HYDROGEN IMPLEMENTING AGREEMENT

(DISCO-H2)
Distributed and Community Hydrogen

Final Report
for
IEA – International Energy Agency
HIA – Hydrogen Implementing Agreement

Task 29: Distributed and Community Hydrogen (DISCO-H2)
Subtask 3: Model Concept Development

Wrapped up by: Hiroshi Ito

Operating Agent

National Institute of Advanced Industrial Science and Technology (AIST)

1-2-1 Namiki, Tsukuba 305-8564, Japan

E-mail: ito.h@aist.go.jp

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IEA HYDROGEN IMPLEMENTING AGREEMENT (HIA) SECRETARIAT

9650 ROCKVILLE PIKE

CARRIAGE HOUSE

BETHESDA, MD 20814

+1 301 634 7423

MVALLADARES@IEAHIA.ORG

WWW.IEAHIA.ORG

Task 29

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Wrapped up by:
Hiroshi Ito
Operating Agent
National Institute of Advanced Industrial Science and Technology (AIST)
1-2-1 Namiki, Tsukuba 305-8564, Japan
E-mail: ito.h@aist.go.jp

Contributed by:

Alister Gardiner
Callaghan Innovation, Christchurch, New Zealand

Mary-Rose Valladares
IEA-HIA, Washington DC, USA

Aline Rastetter
ALPHEA, Forbach, France

Emmanuel Stamatakis
CRES, Athens, Greece

Jean-Christophe Hoguet
Helion (Areva), Aix en Provence, France

Raymond Shmid
Hydrogenics, Oevel, Belgium

John Lewis
NREL, Denver, USA

Robert Friedland
Proton Onsite, Wallinford, USA

Daniel Aklil
Pure Energy, Unst (Shetland), UK

Daniel Scamman
ITM Power, Sheffield, UK

And

Federico Villatico Campbell
UNIDO-ICHET, Istanbul, Turkey

1. Executive Summary

The International Energy Agency (IEA) – Hydrogen Implementing Agreement (HIA) has established Task 29: Distributed Community Hydrogen (DISCO-H2). This Task was operated from the beginning of 2011 to the end of 2014 to progress the optimization and replication of "green" hydrogen within distributed and community energy systems. This Task would be accomplished by identifying situations where the use of hydrogen is appropriate and assessing the technical, environmental, economic, and social benefits of such systems.

Subtask 3 (ST3) – Model concept development, is the follow-up to subtask 2 (ST2). In ST2, based on the project survey and data collection, six projects were selected for detailed analysis in ST3; these focus on the following types of communities:

- two islands/rural
- two urban
- two industrial/commercial applications

Software analysis in ST3 provided a host of findings relating to the economic and environment/technical aspects. In rural/island communities, the hydrogen storage system based on renewable energy sources (RES) is a major candidate. However, achieving economic feasibility with this kind of system is considerably difficult at present. In addition, the round-trip efficiency of the hydrogen system (electrolysis – storage – power generation) is about 40% at the highest, and the hydrogen system needs a specific objective such as load leveling or backup power. In urban communities, a small-scale FC-based CHP system has been commercialized and is close to achieving economic feasibility. However, using hydrocarbons as a fuel for CHP means that CO_2 emissions cannot be avoided, and the reduction of CO_2 emissions must be discussed carefully. In industrial/commercial communities, there are several applications where distributed hydrogen systems can be introduced, such as FC-based cogeneration, FC-based backup power and FC-powered forklifts. In the case of FC-powered forklifts in a warehouse, a lower charging frequency (longer driving distance per charge) and shorter charging (fueling) time are major advantages over battery-powered forklifts. A cost comparison of total ownership between these two kinds of forklift revealed that FC-powered forklifts are already competitive with battery-powered forklifts.

Subtask 4 (ST4) activity had drawn on work in the earlier subtasks to analyze the six projects from the viewpoint of their readiness for market replication. This report addresses two outputs:

- It assesses the market readiness of each of the projects under a framework developed by the Task participants by drawing on ST2 and ST3 results and additional analysis to draw market readiness conclusions across the six projects.
- it describes in some detail the framework which was developed for making consistent market readiness assessments across the six projects.

