Final report

1.1 Project details

Project title	'Analyser for kommercialisering af brintteknologier' Analysis for Commercialization of Hydrogen Technologies
Project identification (program abbrev. and file)	64013-0581
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Project managing company/institution (name and address)	Partnerskabet for brint og brændselsceller Vodroffsvej 59, 1900 Frederiksberg C
Project partners	Partnerskabet for brint og brændselsceller Dansk Energi Ea Energianalyse A/S Århus Universitet, Center for Energiteknologier AU Herning Syddansk Universitet, Institut for Kemi EnergiMidt A/S HMN Naturgas I/S DTU Energikonvertering DTU Mekanik Dantherm Power A/S GreenHydrogen.dk H2 Logic A/S IRD A/S (Topsoe Fuel Cells A/S)
CVR (central business register)	32190669
Date for submission	May 30, 2016

1.2 Short description of project objective and results

1.3 Project objectives

1.4 Project results and dissemination of results

1.5 Utilization of project results

1.6 Project conclusion and perspective

Annex

Relevant links

1.2 Short description of project objective and results

The purpose of this project has been to analyse and identify the need for more technological development of hydrogen technologies for these to be integrated in the Danish energy system to come. These analyses will be carried out with starting point in model calculations for identification of technological and financial bottlenecks. Barriers for introduction of hydrogen technologies in the energy system have been identified.

Projektet har haft til formål, at analysere og redegøre for, hvor der er behov for at fremme yderligere brintteknologisk udvikling, for at integrere brintteknologierne i det danske energisystem. Kritiske teknologiske og økonomiske flaskehalse for brintteknologierne er blevet identificeret og vurderet sammen med betydende rammevilkår og barrierer.

1.3 Executive summary

In Denmark a few analyses and modellings have already been carried out to identify how to store renewable energy in a forthcoming 100 % based renewable energy system. Over the last years existing models have been developed and expanded in order to include input data from new technologies. The added value of this project is the inclusion of all relevant hydrogen technologies in the modelling process, and a concrete assessment of how hydrogen tecknologies will be able to benefit a future energy system, independent of fossil fuels. Accumulated knowledge from all project partners, all members of the Partnership as well as external sources has formed a platform of information on which modelling of opportunities in relation to the energy system has been done.

The analyses have been focused on hydrogen technologies, and as part of the project, different scenarios has been defined. The scenarios are based on projections from World Energy Outlook and Futures from November 2015. Alternatives to hydrogen technologies have been included in the model and calculations to be able to benchmark technologies to one another.

The project has resulted in an updated version of "Energistyrelsens Energiteknologikatalog". The data from this project has already been handed over to the Energy Agency for their modelling work. This project has also resulted in updated roadmaps for hydrogen technologies, which will set the participating industrial stakeholders in a much better position for developing improved strategies for deployment and commercialization of hydrogen technologies. Investors' background for decisions of investments in hydrogen technologies is improved.

Furthermore the project has run several simulations in the Balmoral model and created interesting calculations for the involved technologies. The calculations are of great use for the involved parties since they have given a direction for where to further develop the technologies.

Almost all relevant Danish stakeholders dealing with hydrogen technologies and forecasts for a future energy system based on renewable energy have participated, which gives the project a solid foundation within the sector. However – as with all 20 years projections – the results are combined with a certain level of uncertainty – especially when looking at the long term development of a single technology, whereas the system analysis is more reliable although also a projection.

Perhaps most importantly, that project in WP4 identified the main obstacles for a further integration of hydrogen technologies in the Danish Energy System and identified both financial and technological bottlenecks in the system, as well as defined the main obstacles created by the current framework conditions.

These analysis where put together to form a number of recommendations for which kind of technologies to fast track, and which framework conditions that could be applied in order to assist in creating a new and better fast forward scheme.

1.4 Project objectives

This project is not like many other technological development projects. The core focus in this project has been on analysis for where and how the hydrogen technology should develop. The project has been running from January 1st 2014 to April 30 2016.

