechanical characterization of solid particles
- Process technology and simulation
- Chemical engineering
- Reactor modeling

Core competence- H_2 relevant materials:

- High temperature CO_2-sorbents for H_2 production from hydrocarbons
- Multi functional high temperature materials combining CO_2-sorbent and reforming catalyst

Core competence- System:

- Integration of the sorption-enhanced reforming process with steam boilers, gas turbines and solid oxide fuel cells
- Co-production of hydrogen and electric power from hydrocarbons with integrated CO_2 capture

Experimental versus theoretical competence:

- Experimental based activities
- Experimental validation of theoretical models
- Demonstration via development of small pilots

Method competence:

- Synthesis of new materials via sol-gel and low temperature methods
- Testing of materials in thermo-gravimetric analyzer
- Characterization of materials by X-ray diffraction, scanning electron microscopy, porosimetry, BET-analysis
- Production of granules by compaction, agglomeration methods
- Testing of chemical reactions in small experimental test bench reactor systems
- Model development using mass and energy balances
- Process simulation

Special conditions competence:

Nature of activities:

Basic

Other H_2 relevant (generic) fields:

Strategic cooperation partners- internally:

ENSYS department at IFE, Mechanical workshop at IFE

Strategic cooperation partners- externally:

National: Christian Michelsen Research, NTNU, UiO

International: Institute of Carbon Chemistry (CSIC-ICB, Spain), University of British Columbia (UBC, Canada), Louisiana State University (LSU, USA), Los Alamos National Laboratory (LANL, USA), Energy Research Center of the Netherlands (ECN, Netherland), Center for Solar Energy and Hydrogen (ZSW, Germany), The Institute of Chemical Engineering and High Temperature Chemical Processes (ICE-HT, Greece), Politecnico di Milano (PTM, Italy)

Selected publications

1) Johnsen K., Grace J.R. High temperature attrition of sorbents and a catalyst for sorption enhanced steam methane reforming in a fluidized bed environment. Powder Technology, 2007, 173, 200-202.

2) Johnsen K., Grace J.R., Elnashaie S.S.E.H., Kolbeinsen L., Eriksen D. Modeling of sorption-enhanced steam reforming in a dual fluidized bed bubbling bed reactor. Industrial & Engineering Chemistry Research, 2006, 45, 4133-4144.

3) Johnsen K., Ryu H-J., Grace J.R., Lim J. Sorption-Enhanced Steam Reforming of Methane in a Fluidized Bed Reactor with Dolomite as CO_2 –Acceptor. Chemical Engineering Science, 2006; 61:1195-1202.

4) Mastin J., Meyer J., Råheim A. Particulate, heterogeneous solid CO_2 absorbent composition, method for its preparation and method for separating CO_2 from process gases with use thereof. International publication number: WO 2011/005114A1. International application number: PCT/NO2010/000272.

5) Mastin J., Aranda A., Meyer J. New synthesis method for CaO-based synthetic sorbents with enhanced properties for high-temperature CO_2–capture. Energy Procedia, Volume 4, 2011, Pages 1184-1191.

6) Meyer J., Mastin J., Bjørnebøle T.K., Ryberg T., Eldrup N. Techno-economical study of the Zero Emission Gas power concept. Energy Procedia, Volume 4, 2011, Pages 1949-1956.

Relevant PhDs:

Kim Johnsen: Sorption-Enhanced Steam Methane Reforming in Fluidized Bed Reactors. PhD thesis at NTNU, 2006:116.

Telemark University College (HiT); Faculty of Technology; Combustion, Explosion and Process Safety Group

Contacts:

Prof. Dag Bjerketvedt, dag.bjerketvedt@hit.no
Asc.prof. Knut Vågsæther, knut.vagsather@hit.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

Cross-cutting issues

Subjects and disciplines:

- Combustion
- Hydrogen Safety
- Detonations and flame acceleration

Core competence - H_2 related chemistry and processes:

- Combustion
- Gas explosion research
- Testing of process equipment
- Simulation of flame acceleration, transition to detonation and shock propagation
- Hydrogen safety
- Accident surveys

Core competence - H_2 relevant materials:

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

We have industrial, experimental and theoretical competence.

Method competence ("How we do it"):

- Flexible and mobile experimental diagnostic system applicable for both large and small scale gas explosion testing.
- Code development. Simulation of flame acceleration, transition to detonation and shock propagation
- Work with the industry

Special conditions competence:

Main focus is studies of detonation deflagration transition (DDT)

Nature of activities; Alternatives: Basic, applied, development, demonstration

Basic and applied

Other H_2 relevant (generic) fields:

- High speed filming
- Detonation and DDT

Strategic cooperation partners - internally:

- Biomass gasification - Prof. B. Halvorsen
- Biogas production - Prof. R. Bakke
- Gas processing - Prof. K. Jens

Strategic cooperation partners - externally:

- IEA-HAI-Task 31 (Hydrogen Safety) partners
- Statoil
- CMR-GexCon
- HyNor

Selected key publications describing typical activity

1) Bjerketvedt, D and Mjaavatten, A. "A hydrogen-air explosion in a process plant: A case history" HySafe conference, Pisa, 2005

2) Vaagsaether, K. Knudsen V. and Bjerketvedt D. 2007,"Simulation of flame acceleration and DDT in H_2-air mixture with a flux limiter centered method" International Journal of Hydrogen Energy, Vol. 32, Is. 13, Sept., Pages 2186-2191

3) "Application of background oriented schlieren for quantitative measurements of shock waves from explosions Author(s): Sommersel, O. K., Bjerketvedt, D., Christensen, S. O., Krest, O., Vaagsaether, K Source: Shock Waves, DOI 10.1007/s00193-008-0142-1, 2008"
4) Sommersel, O. K., Bjerketvedt, D., Vaagsaether, K., and Fannelop, T.K., Experiments with release and ignition of hydrogen Gas in a 3 m long channel. International Journal of Hydrogen Energy, Volume: 34 Issue: 14 Special Issue: Sp. Iss. SI Pages: 5869-5874 Published: JUL 2009
5) "Experiments with flame propagation in a channel with a single obstacle and premixed stoichiometric H2-air Andre Vagner Gaathaug, Dag Bjerketvedt, Knut Vaagsaether Combustion Science and Technology, Volume 182, Issue 11 & 12 November 2010 "
6) Gas Explosion Field Test with Release of Hydrogen from a High Pressure Reservoir into a Channel, Kanchan Rai, Dag Bjerketvedt, and André V.Gaathaug., 8th ISHPMIE, September 5-10, 2010, Yokohama, Japan

List of relevant PhDs

1) Kjetil Kristoffersen, 2004, Gas explosions in process pipes
2) Vegeir Knudsen, 2006, Hydrogen gas explosions in pipelines, modeling and experimental investigations
3) Knut Vågsæther, 2010, Modeling of gas explosions

Telemark University College (HiT); Faculty of Technology; Gas Processing Group

Contact:

Prof. K.-J. Jens; klaus.j.jens@hit.no

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues

End use

Subjects and disciplines:

- Heterogeneous catalysis
- Catalyst chemistry and kinetics
- Process engineering and technology

Core competence - H_2 related chemistry and processes:

- Natural gas conversion (current and future)
- Catalytic synthesis of H_2 carriers (CH_3OH, DME)
- Dehydrogenation (C_3H_8 to C_3H_6 and C_4H_{10} to C_4H_8)

Core competence - H_2 relevant materials:

- Catalyst development
- Carriers
- Porous materials
- Oxides

Core competence - System (meaning "combining technologies or functions"):

- One-combination of multistage reactions to facilitate product separation; i.e. syngas through methanol to DME
- Membrane reactors

Experimental versus theoretical competence:

- Emphasis on experimental studies
- Techno economic analysis in conjunction with Tel-Tek

Method competence ("How we do it"):

- Laboratory catalyst testing, homogeneous (autoclave); heterogeneous (plug flow rig)
- Product analysis by LC, GC, GC-MS, spectroscopy (UV/VIS, IR)
- Catalyst characterisation by chemical reactions and spectroscopy
- In depth catalyst characterisation by surface analysis method in co-operation with UiO

Special conditions competence:

Relevant industrial experience to guide approach and experimental set up

Nature of activities; Alternatives: Basic, applied, development, demonstration

Applied educational approach

Other H_2 relevant (generic) fields:

- Biomass gasification - Prof. B. Halvorsen
- Biogas production - Prof. R. Bakke

Strategic cooperation partners - internally:

- Biomass gasification - Prof. B. Halvorsen
- Biogas production - Prof. R. Bakke
- Combustion and gas safety - Prof. D.Bjerketvedt
- Strategic cooperation partners - externally:
- Norner As

Selected publications

List of relevant PhDs

1) Li Bo: Low temperature and pressure homogeneous catalytic methanol synthesis (PhD)
2) Baohan Zhou: Metal nano particle based catalysts for low temperature methanol synthesis (Post Doc.)

University of Bergen (UiB), Dept. Physics and Technology, Group Multiphase Systems

Contact:

Alex C. Hoffmann

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

End-Use; Solid Oxide Fuel Cells

Subjects and disciplines:

- Particle and dispersed phase technology
- Computational fluid dynamics
- Molecular dynamics simulations

Core competence - H_2 related chemistry and processes:

Solid Oxide Fuel Cells

Core competence - H_2 relevant materials:

- Functional ceramics
- Oxygen ion conducting ceramics.

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

Method competence ("How we do it"):

Special conditions competence:

Nature of activities; Alternatives: Basic, applied, development, demonstration

Other H_2 relevant (generic) fields:

Strategic cooperation partners - internally:

Strategic cooperation partners - externally:

Selected key publications describing typical activity

List of relevant PhDs

University of Oslo (UiO), Dept. Chemistry

Contact:

Professor Truls Norby; truls.norby@kjemi.uio.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End use
- Cross-cutting issues

Subjects and disciplines:

- Solid State Electrochemistry
- Materials chemistry

Core competence - H_2 related chemistry and processes:

- Defect chemistry
- Hydrogen separation membranes
- Fuel cells
- Electrolyzers
- Corrosion

Core competence - H_2 relevant materials:

- Solid-state electrolytes
- Proton conductors
- Mixed electron-proton conductors for hydrogen permeation membranes
- Electron conductors for electrodes

Core competence - System (meaning "combining technologies or functions"):

Experimental versus theoretical competence:

Method competence ("How we do it"):

Special conditions competence:

Nature of activities; Alternatives: Basic, applied, development, demonstration

Other H_2 relevant (generic) fields:

Strategic cooperation partners - internally:

Strategic cooperation partners - externally:
Selected key publications describing typical activity

List of relevant PhDs

2.3 Infrastructure by organization

SINTEF MC - Applied mechanics and corrosion

Contact:

Vigdis Olden, Vigdis.Olden@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Distribution
- Cross cutting issues

Practical/Experimental working Scale:

meso, micro and macro

Laboratories dedicated H_2 research / demonstration:

Experimental assemblies (test facilities / rigs) dedicated H2 research

- Constant load fracture mechanics test rig for fracture toughness testing under cathodic protection conditions. Four axis with individual control of tensile load. Temperature and CP level can be altered.
- Hydrogen charging under cathodic protection conditions.
- Full scale testing set up of hydrogen pressurised pipelines, instrumented with: Strain gages, timing wires, pressure transducers, high speed cameras. Initial crack made with shaped charge. Tests performed at Giskås military shooting field, Ogndal/Norway.

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- CORMET electrochemical hydrogen diffusion permeation cell for metal samples. Temperature (20-80°C), pressure (1-100 bar)
- and tensile stress/plastic strain can be applied. Cooperation with NTNU in projects and with student and PhD work.
- HYSITRON Nano indenter (nano indentation, pillar testing). Hydrogen influence on dislocation and plastic behavior of metals.
- Owned by NTNU IPM and SINTEF Applied Mechanics and corrosion.

- Hyperbaric welding chamber with possible H2 addition in chamber gas.
- User developed cohesive model including the effect of hydrogen concentration on mechanical properties. Applied software: ABAQUS Standard
- Hydrogen measurement apparatus for hydrogen content in metals. Melt and hot extraction: Juwe H-MAT 225 hydrogen analyzer
- FE-model (coupled fluid-structure interaction) for simulation of running ductile fracture in pressurised pipelines (user subroutine
- implemented in LS-DYNA)

SINTEF MC - Energy Conversion and Materials

Contact:

Research manager Steffen Møller-Holst, steffen.moller-holst@sintef.no

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End use

Practical/Experimental working Scale:

- Laboratory scale
- Testing of membrane surface areas of i.e. 100 cm^2 using feed gas mixtures of i.e. 500 mL/min

Laboratories dedicated H_2 research / demonstration:

- Membrane process lab
- Ceramic synthesis and shaping lab
- Fuel cell characterisation lab
- TG laboratory
- Sour gas (i.e. CO_2 and H_2S) laboratory
- Experimental assemblies (test facilities / rigs) dedicated H2 research
- Electrochemical characterization instrumentation
- Advanced FC single cell test rigs
- Parallel cell test rigs for experimental design
- High pressure TG

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- LabView

SINTEF MC - Process Chemistry
NTNU - Faculty of Natural Sciences and Technology, Dept. Chem. Eng.