The cases study projects were selected and a SWOT analysis performed under ST 2.

In drawing the conclusions about maturity of the technologies several qualitative assessment tools were used to create a “Market Readiness” framework with which to assess each project. These were drawn from a range of different sources and the framework was developed specifically for this study. A review of literature in the area did not reveal any suitable pre-developed methodology which could be used to assess, at a qualitative level, the “market readiness” of the range of hydrogen energy projects selected. The methodology may be a useful as a basis for assessment of other new technologies and products.

From this summary, it can be seen that no project illustrates a high success signature in all market readiness dimensions. Projects that offer good economic value are less positive in environmental benefits, and the converse is also true. Commercially advanced projects do not necessarily show a positive economic signature, as they may still be supported by government policy and subsidies of some kind. Standouts in ongoing commercialisation progress to date are the Residential CHP systems (Enefarm) and the MHE (Fedex Distribution Centre).

Of the case studies themselves, our hope is that these representative examples of distributed hydrogen technology applications will contribute to the development of “a how to guide” that informs professionals (planners, architects, engineers), policymakers (especially at sub-national levels) and businesspeople as to utilize the process and the “need to know” aspects of utilizing hydrogen solutions for their respective remote/island, urban, and industrial applications. The aim is to increase awareness of the market maturity of the different attributes of these hydrogen projects, and support the progress of similar hydrogen technologies and systems through to commercialisation.

2. Task overview

2.1 Background

Task 29: Distributed Community Hydrogen (DISCO-H2) was proposed as follow-on to Task 18: Integrated Systems Evaluation as a further activity conducted under the International Energy Agency (IEA) – Hydrogen Implementing Agreement (HIA). The proposal was approved at the executive committee (ExCo) meeting of HIA in November 2010, and the Task started in early 2011. The proposal is to study the integration of hydrogen systems with electricity and other energy and mobility networks. The Task should have considerable industrial input and create impetus toward commercialization of hydrogen systems.

2.2 Objectives

To progress the optimization and replication of "green" hydrogen within distributed and community energy systems, this Task would be accomplished by identifying situations where the use of hydrogen is appropriate and assessing the technical, environmental, economic, and social benefits of such systems. Analysis includes:

- cost-benefit analysis
- business case and market research
- identification of technical benefits and gaps
- materials for education and raising awareness
- materials to help planners and regulatory authorities facilitate incorporation of hydrogen systems within energy networks

This should form part of the foundation for commercialization efforts and favor new job opportunities.

2.2 Scope of Task 29: DISCO-H2

This Task will be successful when the technical, economic, social, and environmental benefits of hydrogen in communities are evident and the Task has played a role in helping to implement such systems, leading to replication or mass production. To this end, the Task aims to take a holistic view of low-carbon energy networks and to identify the appropriate situations where integrating hydrogen systems within such networks offers added value.

The Task has focused on hydrogen applications in energy communities and distributed systems mostly involving stationary applications, but it also looked at potential benefits for transportation. An "energy community" is defined as a group of interacting people living in a common location that features a shared geographical location and energy needs.

The scope of distributed and community hydrogen covers:

- hydrogen applications in island and rural communities
- hydrogen applications in urban communities
- hydrogen applications in industrial and commercial communities

The hydrogen used should be produced at the local level (i.e., distributed) rather than at a centralized industrial site. Communities to be considered should have up to 1000 people, and the total installed power capacity of the hydrogen energy technologies (both producing and consuming hydrogen) in the communities should not exceed 500 kW.

The Task would be broken down into the following subtasks (ST), which would be articulated in various activities:

Subtasks (suggestions in parentheses):

1. Management
   - 1.1 Management and reporting
2. Analysis and selection
   - 2.1 Community identification
   - 2.2 Data collection (in relation to economic, social-regulatory, environmental, and technical areas)
   - 2.3 Project selection
3. Model concept development
   - 3.1 Analysis of island/rural projects
   - 3.2 Analysis of urban projects
   - 3.3 Analysis of industrial/commercial projects
4. Concept replicability
   - 4.1 Technology readiness assessment
   - 4.2 Market readiness assessment
5. Dissemination
   - 5.1 Dissemination of task results
   - 5.2 Scientific community
   - 5.3 Industrial sector
   - 5.4 Regulatory authorities

Figure 1 shows the logical flow of subtasks. The main flow of the overall Task lies in ST2, ST3, and ST4. ST2 surveys the projects worldwide and selects those that will be further analyzed in ST3. ST3 focuses on the projects selected in ST2 and develops and defines three main concept models, one for each project category. ST4 studies the potential for the concept replicability among selected stakeholders by suggesting application sectors in order to achieve market penetration.