Luckily the technologies encompassed in this project are developing rapidly to a new and more efficient stage. This is of course something positive, and not least due to the support from EUDP and other sources, that has led Denmark to be a leader within Hydrogen and Fuel Cells technology today. However, this has also been a significant challenge, for the project partners. It has been more difficult than originally anticipated to achieve the same measuring parameters in the energy technology catalogue were hard to determine for a wide range of different technologies. Furthermore it is difficult to map a learning curve 30 years ahead and to predict the prices on fossil fuels. The EUDP secretariat has had great insight in the challenges and has understood the necessary changes asked from the project manager. Hereunder you will find an overview of the work packages and a brief insight in the work done in them from each work package leader.

The project ends four month later than originally planned but has fulfilled all deliverables and milestones, and last but not least created great learning for all the involved project partners and stakeholders outside the project.

WP0

Number	Description	Deadline	Status
Task 0.1	Conduction of advisory group meetings	Every 6th month	-
D 0.1	Cooperation contract between project partners	March 2014	Signed in time
Task 0.2	Conduction of steering group meetings	Each quarter	-
D 0.2	Payment requests	Every 6th month	Submitted in time
Task 0.3	Project coordination, meetings and administration	Continuous	-
D 0.3	Annual report	Annual	Submitted in time
Task 0.4	Reporting	Continuous	-
D 0.4	Final Report	30th of June 2016	Submitted in time
Task 0.5	Conduction of workshops, conferences and other dissemination	Continuous, five events in total	Conducted on June 2nd 2014, September 22nd 2014, February 27th 2015, October 20th 2015 and March 31st 2016

The project management was conducted by the Danish Partnership for Hydrogen and Fuel Cells. The official project manager was replaced on September 1st 2015 due to retirement of the now former CEO of the Partnership.

Unfortunately, a classical mistake was made in this project, as it has been done in so many other projects before this one: too much time was used on work package one, which eventually lead to a prolonging of the project with four months, in order to have time to fulfil the obligations in work package three and four properly. This could have been prevented if the project management, together with the WP leaders, had controlled the project a tighter. However, as it is described below, the delay was to a large extend caused by the desire from projects partners etc. to ensure that all technologies where represented with the newest and most correct dataset, and it is – in a mainly theoretical project – a somewhat harder case to bring so many partners together one single estimation for the development of somewhat competing technologies. This is an obstacle, which perhaps should have been anticipated from the start of the project.

Task 0.1 Conduction of advisory group meetings

In the project there has been a good communications with the relevant stakeholders outside the project. Representatives from the Energy Agency, Energinet.dk, DONG and other key actors within the sector have been a part of an advisory group. There has been an ongoing communication with the members of the advisory group throughout the project. The group's job was mainly to guide the work done in the project and to secure that data collected in the project was of a certain quality. This led to the involvement of Danish Gas Technology Centre as an external reviewer of the involved hydrogen technologies. Meetings are held in correlation with the workshops in the project and bilateral communication with work packages leaders.

Task 0.2 Conduction of steering group meetings

To secure a continuous progress in the project a steering group was formed. The steering group mainly consisted of the work package leaders from the Partnership for Hydrogen and Fuel Cells, Dansk Energi and Ea Energianalyse. The group have held numerous meetings to secure a successful completion of the different tasks in the project, to allocate the necessary funds and resources between the project partners, and to make sure knowledge was shared. The group was intended to meet three to four times a year, but the group has met more often and this has created a smooth and thorough communication within the steering group.

Task 0.3 Project coordination, meetings and administration

The Partnership for Hydrogen and Fuel Cells has planned meetings with the groups mentioned above, the project partners and the EUDP Secretariat when needed to create progress in the different work packages. Dansk Energi and EA Energianalyse have planned a number of smaller workshops and meetings within the specific work packages that they led.