Contacts (KinCat Gemini Center):

SINTEF; Senior Scientist Rune Lødeng, Rune.Lodeng@sintef.no
NTNU; Professor Hilde J. Venvik, Hilde.Venvik@chemeng.ntnu.no

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production (of H_2)
- Storage ("Liquid hydrogen carriers", as well as CNF)

Practical/Experimental working Scale:

- Dominantly laboratory scale / "bench scale"; Examples of large scale are Tjeldbergodden CH_3OH plant, Mongstad refinery etc. in the industrial process technology field
- Typical catalyst amounts: 10 grams during preparation, < 1 gram during testing
- Typical feed amounts during testing: < 3 Nl/min (most typical < 500 ml/min)

Laboratories dedicated H_2 research / demonstration:

- "H_2 laboratory"; Facilities including a multipurpose rig including gas and liquid feed and possibilities for testing CPO/reforming combined with WGS and potentially a fuel cell at the exit (Feed range: < 2 Nl hydrocarbon/minutes, < 25 g H2O/h)
- SSITKA - laboratory (Steady-state transient kinetic analysis); Dedicated for fundamental CO hydrogenation studies
- TEOM laboratory (Tapered element oscillating microbalance) dedicated for natural gas reforming, dehydrogenation, and carbon nanofiber (decomposition) studies

Experimental assemblies (test facilities / rigs) dedicated H_2 research

- Catalyst test rig for SMR and metal dusting studies (high temperatures and pressures) / Research and educational use
- Test rig for Fischer-Tropsch synthesis (4 parallel reactor set-up) / Used in contract research (Statoil)

- Test rig for Fischer-Tropsch synthesis (1 reactor) / Educational use
- Test rig for microstructured reactors (H_2 laboratory) / Research and educational use
- Test rig dedicated pyrolysis (special oven for temperatures up to 1500 ^{o}C) / Used so far for contract research
- Test rig dedicated CH_3OH synthesis (including microstructured reactors) / Used so far for educational purposes
- Test rigs for partial oxidation of natural gas / Used for contract research - free for educational use
- Test rig for alternating oxidation (chemical looping oxidation or combustion) / Used for educational purposes
- Test rig dedicated DME synthesis / Used for educational purposes
- Test rig dedicated CNF production / Used for educational
- Test rig for dehydrogenation and oxidative dehydrogenation / Used for educational purposes
- Test rig (TEOM - oscillating microbalance fixed-bed reactor) for study of reforming, dehydrogenation, and CNF+H_2 production / Dedicated contract research
- Circulating fluidized bed reactor for hydrogen production via sorption enhanced steam methane reforming

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- TGA-DSC (Thermogravimetric analysis + differential scanning calorimetry) + combined with mass spectroscopic analysis
- SSITKA kinetic analysis (used for CO_x hydrogenation with isotopes to CH_4, as a model reaction for Fischer-Tropsch synthesis)

SINTEF MC - Synthesis and properties

Contact:

Research Manager Ragnar Fagerberg, ragnar.fagerberg@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- Storage
- End use
- Cross-cutting issues: materials

Practical/Experimental working Scale:

Laboratories dedicated H_2 research / demonstration:

Experimental assemblies (test facilities / rigs) dedicated H2 research

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- Cryo-milling for preparation of (meta-stable) nanomaterials
- Several techniques for preparation of thin films and multilayers of metals, semiconductors, and ceramics
- Lithographic processes for preparation of structured devices
- Electron microscopes (SEM/TEM)
- Electron spectroscopy techniques (XPS, Auger)
- SIMS
- AFM
- Several XRD geometries, incl. in-situ
- Equipment for measuring permeability of liquids and gases through polymer matrices.
- Software for performing first-principles calculations of materials (VASP, PHONON, various scripts and computer tools)

SINTEF Energy - Energy processes

NTNU Energy and Process Engineering

Contacts:

Senior Research Scientist, Prof. II, Petter Nekså Petter.Neksa@sintef.no
Professor Erling Næss Erling.Nass@ntnu.no
Senior Research Scientist, Marie Bysveen (Marie.Bysveen@sintef.no)

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Storage and distribution, liquefaction of hydrogen
- H_2 combustion in end use of H2 as fuel in gas turbines and engines.

Practical/Experimental working Scale:

Laboratory scale, small scale

Laboratories dedicated H_2 research / demonstration:

Energy and process engineering laboratories, dedicated to various aspects of energy technologies

- Laboratory facilities related to low temperature refrigeration processes, also processes related to liquefaction of hydrogen
- Laboratory facilities related to storage technologies for hydrogen
- Laboratory facilities related to hydrogen combustion

Experimental assemblies (test facilities / rigs) dedicated H_2 research

- Laboratory test rig for investigating elements of liquefaction of hydrogen, emphasis pre-cooling with mixed refrigerants
- Test rigs for hydrogen storage in porous structures (activated carbon, MOFs etc.)
- Test rigs for thermal conductivity and permeability of porous media
- Test rigs for hydrogen combustion (both atmospheric and high pressure)

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- Instruments and equipment to handle hydrogen at all relevant temperature and pressures, mostly related to liquefaction of hydrogen
- Thermodynamic libraries related to hydrogen properties
- Component modeling and simulation tools
- Hysys and Pro/II models for different liquefaction processes
- Fluent and in-house finite-element models for heat and mass transfer during hydrogen adsorptive storage in porous media.
- Laser laboratory for advanced H2 combustion measurements
- FT-IR system for combustion emissions measurements
- Direct Numerical Simulation code "S3D" (in co-operation with Sandia National Laboratories) for fluid dynamics and combustion
- In-house CFD code "Spider" for fluid dynamics and turbulent combustion with detailed chemistry capability
- Commercial CFD code "Fluent" for fluid dynamics and turbulent combustion with simplified combustion chemistry
- Commercial chemical kinetics software package "Chemkin"

SINTEF Energy – Electric Power System - Energy systems

Contacts:

Research Director: Magnus Korpås (Magnus.Korpas@sintef.no)
Research Scientist, Nils Arild Ringheim (Nils.A.Ringheim@sintef.no)

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End use
- Cross-cutting issues

Practical/Experimental working Scale:

- Laboratory scale, small scale

Laboratories dedicated H2 research / demonstration:

- Energy storage laboratory with facilities related to testing hydrogen components (electrolyser, fuel cells etc)

Experimental assemblies (test facilities / rigs) dedicated H2 research

- Alkaline electrolyser (5,5 kW)
- General DC/DC converters (± 300 A, adaptable voltage) for arbitrary load profiles
- Test rigs for grid connection of hydrogen components (fuel cells, electrolysers etc.). Include emulation of wind turbine generators.

Instruments and other types of equipment (including SOFTWARE - models and simulators)

Hydrogen relevant competence and infrastructure / Research and Educational Sectors

- Numerical models and simulation tools for electrical analysis of hydrogen components in grid connected systems
- Emulation of different renewable power generation sources (e.g. wind turbines) in grid systems where hydrogen components can be connected
- Data acquisition systems (voltage, current, temperature….)

SINTEF ICT - Applied cybernetics

Contact:

Ingrid.Schjolberg@sintef.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- Cross cutting issues

Practical/Experimental working Scale:

No experimental setups

Laboratories dedicated H_2 research / demonstration:

No laboratories

Experimental assemblies (test facilities / rigs) dedicated H2 research

No test facilities

Instruments and other types of equipment (including SOFTWARE - models and simulators)

Dynamic model of fuel cell systems, natural gas conversion processes implemented in Matlab/Simulink

NTNU, Faculty of Engineering Science and Technology
Department of Engineering Design and Materials

Contact:
Andreas Echtermeyer

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues

Practical/Experimental working Scale:
Laboratory for production and mechanical testing
Specimens from small material size to full scale
The lab is a general composite/polymer/mechanical lab. It can well be used for H_2 applications

Laboratories dedicated H_2 research / demonstration:
- Filament winding machine to make composite pressure vessels up 4.5 m x 800 mm
- Mechanical test machine to measure mechanical properties of laminates and liners

The lab is a general composite/polymer/mechanical lab. It can well be used for H2 applications.

Experimental assemblies (test facilities / rigs) dedicated H_2 research
- Pressure testing up to 1000 bar (testing with water)
- Mechanical testing up to 500 ton load and small to full size
- Nondestructive monitoring of structures.

Instruments and other types of equipment (including SOFTWARE - models and simulators)

NTNU, Faculty of Natural Sciences and Technology
Department of Material Science and Engineering

Contact:
Svein Sunde (+4773594051, Svein.Sunde@material.ntnu.no)

Relevant superior H_2 disciplines (EU 7FP.); Alternatives; Production, storage and distribution, end use, cross-cutting issues
- Production
- End use

Practical/Experimental working Scale:
- Laboratory
- Testing of membrane surface areas of i.e. 100 cm^2 using feed gas mixtures of i.e. 500 mL/min

Laboratories dedicated H_2 research / demonstration:
- SPM lab
- Electrochemichal characterisation lab
- 2 synthesis labs including electrode preparation (spraying), access to NTNU nanolab
- Photoelectrochemistry lab and water electrolysis lab

Experimental assemblies (test facilities / rigs) dedicated H_2 research
One test station for high-temperature PEM applications (< 200 degrees C)
50 % share in SINTEF's test stations

Instruments and other types of equipment (including SOFTWARE - models and simulators)
- Approx. 10 electrochemical setups including potentiostats and impedance analysers
- 4 RDEs
- EC-SPM including AFM and STM, high-temperature, inert atmosphere
- DEMS
- In-situ IR set-up
- Photoelectrochemical setup
- Access to characterisation equipment such as XRD etc.

- Surface-potential analyser including particle size
- CO-stripping station
- UV-vis
- 2 quartz-crystal nanobalances
- Vacuum-line
- Recursion-model software for tight-binding
- Access to ab-initio codes (VASP in purchase)
- COMSOL Multiphysics
- 3 high-power potentiostats

NTNU, Faculty of Engineering Science and Technology, Dept. Marine Technology & SINTEF Marintek

Hydrogenrelaterte aktiviteter ved Institutt for marin teknikk

1. Hydrogenlaboratorium for hydrogenforbrenning.

Kontaktperson: Harald Valland

Med støtte fra NTNU (Avansert vitenskapelig utstyr 2004/2005) og fra Marintek har Institutt for marin teknikk og Marintek etablert en hydrogen laboratorieprøvestand i Maskinerilaboratoriet på Tyholt. I prøvestanden inngår systemer for lagring av hydrogengass, rørframføring til prøvestanden, sikkerhetsutrustning av prøvestand med ventilasjon og systemer for overvåking og automatisk nedstenging. Prøvestanden har vært gjenstand for omfattende sikkerhetsvurdering, og både utstyr og operasjonsprosedyrer er godkjent.

Hydrogenprøvestanden er en forutsetning for å drive eksperimentell virksomhet innen forbrenning av hydrogen og hydrogenrike gassblandinger i motorer og brennere. Prøvestanden kan også brukes for eksperimenter med brenselceller.

Anlegget er dimensjonert for termisk effekt i området opp til ca 300 kW.

2. Nullutslipps hydrogenmotor

Kontaktperson: Harald Valland

Institutt for marin teknikk i samarbeid med Marintek har installert en liten forbrenningsmotor som kan bruke gassformig drivstoff. Den har vært testet med metan og hydrogen. Motoren er innrettet for å operere i en ”lukket” prosess. Konseptet går i korthet ut på å erstatte forbrenningsluft med en inert buffergass i kombinasjon med tilførsel av rent oksygen og hydrogen. Produktet fra forbrenningen, dvs vanndamp, kondenseres ut og selve buffergassen resirkuleres i et lukket system.

En forstudie med teoretisk prosessanalyse konkluderer med at konseptet i tillegg til å være miljømessig ekvivalent med brenselcelleteknologi også har et høyt virkningsgradspotensial.

Konseptet har alle muligheter til å kunne realiseres ettersom teknologiplattformen er kjent. Det benyttes bare konvensjonelle komponenter i en ny kombinasjon. Levetid og driftserfaringer er kjent blant sluttbrukere.

Konseptet anses å være spesielt godt egnet i kombinasjon med vannelektrolysør hvor man har tilgang på både hydrogen og oksygen i ønsket forhold.

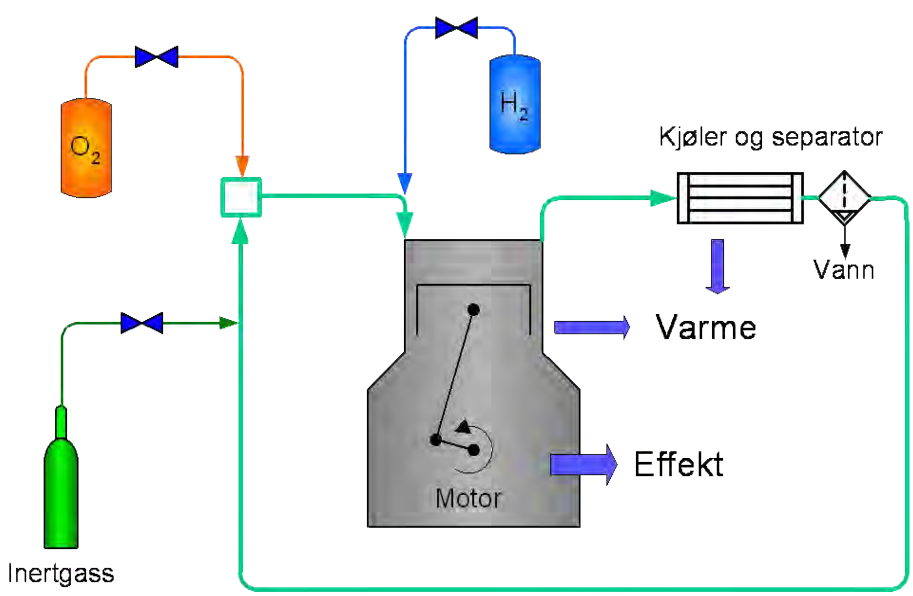
UTSLIPPSFRI HYDROGENMOTOR

Konseptet går i korthet ut på å erstatte luft som arbeidsmedium med en ikke-nitrogenbasert buffergass i kombinasjon med tilførsel av rent oksygen og hydrogen. Produktet fra forbrenningen, dvs vanndamp, kondenseres ut og selve buffergassen resirkuleres i et lukket system, se Figur 1.