In the long term, whole cities may integrate hydrogen into their energy networks. However, DISCO-H2 will concentrate on developments at the subdivision level or smaller, as it is envisaged that this is how distributed and community hydrogen systems will be built up. A full range of energy applications for which hydrogen may be used shall be considered; examples include heat, power, transport, and cooking. This will allow studies of how hydrogen can be used as a vector to bridge different energy networks and manage peaks of load consumption and generation. Thus, electrolyzers, reformers, fuel cells, ICEs, hydrogen burners, and renewable energy generation systems are all likely to be components. DISCO-H2 will take a holistic view of how these components can be integrated in and complement existing energy networks. The investigated sources of hydrogen would preferably be those that are renewable, but other sources like reforming of natural gas or wastes will be taken into consideration.

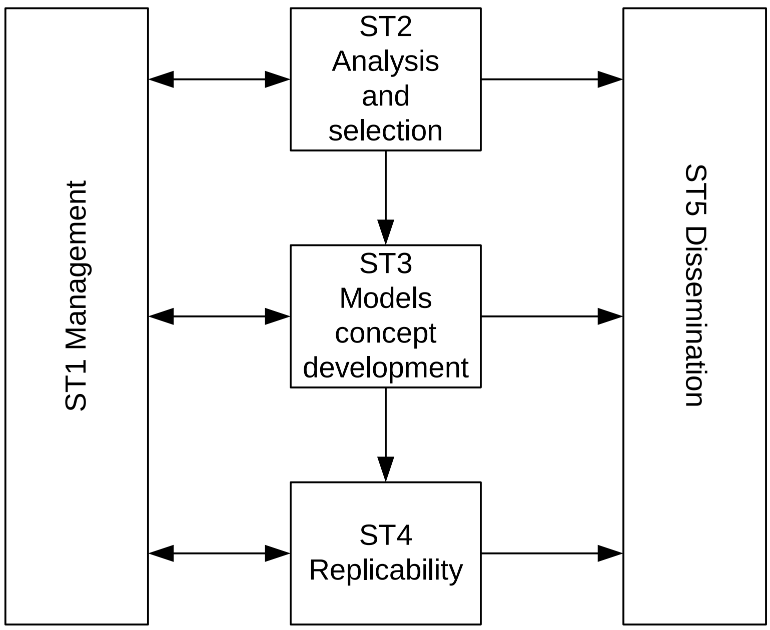

Figure 1. Logical flow of DISCO-H2 subtasks.

2.3 Participants

There had been total 12 participants in Task 29 from 8 different countries as listed below.

1) Hiroshi Ito (operating agent, ST3 leader): AIST, Japan
2) Alister Gardiner (ST4 leader): Callaghan Innovation, Christchurch, New Zealand
3) Mary-Rose Valladares: IEA-HIA, Washington DC, USA
4) Aline Rastetter: ALPHEA, Forbach, France

5) Emmanuel Stamatakis (ST2 leader): CRES, Athens, Greece
6) Jean-Christophe Hoguet: Helion (Areva), Aix en Provence, France
7) Raymond Shmid: Hydrogenics, Oevel, Belgium
8) John Lewis, NREL: Denver, USA
9) Robert Friedland: Proton Onsite, Wallinford, USA
10) Daniel Aklil, Pure Energy: Unst (Shetland), UK
11) Daniel Scamman: ITM Power, Sheffield, UK
12) Federico Villatico Campbell (former operating agent): UNIDO-ICHET, Istanbul, Turkey

2.4 Meetings

Total 8 biannual meeting were held from 2011 to 2014 as below.