Task 0.5 Planning and conduction of workshops, conference and other dissemination

The Partnership for Hydrogen and Fuel Cells has organised a number of open workshops held as a part of the project, with both external participation, as well as the project partners off course. These workshops gave space for debates on hydrogen technologies with a range of key stakeholders which would not have taken place otherwise, and served the dual purpose of both qualifying the project results due to the contributing from external parties and disseminating the project results to key external stakeholders.

WP 1

Number	Description	Deadline	Status
Task 1.1	Development of data template	April 30 2014	-
Task 1.2	Selection of key technologies	May 31 2015	
Task 1.3	Collection of data	May 31 2015	
D 1.2	Data on key technologies collected in the Energy Technology Catalogue	May 31 2015	Data collected
Task 1.4	Review of the data	May 31 2015	The review ended on April 30, 2016.
D 1.3	Data from project partners is drawn up and reviewed	May 31 2015	The first edition of the technology catalogue was handed over to the DEA on June 2015, but a new revised edition of the catalogue is submitted with the final report.

The purpose of work package 1 has been to establish data for hydrogen technologies and other selected key technologies from the project participants' knowledge on the development of the respective technologies. These data have been benchmarked against national and international data. The data has been used for the identification of technological and financial bottleneck and as input for the model calculations analyzing the future role of hydrogen technologies in the Danish Energy System.

According to the original time schedule WP1 was intended to end in the beginning of January 2015. In practice, the development of the draft catalogue was not finished before May 2015. The reason for this was threefold:

1) The setup of developing a new catalogue of technologies for WP1, including not only hydrogen technologies but also competitive technologies, was ambitious
2) The participating organization had quite differing views on many technologies
3) Some of the participating organizations were not used to communicating results and technologies to energy planners. This involved lengthy discussion about the format for the data and the requirements to presentation of data and assumptions.

The process with the development of scenarios in WP2 and WP3 also demonstrated to need to continuously quality check and improve data. Therefore, WP1 was only finally ended in parallel with the rest of the project.

Task 1.1 Development of data template

Compared to the original catalogues of the DEA the data sheet and the setup for data collection were improved in a number of ways:

- For each technology an organization was responsible for preparing the data sheet and another organization was responsible for auditing the datasheet. This review process was decided to improve data quality and in particular to avoid biased data due to the possible interests in the promotion of specific technologies among a number of the participating organizations.
- The names of both author and auditor are displayed in the catalogue.

- A categorization of the technological maturity of the technology. This is important to understand the uncertainty related to the projected performance and cost data.
- Technology projections should be related to a projection of the demand for the specific technology.

Different methodologies were forecasting technology data were discussed in the project between the project partners and the DEA and Energinet.dk. The learning curve approach has many appealing features, allowing in principle, a neutral projection methodology where all technologies are treated equally by applying the same learning rate. As part of the project a review of the learning curve methodology was prepared and discussed with experts. In practice, learning curves proved difficult to apply for several reasons.

- For the most technologies there is not sufficient data to create a learning curve or it will be very time consuming to collect the relevant data.
- Most hydrogen technologies are in the research or demonstration phase and hence there is no or very limited data to extrapolate from; the accumulated production volumes are very small and even today's prices are associated with uncertainties.
- The development of some technologies is highly affected by external drivers. As an example the market for membranes for upgrading biogas will probably not be pushed primarily by the biogas industry but rather for use in other industrial purposes, water treatment etc.

Therefore the projections the catalogue have mainly relied on expert assessments from the contributing organization and reported data from national and international references.

Task 1.2 Selection of key technologies

Already from the outset of the project the Danish Energy Agency and Energiet.dk expressed interest in using the data collected in the project for updating the official Danish catalogues displayed at the website of the Danish Energy Agency. Therefore, at the first steering group meeting, it was decided to present the data in the form of a catalogue resembling the layout of the DEA's catalogue. At the same steering group meeting approximately 20 technologies were selected for analyses and inclusion in the catalogue. The majority of these technologies were directly related to the hydrogen value chain, such as fuel cell systems and electrolysers. However, a number of competing technologies such as electric vehicles and batteries were also selected since these were important for the subsequent analyses. A number of iterations were afterwards made to the list of technologies. The final catalogue includes data for 24 technologies.