En forstudie konkluderer med at konseptet i tillegg til å være miljømessig ekvivalent til brenselcelleteknologi også har et høyt virkningsgradpotensial ved riktig valg av buffergass. Konseptet har alle muligheter til kunne realiseres rent teknologisk, og det med betydelig mindre utviklingsarbeid enn for tilsvarende brenselceller.

Overordnede fordeler med et hydrogen konsept basert på forbrenningsmotoren er at teknologiplattformen er kjent, aktørene er etablert med tilgjengelige produksjonslinjer for et eventuelt nytt produkt, og levetid og driftserfaringer er kjent blant sluttbrukere.

Konseptet anses å være spesielt godt egnet i kombinasjon med en vannelektrolysør hvor man har tilgang til både hydrogen og oksygen i ønsket forhold.



Figur 1: Konseptskisse

Beskrivelse av hydrogen laboratorium

NTNU og MARINTEK etablerte sammen en ny motor prøvestand for hydrogen forbrenning i 2004-2005.

Prøvestanden er plassert i en testcelle i Maskinerilaboratoriet på Marinteknisk Senter på Tyholt, og er dimensjonert for termisk effekt opptil 300 kW. Hydrogenforsyning er for tiden basert på gasslager i trykkflasker, der gasslager er plassert utendørs på inngjerdet område.

Prøvestanden har nødvendig passive og aktive sikkerhetstiltak som er fastsatt i dialog med HMS seksjonene i NTNU og SINTEF, samt Direktoratet for Samfunnssikkerhet og Beredskap (DSB).

Den installerte eksperimentmotoren skal primært brukes til å dokumentere virkningen av å erstatte nitrogen med argon som buffergass. Motoren har en effekt på ca 10 kW.

Ventilasjonskabinett over

TEST-CELLE FOR HYDROGENMOTOR

Test-cellen er utstyrt med ventilasjon og sikkerhetsutrustning

CMR Prototech

Contact:

Senior Researcher: Ivar Wærnhus, ivar.warnhus@prototech.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End use, fuel cells and electrolysis

Practical/Experimental working Scale:

- Laboratory scale
- Testing of fuel cells from single cells up to 2 kW, feed up to 20 Nl/min
- Production of hydrogen up to the same volume
- Material characterisation and development
- System integration

Laboratories dedicated H_2 research / demonstration:

- Energy lab, testing of Fuel cells (PEM, HT-PEM, SOFC), catalysts
- Several labs for processing and characterisation of ceramic fuel cell materials

Experimental assemblies (test facilities / rigs) dedicated H2 research

- Test rigs for SOFC single cells and shortstacks
- Test rigs for SOFC stacks
- Fully automated SOFC module for long term stack testing (3 kW BKK-module)
- Demonstration systems

Instruments and other types of equipment (SOFTWARE - models and simulators)

- Dilatometry, TG
- Tape casting equipment and high temp sintering facilities with advanced machining tools
- EIS, Electrochemical Impedance spectroscopy
- Advanced CFD model of SOFC cells and cell assemblies

Institute for energy technology (IFE), Physics Department

Contact:

Professor/Head of Department Bjørn C. Hauback, bjorn.hauback@ife.no

Relevant superior H_2 disciplines (EU 7FP.);

Alternatives; Production, storage and distribution, end use, cross-cutting issues

Storage: Hydrogen storage in solid materials

Practical/Experimental working Scale:

Laboratory scale. Experimental activities. Sample amounts 1-5 gram

Laboratories dedicated H_2 research / demonstration:

Equipment for synthesis and characterization of hydrogen storage materials:

- Synthesis equipment: arc melter, ball mills including planetary and shaker mills, milling in argon and hydrogen atmosphere up to 150 bar hydrogen pressure, milling at liquid nitrogen temperature (cryomilling). Hydrogenation in Sieverts apparatus up to 200bar hydrogen.
- Thermal characterization equipment: High-pressure DSC, Combined TG-DSC, 3 Sieverts apparatus, so-called PCT-setups (Pressure-Composition-Temperature), TPD (Temperature programmed desorption) with rest gas analyzer
- Experimental assemblies (test facilities / rigs) dedicated H_2 research

See point above

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- X-ray diffractometers, both laboratory equipment at IFE and access to equipment at synchrotron sources
- Neutron scattering equipment at JEEP II reactor at IFE: powder neutron diffractometers PUS and ODIN,
- Small Angle Neutron Scattering (SANS) setup
- High-resolution SEM

Institute for energy technology (IFE), Department of Environmental Technology

Contact: Research scientist, Julien Meyer

Department Head Trond Bøe, trond.boe@ife.no

Relevant superior H_2 disciplines (EU FP7):

Practical/Experimental working scale:

- Laboratory bench scale (few liters per minute, 100 g to 1 kg materials)
- Small pilot scale (few cubic meters per hour, kgs of materials)

Laboratories dedicated H_2 research / demonstration:

- Laboratory for production and test of high temperature CO_2-sorbents and catalysts for use in sorption-enhanced reforming process: micro-powder production, tube furnace for heat treatment of micro-powders, compaction apparatus, fluid bed agglomerator, thermo-gravimetric analyzer, apparatus for measurement of crushing strength.
- Laboratory for bench scale testing of the sorption-enhanced reforming reaction in small fixed bed reactor (few liters per minute).
- Laboratory for small pilot scale testing of the sorption-enhanced reforming reaction in fluidized bed reactor (few cubic meters per hour).

Instruments and other types of equipment:

- X-ray diffraction apparatus
- High resolution scanning electron microscope

Telemark University College (HiT)
Combustion, Explosion and Process Safety Group / Faculty of Technology

Contacts:

Prof. Dag Bjerketvedt, dag.bjerketvedt@hit.no
Asc.prof. Knut Vågsæther, knut.vagsather@hit.no

Relevant superior H_2 disciplines (EU 7FP.); Hydrogen Alternatives; Production, storage and distribution, end use, cross-cutting issues

Cross-cutting issues

Practical/Experimental working Scale:

Laboratory and field tests (typically 0.001 - 40 m3)

Laboratories dedicated H_2 research / demonstration:

- Combustion, Explosion and Process Safety laboratory
- Field test facility at Norward (http://www.norward.no/)
- Access to large scale test sites (Norwegian Defence Construction Service)
- Hydrogen Car (Quantum Toyota Prius HY10003) HyNor Grenland

Experimental assemblies (test facilities / rigs) dedicated H_2 research

Several rigs for studying gas dispersion, flame acceleration

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- High frequency pressure diagnostics
- High sped cameras
- VC laser
- In house soft ware program for simulation of flame acceleration, transition to detonation and shock propagation

Telemark University College
Gas Processing Group / Faculty of Technology

Contact:

Prof. K.-J. Jens; klaus.j.jens@hit.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

End use

Practical/Experimental working Scale:

Laboratory scale / "bench scale"

Typical catalyst amounts: 10 grams during preparation, < 1 gram during testing

Laboratories dedicated H_2 research / demonstration:

- Catalysis laboratory, one 200 ml volume autoclave
- Process hall, plug flow catalyst test rig for 1-5 ml catalyst sample testing

Experimental assemblies (test facilities / rigs) dedicated H2 research

- Catalysis laboratory, one 200 ml volume autoclave
- Process hall, plug flow catalyst test rig for 1-5 ml catalyst sample testing

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- TGA (Thermo gravimetric analysis), DSC (differential scanning calorimetry), BET (surface area measurement)
- Lab view software

University of Bergen (UiB)
Dept. Physics and Technology, Group Multiphase Systems

Contact:
Alex C. Hoffmann

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues
Electrical energy generation with Solid Oxide Fuel Cells, and a beginning interest in Solid Oxide Electrolyser Cells

Practical/Experimental working Scale:
Cell components and single complete cells

Laboratories dedicated H_2 research / demonstration:
Laboratories situated at CMR-Prototech AS

Experimental assemblies (test facilities / rigs) dedicated H_2 research
Laboratories at CMR-Prototech AS comprise:
- Extended infrastructure for testing cell components and cells at elevated temperature
- Infrastructure for producing nanopowders for SOFC raw materials
- Infrastructure for producing cell components from the raw material powders
- Infrastructure for testing the electrochemical properties of cells and cell components at working temperatures

University of Bergen infrastructure comprises:
- Facilities for SEM and TEM
- Facilities for XRD
- Facilities for particle sizing

Instruments and other types of equipment (including SOFTWARE - models and simulators)

University in Oslo (UiO), Dept. Chemistry

Contact:

Professor Truls Norby; truls.norby@kjemi.uio.no

Relevant superior H_2 disciplines (EU 7FP.);
Alternatives; Production, storage and distribution, end use, cross-cutting issues

- Production
- End use
- Cross-cutting issues

Practical/Experimental working Scale:

- Laboratory scale
- Samples in 10 g range
- Flow of hydrogen: < 300 ml/min

Laboratories dedicated H_2 research / demonstration:

- Laboratory for production of substrates and films for button-size fuel cells, electrolysers, and H_2 separation membranes
- Laboratory for testing of button-size fuel cells and hydrogen separation membranes
- Laboratory for testing of electrical properties of hydrogen-related materials at high temperatures in H2 atmospheres
- Laboratory for testing of high temperature corrosion of materials in hydrogen-containing atmospheres
- Experimental assemblies (test facilities / rigs) dedicated H_2 research
- Gas permeation rigs for button-size samples at high temperatures (< 1400 ^oC) and controlled atmospheres, incl. H_2
- Electrical characterisation of hydrogen related materials at high temperatures (< 1400 ^oC) and controlled atmospheres, incl. H_2
- Thermogravimetry of materials at high temperatures (< 1400 ^oC) in controlled atmospheres, incl. H_2

Instruments and other types of equipment (including SOFTWARE - models and simulators)

- Scanning electron microscope (FEG-SEM) with heating stage and H_2 atmosphere possibility

- TGA and TGA+DSC with controlled atmosphere
- Electrical measurement cell ProboStat for high temperatures and controlled atmospheres
- Gas mixers for complex mixtures and gradients

2.4 Projects of hydrogen relevance

SINTEF Materials and Chemistry

Category: Hydrogen production
Title: Ceramic based concept for production of hydrogen/synthesis gas (SMR)
Contact: Rune Lødeng email: Rune.Lodeng@sintef.no Tlf: 98243476
Depts.: Process Technology
Partner NTNU
Type funding Industry – National (2008, 2 persons involved)
Nature: R&D

Category: Hydrogen production
Title: New process technology for production of hydrogen from natural gas
Depts.: Process Technology - Process Chemistry - Energy Conversion and Materials
Contact: Rune Lødeng email: Rune.Lodeng@sintef.no Tlf: 98243476
Partner NTNU
Type Funding RCN-KMB (Competence) (2005 –2007, 4 persons involved)
Nature: Fundamental + R&D

Category: Hydrogen production
Title: NFR-FUNMAT Pd-membranes
Dept: Energy conversion and materials
Contact: Thijs Peters thijs.peters@sintef.no Tlf: 98243941
Partners: NFR, UiO
Type Funding: RCN-F (Researcher project) (2005 – 2008, 6 persons involved)
Nature: Fundamental (F)

Category: Hydrogen production
Activity: EU-CACHET (Integrated project EU-6FP) - Production of hydrogen from natural gas with CO_2 capture)
Depts.: Energy conversion and materials
Contact: Thijs Peters thijs.peters@sintef.no Tlf.: 98243941
Partners: EU, BP, ECN, DICP
Type Funding EU (FPx) + JU (2006 – 2009, 4 persons involved)
Nature Fundamental + R&D

Category: Hydrogen production
Activity: Development of improved Pd-alloy membranes for application in H_2 production under harsh environments
Depts: Energy conversion and materials
Contact: Thijs Peters thijs.peters@sintef.no Tlf.: 98243941
Partners: NTNU
Type funding: RCN-F (Researcher project) (2009 – 2012, 4 persons involved)
Nature: Fundamental + R&D

Category Hydrogen production
Activity: EU-CACHET II (Collaborative project EU-7FP) - Carbon Capture and Hydrogen Production with Membranes
Depts: Energy conversion and materials
Contact Thijs Peters thijs.peters@sintef.no Tlf.: 98243941
Partners EU, BP, ECN, DICP
Type funding EU (FPx) + JU (2010 – 2012, 3 persons involved)
Nature Fundamental + R&D

Category Hydrogen production
Activity: NFR FORNY Demonstrate scale-up production of hydrogen separation membranes
Depts.: Energy conversion and materials
Contact: Thijs Peters thijs.peters@sintef.no Tlf.: 98243941
Partners: NFR, PQL, SINVENT
Type funding “Other” (2010 – 2011)
Nature: Demo