1st meeting: 9-11 February, 2011	at Istanbul, Turkey
2nd meeting: 12-13 September 2011	at Edinburgh, UK (with WHTC)
3rd meeting: 2-3 June 2012	at Toronto, Canada (with WHEC)
4th meeting: 15-16 October 2012	at Brussels, Belgium
5th meeting: 13-14 June 2013	at Methil and Edinburgh, UK (with HYPOTHESIS)
6th meeting: 20-21 November 2013	at New York city, USA
7th meeting: 19-20 May 2014	at Ajaccio, France
8th meeting: 18-20 November 2014	at Wellington, New Zealand

1st meeting at Istanbul

2nd meeting at Edinburgh

Figure 2. Photos at the meetings.

3 Subtask2 - Analysis and selection

3.1 Description of Subtask 2 (ST2)

CRES (Greece) was the ST2 leader (STL). This subtask studied the projects and executed a selection on the ones that will be further analyzed in ST3. It is subdivided into three tasks as follows:

Activity 2.1 (A2.1): Community identification

Activity 2.2 (A2.2): Data collection.

Activity 2.3 (A2.3): Project selection

3.2 Activity 2.1 -Community identification

Activity 2.1 reviewed a list of projects in order to identify communities to be studied in the task. Project selected have been chosen among several criteria:

- Involve a community
- Involve distributed systems
- Stationary and / or transport applications
- Up to 1000 inhabitants and/or power consumption bellow 500 kW

The criteria leaded to make 60 hydrogen and fuel cell projects on the table. Based on the discussion between task members, the selected projects should be sorted in 3 categories:

- Urban communities
- Island and rural communities
- Industrial and commercial distributed H2 applications

The selected projected were submitted to the task expert to be completed by 1) completing missing information in some projects, 2) adding missing projects, and 3) deleting project that did not exactly fit description. Subsequently, a list of 45 projects was validated by the task leader as below:

Urban communities projects:

- Hafen city Hamburg (Germany)
- HyChain (France, Spain, Germany, Italy)
- GlashusEtt "The clever building" (Sweden)
- Halic H2 filling station (Turkey)
- Yorkshire Froward Hydrogen system (UK)
- H2SusBuild (Greece)

Rural and Island communities projects:

- Hychico (Argentina)
- HARP (Canada)
- Ramea island (Canada)
- H2KT Project (Greenland)
- DTE Energy Hydrogen Technology Park (USA)

- Hawaii Power Park (USA)
- Minot (USA)
- Hy-slands (New Zealand)
- Totara Valley (New Zealand)
- Somes Island (New Zealand)
- Faroe Islands (Faroe)
- Hydrogen Community Lolland (Denmark)
- Abalone Energy (France)
- BALISES (France)
- MYRTE (France)
- Enertrag Hybrid Kraftwerk (Germany)
- HYRES (Greece)
- The green Island project Ai Stratis (Greece)
- Lolland CHP (Denmark)
- UTSIRA (Norway)
- HERCULES (Spain)
- Hidrosolar (Spain)
- Hidrotec (Spain)
- HYDROLICA (Spain)
- RESH2 (Spain and Greece)
- Sotavento (Spain)
- Walqa hydrogen park (Spain)
- Hydepark (Turkey)
- Bozcaada Hyland (Turkey)
- Glamorgan (UK)
- H2Office (UK)
- H2SEED (UK)
- HARI (UK)
- Renewable hydrogen croft at LewsCastle College (UK)

Industrial and commercial distributed H2 application projects:

- HyLOG (Austria)
- TeesValley (UK)
- Residential CHPs (Japan)
- Wegmans (USA)
- GENCO (USA)

- UNFI (USA)
- Whole Food Markets (USA)

3.3 Activity 2.2-Data collection

Demonstration projects can be seen as showcases for future commercial products, bridging the gap between near-market products and commercially viable systems. They facilitate the necessary learning process for both technical as well as socio-economic aspects of a technology. In addition, these demonstration projects can act as seeds for other future hydrogen projects or the anticipated large-scale demonstrations. In the activity 2.2, data from 18 hydrogen demonstration projects were collected from various DISCO-H2 partners. A summary Table from those projects is shown below (**Table 1**). These 18 projects were considered to be compliant with DISCO-H2 targets as they guarantee a good balance in terms of geographical distribution and size, technology application and community type.