The analytical phases in WP2 and WP3 showed that it would have been relevant to put a stronger focus on different thermal gasification technologies for the production of synfuels in the catalogue. However, this was discovered relatively late in the process and instead the project has relied on other sources and data from parallel projects. This does of course mean that these data has a different viability than the data generated from the process described above.

Task 1.4 Review of the data

In the preparation of the catalogue it has been a challenge that the project partners have had conflicting, and often very strong views, on the projections of the technologies. The conflicting views have been in respect to the future market potential (sales), how fast technologies bottleneck will be overcome and what levels of economy of scale and learning rates can be expected. Some of these conflicts are probably related to both different perceptions of the technologies but also the different interests of the participating organizations.

In a few cases author and the reviewer was not able to agree on the data and the projections. In these cases, the comments from the reviewer are included together with the data from the author. The approach of having both an author and a reviewer for each technology was useful to improve the quality of data. Still, it is a fundamental challenge of technology forecasting that the companies and organizations that possess the deepest insight in a specific technology would normally also have an interesting in presenting it in a positive perspective. From the perspective of the work package leader, it is recommended that companies that have direct interest in the development of a specific technology, are given an advisory role rather than an implementing role in future similar projects. This is naturally a stronger challenges in a project where projections about technology development are to be made. This is not easy and will be

The development of the catalogue revealed that the access to critical resources, such as rare metals, is an important issue for a number of technologies (for example PEM cells and batteries). Therefore, SDU prepared an analysis of resource criticality, which is included in the catalogue. The analysis indicates, that a wide spectrum of technological substitution options can be found to release technologies from their specific resource dependencies, and that the resource criticality challenge as such may well be less of a constraint than feared by many stakeholders.

During the preparation of the catalogue, two workshops were held with the project partners and other relevant stakeholders. The workshops dealt with cross-cutting issues, like forecasting assumptions and methodologies, and included presentation technology data by the authors. Both workshops had high a number of participants and gave valuable input to the project. The original project schedule included only one workshop in relation to WP1, but during the process it became clear that this was not sufficient.

At the end of the project the DEA and Energinet.dk decided to adopt the data from a number of the technologies in the hydrogen catalogue (fuel cell, electrolysers, hydrogen storage and hydrogen transport) to their existing catalogues.

WP 2

Number	Description	Deadline	Status
Task 2.1	Design of energy consumption model	April 31 2016	
D 2.2	Documentation of energy consumption model	April 31 2016	Part of D.2.2 Submitted with D 3.3
Task 2.2	Development of Balmorel Model	April 31 2016	
D 2.3	Report with documentation of Balmorel model development	April 31 2016	Submitted with D 3.3

The purpose of work package 2 has been to develop an energy system model with the ability to calculate system and utility economy on a utility and system level, to track consumption of resources and monitor carbon dioxide emissions under different scenario setups. A crucial criterion was that the model framework was able to handle new hydrogen technologies in such a way that the system impact, load hours and economy of operation could be analysed.

Initially it was decided that the existing Balmorel energy system model, a partial equilibrium model covering the electricity and CHP sectors, were to constitute a basis on which the model expansions related to new technologies were to be integrated into.

According to the original time schedule WP2 was intended to end in December 2014. During the summer 2015 the delivery was rescheduled to the end date of the project. The reasons was both that the technological data from the technology catalogue was six month late, but also because the analytic work process has shown it made more sense to have a parallel work track with model/scenarios development and continues analytical calculations.

Task 2.1 Design of energy consumption model
Early in the process it was decided to use considerable fewer amounts of resources to develop an energy consumptions model in order to be able to use more resources to conduct two supplementary analyses of the transportation sector and individual heating respectively, which was considered as important analysis for the overall project. These analyses gave valuable insight into expected consumption and preferred technologies in these sectors.

Instead of developing a unique energy consumption model during the project, the energy consumption setup from the Danish Energy Agencies latest scenario work was implemented into the Balmorel model. The decision to use the Energy Agencies demand scenario provided a common base from which to discuss and compares results. The assumptions for consumptions are described as part of the model documentation report D 2.3.