Category: Storage and distribution
Activity: Methanol synthesis in microstructured reactors
Depts.: Process technology
Contact: Rune Myrstad rune.myrstad@sintef.no
Type funding RCN-KMB (Competence) (2005 – 2009, 1 person involved)
Nature Fundamental + R&D

Category Cross-cutting issues
Activity: NorWays - Providing decision support for introduction of H2 in the Norwegian energy system
Depts.: Energy Conversion and Materials
Contact: Steffen Møller-Holst steffenh@sintef.no 92604534
Type funding RCN-KMB (Competence) (2006 - 2009, 8 persons involved)
Nature R&D

Category: End use
Activity: KeePEMAlive
Depts.: Energy conversion and materials
Contact T. A. Aarhaug
Type funding EU (FPx) + JU (2010 –2012)

Category End use
Activity: Proton conducting fuel cells for stationary power applications
Depts.: Energy conversion and materials
Contact: Marie-Laure Fontaine marie.laure.fontaine@sintef.no
Type funding EU (FPx) + JU (2006, 3 persons involved)

Category: Hydrogen production
Activity: Advanced catalyst/reactor systems for conversion of hydrocarbons to hydrogen for fuel cells
Dept.: Catalysis
Contact: Hilde J. Venvik venvik@chemeng.ntnu.no 92808787
Partner NTNU
Type funding 9. RCN SIP Institutes (Strategical) (2000 – 2004, 5 persons involved9
Nature Fundamental + R&D

Category: Hydrogen production
Activity: An integrated process for hydrogen production and separation
Depts.: Process Technology, Energy conversion and materials, Process chemistry
Contact: Rune Lødeng Rune.Lodeng@sintef.no Tlf.: 98243476
Partners: IFE, NTNU, Statoil
Type funding: RCN-BIP (Innovation) (2008 – End , 6 persons involved)
Nature: F + R&D

Category: Hydrogen production
Activity: Hydrogen production via sorption enhanced reforming
Depts.: Process chemistry
Contact: Rickard Blom Rickard.Blom@sintef.no
Partners NTNU, UiO
Type funding RCN-F (Researcher project) (2007 –2010)
Nature F + R&D

Category: End use
Activity: NORCOAT Nordic Initiative for Low Cost Fuel Cell Bipolar Plate Coatings
Depts.: Energy conversion and materials
Contact: Anders Ødegård anders.odegard@sintef.no 94356595
Partners: VTT, PowerCell, Impact Coatings, Outokumpu, Kromatek
Type funding: RCN-BIP (Innovation) (2010 –2012, 2 persons involved)
Nature R&D

Category: End use
Activity: STAYERS STAtionary PEM fuel cells with lifetimes beyond five YEaRS
Depts.: Energy conversion and materials
Contact: Anders Ødegård anders.odegard@sintef.no 94356595
Partners: Nedstack, SolviCore, Solexis, JRC
Type funding: EU (FPx) + JU (2010 –2013)
Nature: R&D

Category: End use
Activity: NEXPEL Next generation PEM electrolyser
Depts.: Energy conversion and materials
Contact: Magnus Thomassen magnus.thomassen@sintef.no
Type funding: EU (FPx) + JU (2010 –2012, 3-4 persons involved)
Nature: R&D

Category: End use
Activity: NICE
Depts.: Energy conversion and materials ?

Category: End use
Activity: Nanoduramea
Depts.: Energy conversion and materials
Contact: Magnus Thomassen magnus.thomassen@sintef.no

Category: End use
Activity: PEMWE
Depts.: Energy conversion and materials
Contact: Magnus Thomassen magnus.thomassen@sintef.no

Category: Cross-cutting issues
Activity: HISC I-IV, Hydrogen induced stress cracking of stainless steel
Depts.: Applied Mechanics and Corrosion
Contact: Roy Johnsen

Category: Cross-cutting issues
Activity: DEEPIT, Deep water hyperbaric welding of pipeline steel
Depts.: Applied Mechanics and Corrosion
Contact: Odd M. Akselsen

SINTEF ENERGY

Category: Storage and distribution
Activity: Strategic project on Hydrogen Liquefaction
Depts.: Process Engineering
Contact: Mona Mølnvik mona.molnvik@sintef.no
Type funding: Internal Project/Program (Strategical)

Category: Storage and distribution
Activity: Efficient hydrogen liquefaction processes
Depts.: Process Engineering
Contact: Petter Nekså petter.neksa@sintef.no 92606519
Partners: Shell Hydrogen
Type funding: RCN-KMB (Competence) (2005 –2010, 5 persons involved)
Nature: R&D

Category: Storage and distribution
Activity: IDEALHY (application in contract negotiations with EU)
Depts.: Process Engineering
Contact: Petter Nekså petter.neksa@sintef.no 92606519
Partners: Shell, Linde Kryo, TU Dresden and several others, maybe also Japanese partners
Type funding: EU (FPx) + JU (2011 –2012, 5 persons involved)
Nature: R&D

Category: End use
Activity: BIGCO2 Task C
Depts.: Energy Processes
Contact: Mario Ditaranto
Partners: TUM
Type funding: RCN-KMB (Competence) (2007 –2011)

Category: End use
Activity: BIGCCS Task 1.3
Depts.: Energy Processes
Contact: Andrea Gruber
Partners: Sandia, TUM, UC Berkeley
Type funding: National Research centers (FME) (2009 –2016)

Category: End use
Activity: BIGH2
Depts.: Energy Processes
Contact: Marie Bysveen
Partners: Alstom, DLR
Type funding: Other (Gassnova) 2008

Category: End use
Activity: DECARBit SP4
Depts.: Energy Processes
Contact: Nils Erland L. Haugen
Partners: Alstom, ENEL, Siemens
Type funding: EU (FPx) + JU (2008 –2011)

SINTEF ICT

Category: Hydrogen production
Activity: IEA-HIA Task 23 Small scale reforming
Depts.: Applied Cybernetics
Contact: Ingrid Schjølberg Ingrid.Schjolberg@sintef.no 93066355
Partners: Tokyo Gas, Haldor Topsøe, Mahler AGS, HyGear, Catator, Tubitak, ECN, Statoil, GdSuez, Intelligent Energy, ENEA, SGC
Type funding: RCN-BIP (Research Project) (2006 –2011, 2 persons involved)

Category: Hydrogen production
Activity: Hydrofueler
Depts.: Applied Cybernetics
Contact: Ingrid Schjølberg Ingrid.Schjolberg@sintef.no 93066355
Partners: University of Warwick
Type funding: EU (FPx) + JU (2003 –2006, 3 persons involved)
Nature: R&D

Norwegian University of Technology and Science (NTNU)

Category: Storage and distribution
Activity: Onboard vehicle H2 storage in adsorption materials
Dept.: EPT
Contact: Erling Næss erling.nass@ntnu.no
Type funding: EU (FPx) + JU (2004, 4 persons involved)

Category: Storage and distribution
Activity: Advanced MOFs for hydrogen storage in cryo adsorption tanks
Depts.: Energy and process engineering
Contact: Erling Næss erling.nass@ntnu.no Tlf.: 91897970
Partners: MPI, Stuttgart, TU Dresden
Type funding: Other (2009 –2013, 4 persons involved)
Nature: F + R&D

Category: End use
Activity: FUNMAT/PhD Stein Trygve Briskeby/carbon-supported electrocatalysts
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051 10250200
Partners: Chem Eng, NTNU
Type funding: RCN-F (Researcher project) (2004 –2008)
Nature: F + R&D
Persons: Stein Trygve Briskeby, Mikhail Tsypkin, De Chen, Magnus Rønning

Category: Hydrogen production
Activity: PEM Water electrolysis/PhD Ingrid Anne Lervik
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Type funding: RCN-F (Researcher project) (2004 –2008, Ingrid Anne Lervik)
Nature: F + R&D

Category: End use

Activity: PhD Axel Baumann Ofstad/Degradation in PEMFC
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: SINTEF
Type funding: RCN-F (Researcher project) (2004 –2010, Axel Ofstad)
Nature: F + R&D

Category: Hydrogen production
Activity: Improved efficiency and durability of PEMWE
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: Statoil
Type funding: RCN-KMB (Competence) (2007 –2012, Liudmila Ilyukhina, Mikhail Tsypkin)
Nature: F + R&D

Category: End use
Activity: Nanomat core-shell electrocatalysts
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: Univ Maryland (USA)
Type funding: RCN-F (Researcher project) (2008 –2011)
Nature: Fundamental (F)
Persons: Jose Gomez, Mikhail Tsypkin, Piotr Ochal, De Chen, Magnus Rønning, Navaneethan Muthuswamy

Category: End use
Activity: Nanoduramea
Depts.: Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: SINTEF, VTT, Aalto Univ, KTH, SDU
Type funding: Nordic Energy Research (2008 –2012, Mahdi Darab)
Nature: F + R&D

Category: Hydrogen production
Activity: PhD Elizaveta Kuznetsova
Depts.: Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: SINTEF, Statoil
Type funding: RCN-KMB (Competence) (2009 –2012, Elizaveta Kuznetsova)
Nature: F + R&D

Category: End use
Activity: MITHT collaboration project
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: MITHT
Type funding: Other (2008 –2011, Mikhail Tsypkin, MITHT staff)
Nature: Fundamental (F)

Category: End use
Activity: FURIM
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: DTU, UNEW and others
Type funding: EU (FPx) + JU (2007, Frode Seland)
Nature: R&D

Category: Hydrogen production
Activity: WELTEMP
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: DTU, ICTP, DPS and others
Type funding: EU (FPx) + JU (2008 –2011, Lars-Erik Owe, Mikhail Tsypkin)
Nature: R&D

Category: Hydrogen production
Activity: SUSHGEN
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: UNEW, Montpellier and others
Type funding: EU (FPx) + JU (2010 –2013, Frode Seland, Agnieszka Zlotorowicz)
Nature: F + R&D

Category: Hydrogen production
Activity: PhD Morten Tjelta/Photoelectrochemical production
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: Inorganic group, NTNU
Type funding: Internal Project/Program (Strategical) (2009 - 2012, Morten Tjelta)
Nature: Fundamental (F)

Category: Hydrogen production
Activity: PhD Anita Reksten/water electrolysis
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Type funding: Internal Project/Program (Strategical) (2011 - 2015, Frode Seland, Anita Reksten)
Nature: Fundamental (F)

Category: Hydrogen production
Activity: PhD Lars-Erik Owe
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Partners: WELTEMP partners
Type funding: Internal Project/Program (Strategical) (2007 -2011, Lars-Erik Owe, Mikhail Tsypkin)
Nature: Fundamental (F)

Category: End use
Activity: PhD Helge Weydahl
Depts.: Dept Materials Science and Engineering
Contact: Svein Sunde Svein.Sunde@material.ntnu.no 4773594051
Type funding: RCN-F (Researcher project) (2002 - 2006, Helge Weydahl)
Nature: R&D

Category: End use
Activity: Oxidation of small organic molecules. PhD Per Kristian Dahlstrøm
Depts.: Dept Materials Science and Engineering
Contact: Frode Seland frodesel@material.ntnu.no 73594042
Partners: University of Victoria
Type funding: Internal Project/Program (Strategical) (2008 - 2012, Per Kristian Dahlstrøm, David Harrington)
Nature: Fundamental (F)

Category: End use
Activity: High Temperature PEM Fuel Cells Operating with Organic Fuels. Post Doc. Dmitry Bokach
Depts.: Dept Materials Science and Engineering
Contact: Frode Seland frodesel@material.ntnu.no 73594042
Type funding: RCN-F (Researcher project)

Category: End use
Activity: Biofuel electrooxidation
Depts.: Dept Materials Science and Engineering
Contact: Frode Seland/Reidar Tunold frodesel@material.ntnu.no 73594042
Partners: UVic, Sherbrook, etc.
Type funding: RCN-bilateral (2005 -2006)

Category: End use
Activity: Fuel cell test station. Thermal conductivity apparatus
Depts.: Department of chemistry
Contact: Signe Kjelstrup 73594179
Partners: SINTEF/IFE
Type funding: NFR/ NANOMAT

Institute for Energy Technology (IFE)

Category: Storage and distribution
Activity: HYSTORY
Depts.: Physics Department
Contact: Jiri Muller jiri.muller@ife.no
Partners: CNRS, Stockholm Univ, Treibacher, MCP, ABB, NCSRD
Type funding: EU (FPx) + JU (2002 – 2005)
Nature: F + R&D

Category: Storage and distribution
Activity: StorHy
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: FZK, GKSS, Dailmer, NCSRD
Type funding: EU (FPx) + JU (2004 – 2009)
Nature: F + R&D

Category: Storage and distribution
Activity: HyTrain
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: Salford Univ, CNRS, GKSS, Univ. Geneva etc
Type funding: EU (FPx) + JU (2005 – 2009)
Nature: F + R&D

Category: Storage and distribution
Activity: HYSIC
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: NCSRD, Stockholm Univ, Salford Univ
Type funding: EU (FPx) + JU (2006 – 2007)
Nature: F + R&D

Category: Storage and distribution
Activity: NESSHY
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: NCSRD, Stockholm Univ, Salford Univ, FZK, GKSS, Risø, Univ. of Iceland, Daimler etc
Type funding: EU (FPx) + JU (2006 – 2010)
Nature: F + R&D

Category: Storage and distribution
Activity: NanoHy
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: FZK, NCSRD, Carbon Future, CNRS, CNRS, MPI, UiO
Type funding: EU (FPx) + JU (2008 -2011)
Nature: F + R&D