Task 2.2 Development of Balmorel Model
As mention above, the model development work had been an integrated part of the continued calculations and has thus been ongoing affected by the projects preliminary results. Sub-analyses and results from early calculations was taken into account to limit the amount of technologies implemented into Balmorel, so only the most promising technologies was included. During the project it became obviously that it was relevant to put a stronger focus on thermal gasification technologies and the technologies associated with the production of synfuels. As a result gasification and synfuels technologies data from other sources and from parallel projects was implemented into Balmorel in addiction to the original plan.

Balmorel has been used to calculate power and hydrogen production cost (prices), overall energy system cost and emission impact. Furthermore Balmorel has been used to analyse storage and capacities optimization.

Model documentation and modelling results can be found in the model documentation report D 2.3.

WP 3

Number	Description	Deadline	Status
Task 3.1	Comparison of assumptions and results from other analysis	December 31 2015	Included in D 3.2.
D 3.1	Analysis of road transportation and individual heating solutions	June 31 2015	The presentation of individual heating solution was finished on March 24th 2015. The report on road transportation was published June 24th on DE's

			website. Submitted by the end of the project
Task 3.2	Creation of scenarios	December 31 2015	Documented in D 3.2.
D 3.2	Analysis of energy carriers	December 31 2015	Submitted by the end of the project.
Task 3.3	Calculations	December 31 2015	Documented in D 3.2. and D 3.3
D 3.3	Final report WP2 &WP3	April 31 2016	Submitted by the end of the project
Task 3.4	Interpretation/communication of results	April 31 2016	Cf. Task 0.5

A central element in work packages three was to set the conditions for the scenario framework. A decision was made to focus solely on 2035 as this year could be used as a beacon for the road mapping of the hydrogen technologies in WP 4. As a result of currently vague political RES directions in regards to the goals for the Danish energy sector in 2035 it was furthermore decided to abandon an energy system setup merely base on a pure RES scenario. Instead the Balmorel model has been allowed to invest in the most economical feasible technology. This setup enables a higher degree of insight into actual emission from the power sector under implementation of the new hydrogen technologies.

Task 3.1 and 3.2

As part of the initial modelling and scenario discussions a workgroup forum was established that was to discussion the potential of energy carriers under different conditions. The results and the conclusions were to be included in D 3.2. This work and the report concerning energy carriers was initially not part of the setup, but was deemed essential by the majority of project participants.

D 3.1 Analysis of road transportation and individual heating solutions

As mention above it was decided to focus project resources on two specific analyses, namely an analysis of the transportation sector and individual heating respectively. During the project it became obvious that it was relevant to focus on subject specific analysis of selected areas.

It was especially imperative to get a deeper insight into the transport sector as much of the demand for hydrogen and hydrogen-based synfuels was expected to come from this sector. A vehicle transport model was developed, which has been submitted to the Energy Authorities to help improve their own model. The result from D 3.1 was presented on an official seminar held June 24th 2015 at Dansk Energi in Copenhagen.

The analysis of individual heating was performed by the construction of an economic heating technology model which made it possible to compare the different heating solutions under different conditions. The results were presented for the project partners.

D 3.2 Analysis of energy carriers

The report was written as a joint project with input from several participants which contributed with valuable knowledge from own studies and field experiences. During the preparation of the report, five workshops were held with some of the project partners and other relevant stakeholders.

The overall framework for the scenarios used in the modelling work in Task 2.2 and in the economical calculation in Task 3.3 was established during the work with the report. In the report the energy balance of essential technologies were presented and an economic comparative analysis of the different electrolysis technology were also included. The best performing technologies was then implemented in Balmorel.

Task 3.3 Final report
Corresponding with the work related to the energy carriers an economic model for future RES technologies was developed. Initially it was planned that only the project's technology data should have been used in the model, but as some of the data for thermal gasification and synfuel-production was inadequate or missing it was necessary to collect and use data from other sources and studies.