Category: Storage and distribution
Activity: FLYHY
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: GKSS, Univ. Torino, Aarhus Univ, CONICET, Tropical
Type funding: EU (FPx) + JU (2009 – 2012)
Nature: F + R&D

Category: Storage and distribution
Activity: SSH2S
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no ,
Partners: Univ. Torino, KIT, DLR, Tecnodelta, Serenergy, Fiat, JRC
Type funding: EU (FPx) + JU (2011 – 2014)
Nature: F + R&D

Category: Storage and distribution
Activity: Marie Curie H-storage project
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Type funding: EU (FPx) + JU (2004 – 2006, 1 person involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Marie Curie H-storage project 2
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Type funding: EU (FPx) + JU (2010 – 2012, 1 person involved)
Nature: Fundamental (F)

Category: Cross-cutting issues
Activity: FUNMAT - Materials for hydrogen technology
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO, NTNU, SINTEF
Type funding: RCN-F (Researcher project) (2004 – 2009, 15 persons involved)
Nature: F + R&D

Category: Storage and distribution
Activity: Novel nanomaterials and nanostructured materials for hydrogen storage applications
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO, NTNU, SINTEF
Type funding: RCN-F (Researcher project) (2006 - 2012, 5 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Development of novel Mg-based metal hydrides with large hydrogen storage
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO, NTNU
Type funding: RCN-F (Researcher project) (2004 – 2007, 3 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: High capacity hydrogen storage materials studied by X-ray synchrotron diffraction
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Type funding: RCN-Post Doc. (2005 -2008, 1 person involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Hydrogen storage in metal hydrides based on magnesium
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO. NTNU, SINTEF
Type funding: RCN-F (Researcher project) (2005 -2008, 3 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Novel light-weight metal hydrides for hydrogen storage applications
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO
Type funding: RCN-F (Researcher project) (2008 -2011, 2 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Hydrogen storage in novel boron-based compounds
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Type funding: RCN-F (Researcher project) (2010 -2013, 3 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Nanophase materials for hydrogen applications ‘
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO, IITM, India
Type funding: RCN-bilateral (2011, 5 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: New metal hydrides for hydrogen storage
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO, Uppsala Univ, Stockholm Univ, Risø, DTU, Univ. of Iceland, Lei, Lithuania
Type funding: Nordic Energy Research (2003 – 2006, 10 persons involved)
Nature: Fundamental (F)

Category: Storage and distribution
Activity: Nordic Center of Excellence on Hydrogen storage materials
Depts.: Physics Department
Contact: Bjørn Hauback bjorn.hauback@ife.no
Partners: UiO. Uppsala Univ, Stockholm Univ, Risø, DTU, Aarhus Univ, Univ. in Iceland, LEI, Lithuania
Type funding: Nordic Energy Research (2007 – 2010, 12 persons involved)
Nature: Fundamental (F)

University of Oslo (UiO) – Center for Material Science and Nanotechnology (SMN)

Category: Cross-cutting issues
Activity: Hydrogen in oxides (NFR FRINAT)
Depts.: Chemistry, FERMiO
Contact: Truls Norby truls.norby@kjemi.uio.no 99257611
Type funding: RCN-F (Researcher project) (2006 - 2011, 3 persons involved)
Nature: Fundamental (F)

Category: End use
Activity: EFFIPRO (EU 7FWP Energy) proton conducting fuel cells
Depts.: Chemistry, FERMiO
Contact: Truls Norby truls.norby@kjemi.uio.no 99257611
Partners: UiO, SINTEF, Julich, DTU-Risø, cerPoTech, CSIC ITQ Valencia, CNRS IMN Nantes
Type funding: EU (FPx) + JU (2009 - 2013, 2 persons involved)
Nature: F + R&D

Category: End use
Activity: StackPro (NFR Renergi) proton conducting fuel cells
Depts.: Chemistry, FERMiO
Contact: Truls Norby truls.norby@kjemi.uio.no 99257611
Partners: UiO, SINTEF, NTNU
Type funding: RCN-F (Researcher project) (2008 - 2012, 3 persons involved)
Nature: F + R&D

Category: Hydrogen production
Activity: SPECHY (NFR Renergi) Solid state solar water splitting
Depts.: Chemistry, FERMiO
Contact: Truls Norby truls.norby@kjemi.uio.no 99257611
Type funding: RCN-F (Researcher project) (2009 – 2013, 2 persons involved)
Nature: F + R&D

Category: Cross-cutting issues
Activity: NANIONET (NFR) Fundamental studies of fuel cell electrodes
Depts.: Physics, FERMiO
Contact: Anette Gunnæs a.e.gunnas@fys.uio.no 22852812
Partners: UiO, SINTEF
Type funding: RCN-F (Researcher project) (2007 – 2011, 2 persons involved)
Nature: Fundamental (F)

University of Bergen (UiB)

Category: End use
Activity: MSOFC,
Type funding: NFR sponsored project hosted at CMR Prototech
Contact: Axel Hoffmann

Category: End use
Activity: NanoSOFC
Type funding: NFR sponsored project hosted at CMR Prototech
Contact: Axel Hoffmann

Telemark University College (HiT)

Category: Cross-cutting issues
Activity: HY10003 HyNor Grenland (TUC's H2 car)
Fac.: Faculty of Technology
Contact: Dag Bjerketvedtdag.bjerketvedt@hit.no 35575232
Type funding: 2012
Nature: Demo

Category: Cross-cutting issues
Activity: Hydrogen Safety IEA HAI Task 31
Fac.: Faculty of Technology
Contact: Dag Bjerketvedtdag.bjerketvedt@hit.no 35575232
Type funding: x (2011 – 2013, 3 persons involved)
Nature: F + R&D

CMR Prototech

Category: Hydrogen production
Activity: Høyeffektiv hydrogenproduksjon fra fornybar energi Teknologiverifisering av Faststoff Elektrolysør med integrert metall hydrid kompressor
Contact: Ivar Wærnhus ivar.warnhus@prototech.no 91157913
Partners: Hystorsys
Type funding: RCN-BIP (Innovation) (2011 – 2012)
Nature: R&D

Category: End use
Activity: Technology development for 200 kW SOFC CHP unit
Contact: Sonia Faaland sonia.faaland@prototech.no
Partners: UiB
Type funding: RCN-BIP (Innovation) (2009 -2012)
Nature: R&D

Category: Storage and distribution
Activity: Innovative gas storage for satellites
Contact: Jarle Farnes jarle.farnes@prototech.no
Partners: ESA
Type funding: Industry - Foreign

Category: Storage and distribution
Activity: High temperature fuel cells
Contact: Ivar Wærnhus ivar.warnhus@prototech.no 91157913
Partners: Certh, ESA
Type funding: Industry - Foreign (2009 – 2012)
Nature: R&D

Category: End use
Activity: Bio-HTPEM
Contact: Helge Weydahl helge.weydahl@prototech.no
Type funding: RCN-BIP (Innovation) (2009 – 2011)
Nature: R&D

ZEG POWER

Category: Hydrogen production
Activity: Zero Emission Gas, former projects
Contact: Bjørg Andresen bjorg.andresen@ife.no
Partners: IFE, CMR
Type funding: Div. prosjekter 2000
Nature: R&D

Category: Hydrogen production
Activity: "Zero Emission Gas Power Technology Qualification for Industrial Scale ZEG Plants"
Contact: Ivar Wærnhus ivar.warnhus@prototech.no 91157913
Partners: IFE, CMR
Type funding: RCN-BIP (Innovation) (2011 – 2012)
Nature: R&D

Category: Hydrogen production
Activity: Kostnadseffektiv konvertering av biomasse til hydrogen og elektrisitet for transportformål – BioZEG
Contact: Arild Vik arild.vik@prototech.no
Partners: IFE, CMR
Type funding: IN (2011 – 2013)
Nature: Demo

Cell Power

Category:	End use
Activity:	Ren Marin Kraft og fremdrift 1 og 2
Contact:	Arild Vik arild.vik@prototech.no
Partners:	Mange RCN, IN, Privat 2007 2013
Nature:	Demo

3. Infrastructure overview tables

3.1 Infrastructure sorted by category of application

Hydrogen related research infrastructure

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
Catalyst					
	Exp. Ass.				
		KinCat Gemini center			
					Catalyst test rig for SMR and metal dusting studies
					Test rig for Fischer-Tropsch synthesis (4 parallell reactor set-up)
					Test rig for Fischer-Tropsch synthesis (1 reactor)
		Telemark University College			
			Faculty of Technology	Gas Processing	Plug flow catalyst test rig for 1-5 ml catalyst sample testing
			Faculty of Technology	Gas Processing	One 200 ml volume autoclave
	Instr.				
		KinCat Gemini center			
					SSITKA kinetic analysis
	Lab.				
		CMR-Prototech			
					Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC)
		KinCat Gemini center			
					SSITKA-laboratory
		Telemark University College			
			Faculty of Technology	Gas Processing	Catalysis laboratory
			Faculty of Technology	Gas Processing	Process hall

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
Demonstration					
	Exp. Ass.				
		CMR-Prototech			
					Demonstration systems
		NTNU Marine technology / SINTEF Marintek			
					Nullutslipps hydrogenmotor. Forbrenningsmotor som kan bruke gassformig drivstoff (deriblant H2). Effekt ca. 10 kW.
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	Hydrogen Car (Quantum Toyota Prius HY10003) HyNor Grenland
Distribution					
	Exp. Ass.				
		SINTEF			
			Materials and Chemistry	Applied Mechanics and Corrosion	Full scale testing set up of hydrogen pressurized pipelines, instrumented with: Strain gages, timing wires, pressure transducers, high speed cameras. Initial crack made with shaped charge. Tests performed at Giskås military shooting field, Ogndal/Norway
End use					
	Exp. Ass.				
		KinCat Gemini center			
					Test rig for alternation oxidation (chemical looping oxidation or combustion)
		SINTEF			

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Materials and Chemistry	Energy Conversion and Materials	Experimental assemblies (test facilities / rigs) dedicated H2 research
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Test rigs for hydrogen combustion (both atmospheric and high pressure)
	Instr.				
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					FT-IR system for combustion emissions measurements
	Lab.				
		KinCat Gemini center			
					"H2 laboratory"
		NTNU Marine technology / SINTEF Marintek			
					Hydrogen laboratorieprøvestand. Inngår: systemer for lagring av H2-gass, rørframføring til prøvestanden, sikkerhetsutrustning, etc. Formål: eksperimentell virksomhet innen forbrenning av H2 (etc.) og evt. FC etc. Max. termisk effekt 300kW.
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Laser laboratory for advanced H2 combustion measurements
					Laboratory facilities related to hydrogen combustion

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	Combustion, Explosion and Process Safety laboratory
Fuel cell					
	Exp. Ass.				
		CMR-Prototech			
					Test rigs for SOFC stacks
					Fully automised SOFC module for long term stack testing (3 kW BKK-module)
					Test rigs for SOFC single cells and shortstacks. Single cells up to 2 kW, feed up to 20 Nl/min
		NTNU			
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	One test station for high-temperature PEM applications (< 200 degrees C), 50 % share in SINTEF's test stations
		SINTEF			
			Materials and Chemistry	Energy Conversion and Materials	Parallell cell test rigs for experimental design
			Materials and Chemistry	Energy Conversion and Materials	Advanced FC single cell test rigs
	Lab.				
		CMR-Prototech			
					Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC), catalysts.
		SINTEF			

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Materials and Chemistry	Energy Conversion and Materials	Fuel cell characterization lab
		University of Oslo (UiO)			
				Chemistry	Laboratory for testing of button-size fuel cells and hydrogen separation membranes
Generic					
	Exp. Ass.				
		NTNU			
			Fac. of Eng. Science and Techn.	Engineering Design and Materials	Mechanical test machine to measure mechanical properties of laminates and liners up to 500 ton load and small to full size
		SINTEF			
			Materials and Chemistry	Applied Mechanics and Corrosion	Constant load fracture mechanics test rig for fracture toughness testing under cathodic protection conditions. Four axis with individual control of tensile load. Temperature and CP level can be altered.
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	Several rigs for studying gas dispersion, flame acceleration
		University of Oslo (UiO)			
				Chemistry	Gas mixers for complex mixtures and gradients
				Chemistry	Experimental assemblies (test facilities/rigs) dedicated H2 research
	Instr.				
		CMR-Prototech			
					Dilatometry, TG

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
					EIS, Electrochemical Impedance spectroscopy
					Tape casting equipment and high temp sintering facilities with advanced machining tools
		Institute for Energy Technology (IFE)			
				Environmental Technology	X-ray diffraction apparatus
				Environmental Technology	High resolution scanning electron microscope
				Physics	High-resolution SEM
				Physics	Neutron scattering equipment at JEEP II reactor at IFE: powder neutron diffractometers PUS and ODIN, Small Angle Neutron Scattering (SANS) setup
				Physics	X-ray diffractometers, both laboratory equipment at IFE and access to equipment at synchrotron sources
		KinCat Gemini center			
					TGA-DSC, combined with mass spectroscopic analysis.
		NTNU			
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	4 RDE's
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Surface-potential analyser including particle size
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Photoelectrochemical setup
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	UV-vis