The results from the calculations in the economic model were compared with Balmorel results to validate the economic results. Calculations from Balmorel are presented in D 2.3 while the results from the economic model are presented in D 3.3. The results are discussed and compared in the final report D 3.3. Besides these conclusions the final report, D 3.3 also sums up all the results from the previous subanalysis, e.g. transport analysis, individual heating, Balmorel modelling etc.

The results were presented on the final conference on March 31st 2016.

Although the calculations and the reports have been done in coherence with the project and requiring a substantial effort from the WP Leader, Dansk Energi, it is also clear that reports where some of the most problematic in the project.

First of all, in hindsight it will need to be considered if the strict focus on financial optimisation was the best. The means that some unlikely and unrealistic scenarios became part of the calculations. The mainly due to the fact, that it was not taken into consideration, that it is a given and a political condition, that fossil fuels will have to be fazed out. Based on this, we ended up with a number of results, that did reflect a given economic calculation is mainly theoretical.

Furthermore, the calculations are – due to the long range scope, and the earlier mentioned questions about data, insecure in their conclusions and some of the most contested among the project partners. As such, the results of the WP are useful, but not as useful as it in hindsight could have been with another approach, and the results are contested among the project partners.

WP4

Number	Description	Deadline	Status
Task 4.1	Identification and estimation of technological and financial bottlenecks	-	-
Task 4.2	Recommendations to central technological development areas of action	-	-
D 4.1/4.2	Sub report on financial and technological bottlenecks and areas of action	April 30th 2016	Submitted with the final report
Task 4.3	Formulation of road maps for hydrogen technologies	-	-

D 4.3	Sub report on roadmaps for hydrogen technologies	April 30th 2016	Submitted with the final report
Task 4.4	Estimation of framework conditions' influence on hydrogen technologies	-	-
D 4.4	Estimation of framework conditions' influence on hydrogen technologies	April 30th 2016	Submitted with the final report

The work package four was led by the Danish Partnership for Hydrogen and Fuel Cells. The work package has built on top of the results from the previous WPs one and three. The work in WP four has been of great help and learning to the involved partners and in particular the developing industrial actors who have updated their road maps for their technologies with inspiration in the results from WP three and the calculation made there. It is the project participants' hope that the results will be of great value for the relevant authorities and other in the hydrogen and fuel industry. Furthermore the work package comprises some of the most vital recommendations form the project – analyzing the data from work package one and three and with the roadmaps compiling the results into analysis concerning fast-tracking for technologies and framework conditions.

Task 4.1 Identification and estimation of technological and financial bottlenecks
To make a plan for the development of the energy system it is crucial to identify what the barriers are. In this task the involved project partners have taken a look at the bigger picture to identify what the challenges are for hydrogen technology. Hydrogen will by all estimations – from this project, the DEA as well as in almost all other estimations be a part of the energy system of tomorrow, but there are barriers that need to be faced. This task led to a sub report which can be found in appendix D 4.1.

Task 4.2 Recommendations to central technological development areas of action
After identification of barriers in the previous task with data from the current project, it was possible for the project partners to make recommendations for technological areas of action which needs a push to be able to mature enough to play its crucial part in the energy system. These recommendations are also seen in relation to the Danish Energy Agency's scenarios from 2014 and Energinet.dk's 'Energy Concept' from 2015. The calculations made in WP three are made in a Balmorel model which includes the entire energy system for Northern Europe, so the recommendations also rely on transnational view of energy systems. The work done in this task is to be found the sub report 4.2 in appendix D 4.2.

Task 4.3 Formulation of roadmaps for hydrogen technologies
In this project there has been collected a lot of data on hydrogen technologies which has helped in the process of formulating updated roadmaps. The roadmaps go as far as 2035. The roadmaps are made for the technologies that are represented in the project via industrial and university partners. The roadmaps that were to be built from the beginning have been a bit more challenging to write than anticipated and are not quit as comprehensive. The roadmaps can be found in appendix D 4.3.