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	EC-SPM including AFM and STM, high-temperature, inert atmosphere
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Access to characterisation equipment such as XRD etc.
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Approx. 10 electrochemical setups including potentiostats and impedance analyzers
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	DEMS
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Vacuum-line
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	3 high-power potentiostats
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	In-situ IR set-up
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	2 quartz-crystal nanobalances
		SINTEF			
			Materials and Chemistry	Applied Mechanics and Corrosion	Hyperbaric welding chamber with possible H2 addition in chamber gas
			Materials and Chemistry	Applied Mechanics and Corrosion	HYSITRON Nano indenter (nano indentation, pillar testing). Hydrogen influence in dislocation and plastic behavior of metals.
			Materials and Chemistry	Energy Conversion and Materials	High pressure TG
			Materials and Chemistry	Energy Conversion and Materials	Electrochemical characterization instrumentation
			Materials and Chemistry	Synthesis and Properties	Electron microscopes (SEM/TEM)

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Materials and Chemistry	Synthesis and Properties	Cryo-milling for preparation of (meta-stable) nanomaterials
			Materials and Chemistry	Synthesis and Properties	Lithographic processes for preparation of structured devices
			Materials and Chemistry	Synthesis and Properties	Electron spectroscopy techniques (XPS, Auger)
			Materials and Chemistry	Synthesis and Properties	Equipment for measuring permeability of liquids and gases through polymer materials
			Materials and Chemistry	Synthesis and Properties	Several XRD geometries, incl. in.situ
			Materials and Chemistry	Synthesis and Properties	AFM
			Materials and Chemistry	Synthesis and Properties	SIMS
			Materials and Chemistry	Synthesis and Properties	Several techniques for preparation of thin films and multilayers of metals, semiconductors and ceramics
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	High frequency pressure diagnostics
			Faculty of Technology	Combustion, Explosion and Process Safety	High speed cameras
			Faculty of Technology	Combustion, Explosion and Process Safety	VC laser

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Faculty of Technology	Gas Processing	TGA (Thermogravimetric analysis), DSC (differential scanning calorimetry), BET (surface area measurement)
		University of Bergen (UiB)			
			Phys. & Techn.	Group multiphase systems	SEM, TEM, XRD, particle sizing
		University of Oslo (UiO)			
				Chemistry	TGA and TGA+DSC with controlled atmosphere
				Chemistry	Scanning electron microscope (FEG-SEM) with heating stage and H2 atmosphere possibillity
	Lab.				
		CMR-Prototech			
					Several labs for processing and characterization of ceramic fuel cell materials
		NTNU			
			Fac. of Eng. Science and Techn.	Engineering Design and Materials	Laboratory for production and mechanical testing. Specimens from small material size to full scale. General composite/polymer/mechanical lab. Pressure testing up to 1000 bar (testing with water). Can well be used for H2 applications.
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	2 synthesis labs including electrode preparation (spraying), access to NTNU Nanolab
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	SPM lab
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Electrochemical characterization lab
		SINTEF			
			Materials and Chemistry	Energy Conversion and Materials	Sour gas (i.e. CO2 and H2S) laboratory

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Materials and Chemistry	Energy Conversion and Materials	TG laboratory
			Materials and Chemistry	Energy Conversion and Materials	Ceramic synthesis and shaping lab
			Materials and Chemistry	Energy Conversion and Materials	Membrane process lab
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	Field test facility at Norward (www.norward.no)
			Faculty of Technology	Combustion, Explosion and Process Safety	Access to large scale test sites (Norwegian Defence Construction Service)
Hydrogen storage					
	Exp. Ass.				
		KinCat Gemini center			
					Test rig for hydrogenation and oxidative dehydrogenation
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Laboratory test rig for investigating elements of liquefaction of hydrogen, emphasis pre-cooling with mixed refrigerants
					Test rigs for hydrogen storage in porous structures (activated carbon, MOFs, etc.)
	Instr.				

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
		NTNU			
			Fac. of Eng. Science and Techn.	Engineering Design and Materials	Filament winding machine to make composite pressure vessels up to 4.5 m x 800 med mer
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Instruments and equipment to handle hydrogen at all relevant temperatures and pressures, mostly related to liquefaction of hydrogen
	Lab.				
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Laboratory facilities related to storage technologies for hydrogen
					Laboratory facilities related to low temperature refrigeration processes, also processes related to liquefaction of hydrogen
Materials related					
	Exp. Ass.				
		Institute for Energy Technology (IFE)			
				Physics	Experimental assemblies (test facilities/rigs) dedicated H2 research
		SINTEF			
			Materials and Chemistry	Applied Mechanics and Corrosion	Hydrogen charging under cathodic protection conditions
		SINTEF Energy Processes / NTNU Energy and Process Engineering			

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
					Test rigs for thermal conductivity and permeability of porous media
		University of Oslo (UiO)			
				Chemistry	Electrical characterisation of hydrogen related materials at high temperatures (< 1400°C) in controlled atmospheres, incl. H2 (ProboStat)
				Chemistry	Gas permeation rigs for button-size samples at high temperatures (<1400°C) and controlled atmospheres, incl. H2)
	Instr.				
		SINTEF			
			Materials and Chemistry	Applied Mechanics and Corrosion	CORMET electrochemical hydrogen diffsion permeation cell for metal samples. Temperature 20-80°C, pressure 1-100 bar and tensile stress/plastic strain can be applied.
			Materials and Chemistry	Applied Mechanics and Corrosion	Hydrogen measurement apparatus for hydrogen content in metals. Melt and hot wxtraction: Juwe H-MAT 225 hydrogen analyzer
	Lab.				
		Institute for Energy Technology (IFE)			
				Physics	Synthesis equipment: arc melter, ball mills including planetary and shaker mills, milling in argon and hydrogen atmosphere up to 150 bar H2 pressure, milling at liquid nitrogen temperature (cryomilling). Hydrogenation in Sieverts apparatus up to 200 bar.
				Physics	Thermal characterization equipment: High-pressure DSC, Combined TG-DCS, 3 Sieverts apparatus (Pressure-Composition-Temperature, PCT), TPD (Temperature programmed desorption) with rest gas analyser
		University of Oslo (UiO)			
				Chemistry	Laboratory for testing of high temperature corrosion of materials in hydrogen-containing atmospheres

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
				Chemistry	Laboratory for testing of electrical properties of hydrogen-related materials at high temperatures in H2 atmospheres
Production					
	Exp. Ass.				
		KinCat Gemini center			
					Circulating fluidized bed reactor for hydrogen production via sorption enhanced steam methane reforming
					Test rig dedicated CNF production
					Test rig dedicated DME synthesis
					Test rig for partial oxidation of natural gas
					Test rig (TEOM - oscillating microbalance fixed-bed reactor) for study of reforming, dehydrogenation and CNF+H2 production
					Test rig for microstructured reactors (H2 laboratory)
					Test rig dedicated CH3OH synthesis (including microstructured reactors)
					Test rig dedicated pyrolysis
	Instr.				
		NTNU			
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	CO-stripping station
	Lab.				
		Institute for Energy Technology (IFE)			
				Environmental Technology	Laboratory for production and test of high temperature CO2-sorbents and catalysts for use in sorption-enhanced reforming process

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
				Environmental Technology	Laboratory for bench scale testing of the sorption-enhanced reforming reactor in small fixed bed reactor (few liters per minute)
				Environmental Technology	Laboratory for small pilot scale testing of the sorption-enhanced reforming reaction in fluidized bed reactor (few cubic meters per hour)
		KinCat Gemini center			
					TEOM laboratory
		NTNU			
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Photoelectrochemistry lab and water electrolysis lab
		University of Oslo (UiO)			
				Chemistry	Laboratories for production of substrates and films for button-size fuel cells, electrolysers and H2 separation membranes
Software					
	Instr.				
		SINTEF			
			Materials and Chemistry	Energy Conversion and Materials	LabView
	Software				
		CMR-Prototech			
					Advanced CFD model of SOFC cells and cell assemblies
		NTNU			
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Recursion-model software for tight-binding
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	Access to ab-initio codes (VASP in purchase)

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
			Fac. of Nat. Science and Techn.	Materials Science and Engineering	COMSOL Multiphysics
		SINTEF			
			ICT	Applied Cybernetics	Dynamic model of fuel cell systems, natural gas conversion processes implemented in Matlab/Simulink
			Materials and Chemistry	Applied Mechanics and Corrosion	FE-model (coupled fluid-structure interaction) for simulation of running ductile fracture in pressurized pipelines (user subroutine implemented in LS-DYNA)
			Materials and Chemistry	Applied Mechanics and Corrosion	User developed cohesive model including the effect of hydrogen concentration on mechanical properties. Applied software: ABAQUS Standard.
			Materials and Chemistry	Synthesis and Properties	Software for performing first-principles calculations of materials (VASP, PHONON, various scripts and computer tools)
		SINTEF Energy Processes / NTNU Energy and Process Engineering			
					Commercial CFD code "Fluent" for fluid dynamics and turbulent combustion with simplified combustion chemistry
					Thermodynamic libraries related to hydrogen properties
					Component modelling and simulation tools
					Hysys and Pro/II models for different liquefaction processes
					Fluent and in-house finite-element models for heat and mass transfer during hydrogen adsorptive storage in porous media
					In-house CFD code "Spider" for fluid dynamics and turbulent combustion with detailed chemistry capability
					Commercial chemical kinetics software package "Chemkin"

Category	Type of infrastructure	Company / Institution	Division / Faculty	Department	Description of infrastructure
					Direct Numerical Simulation code "S3D" (in co-operation with Sandia National Laboratories) for fluid dynamics and combustion
		Telemark University College			
			Faculty of Technology	Combustion, Explosion and Process Safety	In-house software program for simulation of flame acceleration, transition to detonation and shock propagation
			Faculty of Technology	Gas Processing	Lab view software

3.2 Infrastructure sorted by type

Hydrogen related research infrastructure

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Exp. Ass.					
	Catalyst				
		Catalyst test rig for SMR and metal dusting studies	KinCat Gemini center		
		Test rig for Fischer-Tropsch synthesis (4 parallell reactor set-up)	KinCat Gemini center		
		Test rig for Fischer-Tropsch synthesis (1 reactor)	KinCat Gemini center		
		Plug flow catalyst test rig for 1-5 ml catalyst sample testing	Telemark University College	Faculty of Technology	Gas Processing
		One 200 ml volume autoclave	Telemark University College	Faculty of Technology	Gas Processing
	Demonstration				
		Demonstration systems	CMR-Prototech		
		Nullutslipps hydrogenmotor. Forbrenningsmotor som kan bruke gassformig drivstoff (deriblant H2). Effekt ca. 10 kW.	NTNU Marine technology / SINTEF Marintek		
		Hydrogen Car (Quantum Toyota Prius HY10003) HyNor Grenland	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
	Distribution				
		Full scale testing set up of hydrogen pressurized pipelines, instrumented with: Strain gages, timing wires, pressure transducers, high speed cameras. Initial crack made with shaped charge. Tests performed at Giskås military shooting field, Ogndal/Norway	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
	End use				
		Test rig for alternation oxidation (chemical looping oxidation or combustion)	KinCat Gemini center		
		Experimental assemblies (test facilities / rigs) dedicated H2 research	SINTEF	Materials and Chemistry	Energy Conversion and Materials

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Exp. Ass.					
	End use				
		Test rigs for hydrogen combustion (both atmospheric and high pressure)	SINTEF Energy Processes / NTNU Energy and Process Engineering		
	Fuel cell				
		Test rigs for SOFC single cells and shortstacks. Single cells up to 2 kW, feed up to 20 Nl/min	CMR-Prototech		
		Test rigs for SOFC stacks	CMR-Prototech		
		Fully automised SOFC module for long term stack testing (3 kW BKK-module)	CMR-Prototech		
		One test station for high-temperature PEM applications (< 200 degrees C), 50 % share in SINTEF's test stations	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Parallell cell test rigs for experimental design	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Advanced FC single cell test rigs	SINTEF	Materials and Chemistry	Energy Conversion and Materials
	Generic				
		Mechanical test machine to measure mechanical properties of laminates and liners up to 500 ton load and small to full size	NTNU	Fac. of Eng. Science and Techn.	Engineering Design and Materials
		Constant load fracture mechanics test rig for fracture toughness testing under cathodic protection conditions. Four axis with individual control of tensile load. Temperature and CP level can be altered.	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		Several rigs for studying gas dispersion, flame acceleration	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Exp. Ass.					
	Generic				
		Gas mixers for complex mixtures and gradients	University of Oslo (UiO)		Chemistry
		Experimental assemblies (test facilities/rigs) dedicated H2 research	University of Oslo (UiO)		Chemistry
	Hydrogen storage				
		Test rig for hydrogenation and oxidative dehydrogenation	KinCat Gemini center		
		Test rigs for hydrogen storage in porous structures (activated carbon, MOFs, etc.)	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Laboratory test rig for investigating elements of liquefaction of hydrogen, emphasis pre-cooling with mixed refrigerants	SINTEF Energy Processes / NTNU Energy and Process Engineering		
	Materials related				
		Experimental assemblies (test facilities/rigs) dedicated H2 research	Institute for Energy Technology (IFE)		Physics
		Hydrogen charging under cathodic protection conditions	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		Test rigs for thermal conductivity and permeability of porous media	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Electrical characterisation of hydrogen related materials at high temperatures (< 1400°C) in controlled atmospheres, incl. H2 (ProboStat)	University of Oslo (UiO)		Chemistry
		Gas permeation rigs for button-size samples at high temperatures (<1400°C) and controlled atmospheres, incl. H2)	University of Oslo (UiO)		Chemistry
	Production				
		Test rig dedicated CH3OH synthesis (including microstructured reactors)	KinCat Gemini center		