Task 4.4 Estimation of framework conditions' influence on hydrogen technologies
The challenges of the implementation of hydrogen technologies in the energy system are not always due to technological or financial barriers. The framework conditions favor some technologies over others which in many ways are a very efficient way of controlling the develop-

ment. Therefore it was natural to also include a mapping of the existing framework conditions and recommendations to how they should be changed in order to implement more hydrogen technologies. The result of the work done in this work package is to be found in the sub report in appendix D 4.4.

1.5 Project results and dissemination of results

The overall conclusion of the project is that hydrogen technologies have a very important role in the energy system of tomorrow. It is a key element in linking the power, heat and gas systems together. There are some challenges though, in particular regarding prices and the efficiency of the hydrogen technologies. There are other technologies today that can solve some of the same problems as hydrogen technologies but at a much lower price. Still the hydrogen has an enormous potential which makes the resources spend on research, development and demonstration worth it.

Main Activities

The main activities in the project have been to create a template for technology comparison, collect the data for hydrogen technologies and benchmark-technologies and review the data to secure the reliability. Furthermore the activities have been to develop the Balmorel model to also include electrolysers, fuel cells, hydrogen storage, fuel cell electrical vehicles and methanisation. Afterwards to choose two possible scenarios for the future and run calculations on possible demands for hydrogen prices, OPEX, CAPEX and so on. Finally the main activities have been to identify financial and technological challenges along with potential obstructive framework conditions, and thereafter to give suggestions on how the hydrogen technologies can be implemented in the energy system of tomorrow with an adjusted set of regulations.

All findings are available in the sub reports in the appendix.

Expectations of increased turnover, employment and export?

As mentioned earlier this is not like any other research and development project since the product is pure paper. The papers are valuable and full of knowledge and results that can lead to a massive increase in turnover, employment and export, but only if the public funding and the industry's own research resources are well spend. In this project we have determent how the resources are well spend and where there should be a technology push from the public funding schemes and under which circumstances the hydrogen technologies can play the best roll in the energy system.

Dissemination

The project has been presented in many occasions to key stakeholders. There has been an intense dialog with Energinet.dk and DEA along with other technology developers that where not a part of the project consortium. The close communication with these key actors has secured an anchoring in the sector.

Within the project there have been conducted four larger workshops where stakeholders from outside the project were also invited to feed in to the process.

In June 2015 an 'After work-meeting' on green transportation was held as a part of WP three. The event was hosted by the Danish Energy Association. The meeting was well-attended.

The project ended with a public conference hosted by HMN Natural Gas. At the conference the results of the different work packages were presented. The EUDP secretariat was also invited but was not able to participate.

The Danish Energy Association, WP-leader on WP two and three, has plans of hosting an event in the late summer in addition to the one held in 2015. The knowledge obtained in the project will therefore be share again to another audience than the one at the final conference.

Last but not least, all the project partners will use the knowledge obtained in the project in their work in the future which must be one of the most important goals of the project.

1.6 Utilization of project results

The results from the project will be used as input to other calculations, since the most important thing in predictions of the future is to give the best data input. Shit in, shit out, if we may be so frankly.

The Balmorel model-refinement will be of great value to the Danish Energy Association and EA Energy Analysis in their day to day work and future project since the number of alternatives when calculating the future energy system now has a broader spectre.

The roadmaps are of great value to the technology developers and funding schemes. It gives a clear road toward commercialisation for everyone to see.

The paper on framework conditions will be of great value for the all the members of the Danish Partnership for Hydrogen and Fuel Cells and a big help for the DEA and politicians in their work with the modelling of the energy system of tomorrow.

Realisation of energy policy objectives

As written in the project application the Danish Climate Commission stated that it was possible to be independent of fossil fuels in 2050. Hydrogen and fuel cell technologies were not a part of the commission's work because they were not, at the time, cheap enough nor had the necessary efficiency. This project has shown that a number of the technologies will be a part of the solution and have already now a lower price and a higher efficiency.