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Exp. Ass.					
	Production				
		Test rig (TEOM - oscillating microbalance fixed-bed reactor) for study of reforming, dehydrogenation and CNF+H2 production	KinCat Gemini center		
		Test rig dedicated CNF production	KinCat Gemini center		
		Circulating fluidized bed reactor for hydrogen production via sorption enhanced steam methane reforming	KinCat Gemini center		
		Test rig dedicated DME synthesis	KinCat Gemini center		
		Test rig for microstructured reactors (H2 laboratory)	KinCat Gemini center		
		Test rig dedicated pyrolysis	KinCat Gemini center		
		Test rig for partial oxidation of natural gas	KinCat Gemini center		
Instr.					
	Catalyst				
		SSITKA kinetic analysis	KinCat Gemini center		
	End use				
		FT-IR system for combustion emissions measurements	SINTEF Energy Processes / NTNU Energy and Process Engineering		
	Generic				
		Dilatometry, TG	CMR-Prototech		
		Tape casting equipment and high temp sintering facilities with advanced machining tools	CMR-Prototech		
		EIS, Electrochemical Impedance spectroscopy	CMR-Prototech		
		High resolution scanning electron microscope	Institute for Energy Technology (IFE)		Environmental Technology

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Instr.					
	Generic				
		X-ray diffraction apparatus	Institute for Energy Technology (IFE)		Environmental Technology
		High-resolution SEM	Institute for Energy Technology (IFE)		Physics
		Neutron scattering equipment at JEEP II reactor at IFE: powder neutron diffractometers PUS and ODIN, Small Angle Neutron Scattering (SANS) setup	Institute for Energy Technology (IFE)		Physics
		X-ray diffractometers, both laboratory equipment at IFE and access to equipment at synchrotron sources	Institute for Energy Technology (IFE)		Physics
		TGA-DSC, combined with mass spectroscopic analysis.	KinCat Gemini center		
		Vacuum-line	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		EC-SPM including AFM and STM, high-temperature, inert atmosphere	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		4 RDE's	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Access to characterisation equipment such as XRD etc.	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		DEMS	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		In-situ IR set-up	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Photoelectrochemical setup	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Approx. 10 electrochemical setups including potentiostats and impedance analyzers	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Instr.					
	Generic				
		3 high-power potentiostats	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		2 quartz-crystal nanobalances	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Surface-potential analyser including particle size	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		UV-vis	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		HYSITRON Nano indenter (nano indentation, pillar testing). Hydrogen influence in dislocation and plastic behavior of metals.	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		Hyperbaric welding chamber with possible H2 addition in chamber gas	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		High pressure TG	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Electrochemical characterization instrumentation	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		AFM	SINTEF	Materials and Chemistry	Synthesis and Properties
		Electron microscopes (SEM/TEM)	SINTEF	Materials and Chemistry	Synthesis and Properties
		Several XRD geometries, incl. in.situ	SINTEF	Materials and Chemistry	Synthesis and Properties

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Instr.					
	Generic				
		Lithographic processes for preparation of structured devices	SINTEF	Materials and Chemistry	Synthesis and Properties
		Several techniques for preparation of thin films and multilayers of metals, semiconductors and ceramics	SINTEF	Materials and Chemistry	Synthesis and Properties
		Equipment for measuring permeability of liquids and gases through polymer materials	SINTEF	Materials and Chemistry	Synthesis and Properties
		Electron spectroscopy techniques (XPS, Auger)	SINTEF	Materials and Chemistry	Synthesis and Properties
		Cryo-milling for preparation of (meta-stable) nanomaterials	SINTEF	Materials and Chemistry	Synthesis and Properties
		SIMS	SINTEF	Materials and Chemistry	Synthesis and Properties
		High speed cameras	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
		High frequency pressure diagnostics	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
		VC laser	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
		TGA (Thermogravimetric analysis), DSC (differential scanning calorimetry), BET (surface area measurement)	Telemark University College	Faculty of Technology	Gas Processing
		SEM, TEM, XRD, particle sizing	University of Bergen (UiB)	Phys. & Techn.	Group multiphase systems
		TGA and TGA+DSC with controlled atmosphere	University of Oslo (UiO)		Chemistry

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Instr.					
	Generic				
		Scanning electron microscope (FEG-SEM) with heating stage and H2 atmosphere possibillity	University of Oslo (UiO)		Chemistry
	Hydrogen storage				
		Filament winding machine to make composite pressure vessels up to 4.5 m x 800 med mer	NTNU	Fac. of Eng. Science and Techn.	Engineering Design and Materials
		Instruments and equipment to handle hydrogen at all relevant temperatures and pressures, mostly related to liquefaction of hydrogen	SINTEF Energy Processes / NTNU Energy and Process Engineering		
	Materials related				
		CORMET electrochemical hydrogen diffsion permeation cell for metal samples. Temperature 20-80°C, pressure 1-100 bar and tensile stress/plastic strain can be applied.	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		Hydrogen measurement apparatus for hydrogen content in metals. Melt and hot wxtraction: Juwe H-MAT 225 hydrogen analyzer	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
	Production				
		CO-stripping station	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
	Software				
		LabView	SINTEF	Materials and Chemistry	Energy Conversion and Materials
Lab.					
	Catalyst				

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Lab.					
	Catalyst				
		Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC)	CMR-Prototech		
		SSITKA-laboratory	KinCat Gemini center		
		Process hall	Telemark University College	Faculty of Technology	Gas Processing
		Catalysis laboratory	Telemark University College	Faculty of Technology	Gas Processing
	End use				
		"H2 laboratory"	KinCat Gemini center		
		Hydrogen laboratorieprøvestand. Inngår: systemer for lagring av H2-gass, rørframføring til prøvestanden, sikkerhetsutrustning, etc. Formål: eksperimentell virksomhet innen forbrenning av H2 (etc.) og evt. FC etc. Max. termisk effekt 300kW.	NTNU Marine technology / SINTEF Marintek		
		Laboratory facilities related to hydrogen combustion	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Laser laboratory for advanced H2 combustion measurements	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Combustion, Explosion and Process Safety laboratory	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
	Fuel cell				
		Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC), catalysts.	CMR-Prototech		
		Fuel cell characterization lab	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Laboratory for testing of button-size fuel cells and hydrogen separation membranes	University of Oslo (UiO)		Chemistry

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Lab.					
	Generic				
		Several labs for processing and characterization of ceramic fuel cell materials	CMR-Prototech		
		Laboratory for production and mechanical testing. Specimens from small material size to full scale. General composite/polymer/mechanical lab. Pressure testing up to 1000 bar (testing with water). Can well be used for H2 applications.	NTNU	Fac. of Eng. Science and Techn.	Engineering Design and Materials
		SPM lab	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Electrochemical characterization lab	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		2 synthesis labs including electrode preparation (spraying), access to NTNU Nanolab	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Ceramic synthesis and shaping lab	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Membrane process lab	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		TG laboratory	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Sour gas (i.e. CO2 and H2S) laboratory	SINTEF	Materials and Chemistry	Energy Conversion and Materials
		Field test facility at Norward (www.norward.no)	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Lab.					
	Generic				
		Access to large scale test sites (Norwegian Defence Construction Service)	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
	Hydrogen storage				
		Laboratory facilities related to storage technologies for hydrogen	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Laboratory facilities related to low temperature refrigeration processes, also processes related to liquefaction of hydrogen	SINTEF Energy Processes / NTNU Energy and Process Engineering		
	Materials related				
		Synthesis equipment: arc melter, ball mills including planetary and shaker mills, milling in argon and hydrogen atmosphere up to 150 bar H2 pressure, milling at liquid nitrogen temperature (cryomilling). Hydrogenation in Sieverts apparatus up to 200 bar.	Institute for Energy Technology (IFE)		Physics
		Thermal characterization equipment: High-pressure DSC, Combined TG-DCS, 3 Sieverts apparatus (Pressure-Composition-Temperature, PCT), TPD (Temperature programmed desorption) with rest gas analyser	Institute for Energy Technology (IFE)		Physics
		Laboratory for testing of electrical properties of hydrogen-related materials at high temperatures in H2 atmospheres	University of Oslo (UiO)		Chemistry
		Laboratory for testing of high temperature corrosion of materials in hydrogen-containing atmospheres	University of Oslo (UiO)		Chemistry
	Production				
		Laboratory for production and test of high temperature CO2-sorbents and catalysts for use in sorption-enhanced reforming process	Institute for Energy Technology (IFE)		Environmental Technology

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Lab.					
	Production				
		Laboratory for small pilot scale testing of the sorption-enhanced reforming reaction in fluidized bed reactor (few cubic meters per hour)	Institute for Energy Technology (IFE)		Environmental Technology
		Laboratory for bench scale testing of the sorption-enhanced reforming reactor in small fixed bed reactor (few liters per minute)	Institute for Energy Technology (IFE)		Environmental Technology
		TEOM laboratory	KinCat Gemini center		
		Photoelectrochemistry lab and water electrolysis lab	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Laboratories for production of substrates and films for button-size fuel cells, electrolysers and H2 separation membranes	University of Oslo (UiO)		Chemistry
Software					
	Software				
		Advanced CFD model of SOFC cells and cell assemblies	CMR-Prototech		
		Access to ab-initio codes (VASP in purchase)	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Recursion-model software for tight-binding	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		COMSOL Multiphysics	NTNU	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Dynamic model of fuel cell systems, natural gas conversion processes implemented in Matlab/Simulink	SINTEF	ICT	Applied Cybernetics
		FE-model (coupled fluid-structure interaction) for simulation of running ductile fracture in pressurized pipelines (user subroutine implemented in LS-DYNA)	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion
		User developed cohesive model including the effect of hydrogen concentration on mechanical properties. Applied software: ABAQUS Standard.	SINTEF	Materials and Chemistry	Applied Mechanics and Corrosion

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Software					
	Software				
		Software for performing first-principles calculations of materials (VASP, PHONON, various scripts and computer tools)	SINTEF	Materials and Chemistry	Synthesis and Properties
		Thermodynamic libraries related to hydrogen properties	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Component modelling and simulation tools	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Hysys and Pro/II models for different liquefaction processes	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Fluent and in-house finite-element models for heat and mass transfer during hydrogen adsorptive storage in porous media	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		In-house CFD code "Spider" for fluid dynamics and turbulent combustion with detailed chemistry capability	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Commercial CFD code "Fluent" for fluid dynamics and turbulent combustion with simplified combustion chemistry	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Commercial chemical kinetics software package "Chemkin"	SINTEF Energy Processes / NTNU Energy and Process Engineering		
		Direct Numerical Simulation code "S3D" (in co-operation with Sandia National Laboratories) for fluid dynamics and combustion	SINTEF Energy Processes / NTNU Energy and Process Engineering		

Type of infras	Category	Description of infrastructure	Company / Institution	Division / Faculty	Department
Software					
	Software				
		In-house software program for simulation of flame acceleration, transition to detonation and shock propagation	Telemark University College	Faculty of Technology	Combustion, Explosion and Process Safety
		Lab view software	Telemark University College	Faculty of Technology	Gas Processing

3.2 Infrastructure sorted by institute

Hydrogen related research infrastructure

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
CMR-Prototech					
	Exp. Ass.				
		Demonstration	Demonstration systems		
		Fuel cell	Fully automised SOFC module for long term stack testing (3 kW BKK-module)		
		Fuel cell	Test rigs for SOFC single cells and shortstacks. Single cells up to 2 kW, feed up to 20 Nl/min		
		Fuel cell	Test rigs for SOFC stacks		
	Instr.				
		Generic	Dilatometry, TG		
		Generic	EIS, Electrochemical Impedance spectroscopy		
		Generic	Tape casting equipment and high temp sintering facilities with advanced machining tools		
	Lab.				
		Catalyst	Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC)		
		Fuel cell	Energy lab, testing of Fuelcells (PEM, HT-PEM, SOFC), catalysts.		
		Generic	Several labs for processing and characterization of ceramic fuel cell materials		
	Software				
		Software	Advanced CFD model of SOFC cells and cell assemblies		
Institute for Energy Technology (IFE)					
	Exp. Ass.				
		Materials related	Experimental assemblies (test facilities/rigs) dedicated H2 research		Physics

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
	Instr.				
		Generic	High resolution scanning electron microscope		Environmental Technology
		Generic	X-ray diffraction apparatus		Environmental Technology
		Generic	High-resolution SEM		Physics
		Generic	Neutron scattering equipment at JEEP II reactor at IFE: powder neutron diffractometers PUS and ODIN, Small Angle Neutron Scattering (SANS) setup		Physics
		Generic	X-ray diffractometers, both laboratory equipment at IFE and access to equipment at synchrotron sources		Physics
	Lab.				
		Materials related	Synthesis equipment: arc melter, ball mills including planetary and shaker mills, milling in argon and hydrogen atmosphere up to 150 bar H2 pressure, milling at liquid nitrogen temperature (cryomilling). Hydrogenation in Sieverts apparatus up to 200 bar.		Physics
		Materials related	Thermal characterization equipment: High-pressure DSC, Combined TG-DCS, 3 Sieverts apparatus (Pressure-Composition-Temperature, PCT), TPD (Temperature programmed desorption) with rest gas analyser		Physics
		Production	Laboratory for bench scale testing of the sorption-enhanced reforming reactor in small fixed bed reactor (few liters per minute)		Environmental Technology
		Production	Laboratory for production and test of high temperature CO2-sorbents and catalysts for use in sorption-enhanced reforming process		Environmental Technology
		Production	Laboratory for small pilot scale testing of the sorption-enhanced reforming reaction in fluidized bed reactor (few cubic meters per hour)		Environmental Technology
KinCat Gemini center					

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
	Exp. Ass.				
		Catalyst	Catalyst test rig for SMR and metal dusting studies		
		Catalyst	Test rig for Fischer-Tropsch synthesis (1 reactor)		
		Catalyst	Test rig for Fischer-Tropsch synthesis (4 parallell reactor set-up)		
		End use	Test rig for alternation oxidation (chemical looping oxidation or combustion)		
		Hydrogen storage	Test rig for hydrogenation and oxidative dehydrogenation		
		Production	Circulating fluidized bed reactor for hydrogen production via sorption enhanced steam methane reforming		
		Production	Test rig (TEOM - oscillating microbalance fixed-bed reactor) for study of reforming, dehydrogenation and CNF+H2 production		
		Production	Test rig dedicated CH3OH synthesis (including microstructured reactors)		
		Production	Test rig dedicated CNF production		
		Production	Test rig dedicated DME synthesis		
		Production	Test rig dedicated pyrolysis		
		Production	Test rig for microstructured reactors (H2 laboratory)		
		Production	Test rig for partial oxidation of natural gas		
	Instr.				
		Catalyst	SSITKA kinetic analysis		
		Generic	TGA-DSC, combined with mass spectroscopic analysis.		
	Lab.				
		Catalyst	SSITKA-laboratory		
		End use	"H2 laboratory"		
		Production	TEOM laboratory		

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
NTNU					
	Exp. Ass.				
		Fuel cell	One test station for high-temperature PEM applications (< 200 degrees C), 50 % share in SINTEF's test stations	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Mechanical test machine to measure mechanical properties of laminates and liners up to 500 ton load and small to full size	Fac. of Eng. Science and Techn.	Engineering Design and Materials
	Instr.				
		Generic	2 quartz-crystal nanobalances	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	3 high-power potentiostats	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	4 RDE's	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Access to characterisation equipment such as XRD etc.	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Approx. 10 electrochemical setups including potentiostats and impedance analyzers	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	DEMS	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	EC-SPM including AFM and STM, high-temperature, inert atmosphere	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	In-situ IR set-up	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Photoelectrochemical setup	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Surface-potential analyser including particle size	Fac. of Nat. Science and Techn.	Materials Science and Engineering

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Generic	UV-vis	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Vacuum-line	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Hydrogen storage	Filament winding machine to make composite pressure vessels up to 4.5 m x 800 med mer	Fac. of Eng. Science and Techn.	Engineering Design and Materials
		Production	CO-stripping station	Fac. of Nat. Science and Techn.	Materials Science and Engineering
	Lab.				
		Generic	Laboratory for production and mechanical testing. Specimens from small material size to full scale. General composite/polymer/mechanical lab. Pressure testing up to 1000 bar (testing with water). Can well be used for H2 applications.	Fac. of Eng. Science and Techn.	Engineering Design and Materials
		Generic	2 synthesis labs including electrode preparation (spraying), access to NTNU Nanolab	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	Electrochemical characterization lab	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Generic	SPM lab	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Production	Photoelectrochemistry lab and water electrolysis lab	Fac. of Nat. Science and Techn.	Materials Science and Engineering
	Software				
		Software	Access to ab-initio codes (VASP in purchase)	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Software	COMSOL Multiphysics	Fac. of Nat. Science and Techn.	Materials Science and Engineering
		Software	Recursion-model software for tight-binding	Fac. of Nat. Science and Techn.	Materials Science and Engineering

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
NTNU Marine technology / SINTEF Marintek					
	Exp. Ass.				
		Demonstration	Nullutslipps hydrogenmotor. Forbrenningsmotor som kan bruke gassformig drivstoff (deriblant H2). Effekt ca. 10 kW.		
	Lab.				
		End use	Hydrogen laboratorieprøvestand. Inngår: systemer for lagring av H2-gass, rørframføring til prøvestanden, sikkerhetsutrustning, etc. Formål: eksperimentell virksomhet innen forbrenning av H2 (etc.) og evt. FC etc. Max. termisk effekt 300kW.		
SINTEF					
	Exp. Ass.				
		Distribution	Full scale testing set up of hydrogen pressurized pipelines, instrumented with: Strain gages, timing wires, pressure transducers, high speed cameras. Initial crack made with shaped charge. Tests performed at Giskås military shooting field, Ogndal/Norway	Materials and Chemistry	Applied Mechanics and Corrosion
		End use	Experimental assemblies (test facilities / rigs) dedicated H2 research	Materials and Chemistry	Energy Conversion and Materials
		Fuel cell	Advanced FC single cell test rigs	Materials and Chemistry	Energy Conversion and Materials
		Fuel cell	Parallell cell test rigs for experimental design	Materials and Chemistry	Energy Conversion and Materials
		Generic	Constant load fracture mechanics test rig for fracture toughness testing under cathodic protection conditions. Four axis with individual control of tensile load. Temperature and CP level can be altered.	Materials and Chemistry	Applied Mechanics and Corrosion
		Materials related	Hydrogen charging under cathodic protection conditions	Materials and Chemistry	Applied Mechanics and Corrosion

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
	Instr.				
		Generic	Hyperbaric welding chamber with possible H2 addition in chamber gas	Materials and Chemistry	Applied Mechanics and Corrosion
		Generic	HYSITRON Nano indenter (nano indentation, pillar testing). Hydrogen influence in dislocation and plastic behavior of metals.	Materials and Chemistry	Applied Mechanics and Corrosion
		Generic	Electrochemical characterization instrumentation	Materials and Chemistry	Energy Conversion and Materials
		Generic	High pressure TG	Materials and Chemistry	Energy Conversion and Materials
		Generic	AFM	Materials and Chemistry	Synthesis and Properties
		Generic	Cryo-milling for preparation of (meta-stable) nanomaterials	Materials and Chemistry	Synthesis and Properties
		Generic	Electron microscopes (SEM/TEM)	Materials and Chemistry	Synthesis and Properties
		Generic	Electron spectroscopy techniques (XPS, Auger)	Materials and Chemistry	Synthesis and Properties
		Generic	Equipment for measuring permeability of liquids and gases through polymer materials	Materials and Chemistry	Synthesis and Properties
		Generic	Lithographic processes for preparation of structured devices	Materials and Chemistry	Synthesis and Properties
		Generic	Several techniques for preparation of thin films and multilayers of metals, semiconductors and ceramics	Materials and Chemistry	Synthesis and Properties
		Generic	Several XRD geometries, incl. in.situ	Materials and Chemistry	Synthesis and Properties
		Generic	SIMS	Materials and Chemistry	Synthesis and Properties

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Materials related	CORMET electrochemical hydrogen diffsion permeation cell for metal samples. Temperature 20-80°C, pressure 1-100 bar and tensile stress/plastic strain can be applied.	Materials and Chemistry	Applied Mechanics and Corrosion
		Materials related	Hydrogen measurement apparatus for hydrogen content in metals. Melt and hot wxtraction: Juwe H-MAT 225 hydrogen analyzer	Materials and Chemistry	Applied Mechanics and Corrosion
		Software	LabView	Materials and Chemistry	Energy Conversion and Materials
	Lab.				
		Fuel cell	Fuel cell characterization lab	Materials and Chemistry	Energy Conversion and Materials
		Generic	Ceramic synthesis and shaping lab	Materials and Chemistry	Energy Conversion and Materials
		Generic	Membrane process lab	Materials and Chemistry	Energy Conversion and Materials
		Generic	Sour gas (i.e. CO2 and H2S) laboratory	Materials and Chemistry	Energy Conversion and Materials
		Generic	TG laboratory	Materials and Chemistry	Energy Conversion and Materials
	Software				
		Software	Dynamic model of fuel cell systems, natural gas conversion processes implemented in Matlab/Simulink	ICT	Applied Cybernetics
		Software	FE-model (coupled fluid-structure interaction) for simulation of running ductile fracture in pressurized pipelines (user subroutine implemented in LS-DYNA)	Materials and Chemistry	Applied Mechanics and Corrosion
		Software	User developed cohesive model including the effect of hydrogen concentration on mechanical properties. Applied software: ABAQUS Standard.	Materials and Chemistry	Applied Mechanics and Corrosion

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Software	Software for performing first-principles calculations of materials (VASP, PHONON, various scripts and computer tools)	Materials and Chemistry	Synthesis and Properties
SINTEF Energy Processes / NTNU Energy and Process Engineering					
	Exp. Ass.				
		End use	Test rigs for hydrogen combustion (both atmospheric and high pressure)		
		Hydrogen storage	Laboratory test rig for investigating elements of liquefaction of hydrogen, emphasis pre-cooling with mixed refrigerants		
		Hydrogen storage	Test rigs for hydrogen storage in porous structures (activated carbon, MOFs, etc.)		
		Materials related	Test rigs for thermal conductivity and permeability of porous media		
	Instr.				
		End use	FT-IR system for combustion emissions measurements		
		Hydrogen storage	Instruments and equipment to handle hydrogen at all relevant temperatures and pressures, mostly related to liquefaction of hydrogen		
	Lab.				
		End use	Laboratory facilities related to hydrogen combustion		
		End use	Laser laboratory for advanced H2 combustion measurements		
		Hydrogen storage	Laboratory facilities related to low temperature refrigeration processes, also processes related to liquefaction of hydrogen		
		Hydrogen storage	Laboratory facilities related to storage technologies for hydrogen		
	Software				

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Software	Commercial CFD code "Fluent" for fluid dynamics and turbulent combustion with simplified combustion chemistry		
		Software	Commercial chemical kinetics software package "Chemkin"		
		Software	Component modelling and simulation tools		
		Software	Direct Numerical Simulation code "S3D" (in co-operation with Sandia National Laboratories) for fluid dynamics and combustion		
		Software	Fluent and in-house finite-element models for heat and mass transfer during hydrogen adsorptive storage in porous media		
		Software	Hysys and Pro/II models for different liquefaction processes		
		Software	In-house CFD code "Spider" for fluid dynamics and turbulent combustion with detailed chemistry capability		
		Software	Thermodynamic libraries related to hydrogen properties		
Telemark University College					
	Exp. Ass.				
		Catalyst	One 200 ml volume autoclave	Faculty of Technology	Gas Processing
		Catalyst	Plug flow catalyst test rig for 1-5 ml catalyst sample testing	Faculty of Technology	Gas Processing
		Demonstration	Hydrogen Car (Quantum Toyota Prius HY10003) HyNor Grenland	Faculty of Technology	Combustion, Explosion and Process Safety
		Generic	Several rigs for studying gas dispersion, flame acceleration	Faculty of Technology	Combustion, Explosion and Process Safety
	Instr.				
		Generic	High frequency pressure diagnostics	Faculty of Technology	Combustion, Explosion and Process Safety

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Generic	High speed cameras	Faculty of Technology	Combustion, Explosion and Process Safety
		Generic	VC laser	Faculty of Technology	Combustion, Explosion and Process Safety
		Generic	TGA (Thermogravimetric analysis), DSC (differential scanning calorimetry), BET (surface area measurement)	Faculty of Technology	Gas Processing
	Lab.				
		Catalyst	Catalysis laboratory	Faculty of Technology	Gas Processing
		Catalyst	Process hall	Faculty of Technology	Gas Processing
		End use	Combustion, Explosion and Process Safety laboratory	Faculty of Technology	Combustion, Explosion and Process Safety
		Generic	Access to large scale test sites (Norwegian Defence Construction Service)	Faculty of Technology	Combustion, Explosion and Process Safety
		Generic	Field test facility at Norward (www.norward.no)	Faculty of Technology	Combustion, Explosion and Process Safety
	Software				
		Software	In-house software program for simulation of flame acceleration, transition to detonation and shock propagation	Faculty of Technology	Combustion, Explosion and Process Safety
		Software	Lab view software	Faculty of Technology	Gas Processing
University of Bergen (UiB)					
	Instr.				

Company / Institution	Type of infrastructure	Category	Description of infrastructure	Division / Faculty	Department
		Generic	SEM, TEM, XRD, particle sizing	Phys. & Techn.	Group multiphase systems
University of Oslo (UiO)					
	Exp. Ass.				
		Generic	Experimental assemblies (test facilities/rigs) dedicated H2 research		Chemistry
		Generic	Gas mixers for complex mixtures and gradients		Chemistry
		Materials related	Electrical characterisation of hydrogen related materials at high temperatures (< 1400°C) in controlled atmospheres, incl. H2 (ProboStat)		Chemistry
		Materials related	Gas permeation rigs for button-size samples at high temperatures (<1400°C) and controlled atmospheres, incl. H2)		Chemistry
	Instr.				
		Generic	Scanning electron microscope (FEG-SEM) with heating stage and H2 atmosphere possibillity		Chemistry
		Generic	TGA and TGA+DSC with controlled atmosphere		Chemistry
	Lab.				
		Fuel cell	Laboratory for testing of button-size fuel cells and hydrogen separation membranes		Chemistry
		Materials related	Laboratory for testing of electrical properties of hydrogen-related materials at high temperatures in H2 atmospheres		Chemistry
		Materials related	Laboratory for testing of high temperature corrosion of materials in hydrogen-containing atmospheres		Chemistry
		Production	Laboratories for production of substrates and films for button-size fuel cells, electrolysers and H2 separation membranes		Chemistry