The data collection, calculations and recommendations made in this project will be of high value to everyone whose job it is to promote a society based on renewable energies where conversion and balancing of energy supply is a crucial necessity.

1.7 Project conclusion and perspective

The conclusions in this project have – due to the specific nature of the project are many and wide ranging.

All in all, the project shows that hydrogen technologies can be a sufficient contributor to the future fossil independent energy system. The technologies are wide-ranging, and as the project results indicate not all technologies may be competitive and not all those competitive, will be relevant in a Danish context due to the design of the Danish energy system.

However – a significant conclusion – is that hydrogen technologies will be vital for the energy system as a whole. This is a significant change to the way hydrogen technologies has been perceived in the past. Hydrogen can and most presumably will be, a building block in the future energy system, replacing oil as the building brick of the energy system in all the places where it won't be possible or desirable to use electricity directly.

The conclusions concerning the key areas where hydrogen will play a major role are also vital and relative secure in their estimation that hydrogen will be used both as a fuel itself, but vitally also to produce fuels such as methanised biogas, methanol, synthetic diesel, herby securing not only vital fossil free fuels but also the most efficient use of the most limited fossil-free energy resource biomass.

Also in the transport sector, where Denmark already holds a leading international position, the projects concludes – even with extremely conservative estimations – that there is a significant role for both hydrogen and hydrogen related fuels. Denmark can and will not affect the development of hydrogen cars – or other cars for that matter – but the employment of infrastructure and framework conditions that enables hydrogen powered transport, will enable Denmark to efficiently apply large scale hydrogen based road transport. This conclusion is a milestone, since transport traditionally has been one of the hardest energy consuming sectors to change into zero-emission energy sources while at the same time maintaining the mobility and flexibility required by the customers.

In general the estimations concerning the technologies are very careful. As previously mentioned collection of data and the estimations about the performance of individual technologies are subject to certain level of disagreement between the projects parties, and it is difficult to project the future development of technologies, oil, gas and electricity prices etc. However – the overall conclusions, that hydrogen will be a key factor in a future energy system is clear.

Furthermore, the conclusions from especially WP4 means that the project is able to present clear recommendations for enabling the implementation of hydrogen energy and storage solutions into the Danish energy system. Based on the projects as a whole it is – as mentioned in the WP4 conclusions – clear that the one main technology that is a key factor to all other technologies dealt with in the project is the power2gas production of hydrogen. Electrolysis is key to both producing the hydrogen needed to use all other discussed technologies and to deal with the increased need to balance the electricity system.

Furthermore – it is a key conclusion from the project, that biomass are to be used in combination with hydrogen in order to achieved a sufficient supply of fuels. This will be a key factor in the years to come.

However – as previously mentioned – when looking at the individual technologies, and not on an overall system approach - the accuracy of the conclusions are more uncertain. Especially when we are looking at long term predictions with technologies that are not yet on the market, as it is the case with for instance SOEC and -FC technologies that are currently in an experimental phase.

However – the strict auditing of the technology data means that the conclusions on the development of the technologies all in all can be described as conservative and this insures that the overall conclusions are both valid and perhaps even a bit too cautious.

Overall the project conclusions points towards an energy system with a wide ranging use of hydrogen and hydrogen technologies, especially with regard to use in combination with biomass and to transportation. This will be of importance and significance to the energy planners, the industry and potential investors in order to navigate in the coming energy context.

The overall conclusions will hopefully serve to the further develop both the future Danish energy system and the strategic and commercial development of hydrogen technology.

Annex

D 1.3 Energy Technology Catalogue

D 2.2 Documentation of energy consumption model
D 2.3 Report with documentation of Balmorel model development

D 3.1 Analysis of road transportation and individual heating solutions
D 3.2 Analysis of energy carriers
D 3.3 Final report WP2 &WP3

D 4.1 Technological and economical bottlenecks
D 4.2 Recommendations for areas in need of technology push
D 4.3 Roadmaps for hydrogen technologies
D 4.4 Estimation of and recommendations for framework conditions