A preliminary analysis had been carried out in this activity. Further analysis, evaluation and benchmarking for final 6 selected projects would be undertaken in Activity 2.3. As much as possible in-depths information was collected for these 18 projects trying to cover areas like investment costs, CO2 emissions, etc. Data collection showed unsatisfying communication with projects, underlining the need for a common and mandatory framework of data provision. As previously described, the results were aligned to a fixed set of criteria that was developed for the common analysis of infrastructure, technologies, and communities under Activity A2.1. All metrics (criteria) defined in this Subtask methodology include certain aspects regarding to which current technologies, demonstration sites as well as communities can be rated, such as environmental impact, costs or safety etc.

Table 1 – A summary from 18 projects data collection

No	Name	location	partners	data availability	component size	renewable energy	project status	Aim	Remarks
1	HyLOG	Austria	Fronius, Bitter, Biovest consulting, HyCenta…	ok	2 kW/24 V and 4 kW/48 V Fronius Energy Cell	604 kW PV	finished	HyLOG: hydrogen powered logistic system; to fuel Forlifts with renewable hydrogen	
2	CHP in Japan	Japan	Tokyo gas, Panasonic, …	ok	3000 FC (experimental phase)	no	til 2009	to test FC CHP in order to developp a commercial activity (mai 2009)	task 18
3	FITUP	FCH JU		ok		no RES		The project aims at demonstrating some 20 FC systems for back-up and UPS energy purposes in various sites across Europe	
4	SHEL	FCH JU	CIDETEC, UNIDO-ICHET, CRES, Air Products, …	ok	10 FC forklift trucks	depending on the demo site	since 2011	The project aims at producing a fleet of 10 forklift (FLT) units to be demonstrated in various sites across Europe	
5	Tees Valley	UK	Air Products	ok			to operate in 2014	to produce Syn gas with waste from landfill. The plant also has the potential to generate renewable hydrogen for mobile and stationary energy applications	
6	HyChico	Argentina	Hydrogenics, Capex		60Nm3/h + 30 Nm3/h electrolysers	wind turbines	since 2007	to maximise the use of wind turbine; O2 for industrial uses; H2 coinjected with methane for electricity production	rural
7	POWERING THE FIRST 1,000 HOMES	USA			1000 FC units	0.8% of electricity to multifamily housing is provided by renewable power	2008-2011		
8	HARP	Canada	Hydrogenics	ok	60Nm3/h electrolyser	hydro	since 2009	connecting H2 energy storage tohydro power projects in small communities to reduce diesel consumption	Smart-grid (GE)
9	PEI Wind-Hydrogen Village Project	Canada	Hydrogenics, Labrador hydro, VESTAS, Dynetek…		300 kW (6 kg/hr) unipolar liquid alkaline electrolyser + 130 kW bi-fuel hydrogen/diesel genset	250 kW wind turbines	since 2009	develop an integrated wind-hydrogen energy system that is self supporting and can be operated in isolation of the provincial power grid.	rural
10	Lolland	Denmark	IRD, Baltic Sea Solution, lolland local council, DONG Energy, Danish Energy authority…		20 Nm3/h (PIEL)	3 3 MW windmills	2008	to provide renewable hydrogen by pipe to several homes in order to fuel CHP installations; 35 houses sheduled for phase 3	task 18 rural
11	MYRTE	France	Hélion	ok	Phase 1: FC 100kWe / Electrolyser 10Nm3/h; Phase 2: FC 200kWe / Electrolyser 40Nm3/h	550 kW PV	under construction	RES and insular peak-shaving via hydrogen	Island

12	The green Island project Ai Stratis	Greece		ok	100 kW electrolyzer	wind (2 x 600 kW)+ PV (100kW)	sinse 2012	The project aims to deploy RES to cover most of the island's energy needs.	Island
13	RES2H2	Creece	ITC, INTA, ENDESA, OWK, Planet GbR, CRES	ok	a 25 kW water electrolyser, metal hydride tanks and a hydrogen compressor	500 kW synchronous wind turbine	finidshed 2007	The project goals were to study the individual components for hydrogen production, storage and use, and for desalination by reverse osmosis, and their integration with wind energy. Two experimental plants were realized for the study and demonstration of the integrated wind hydrogen systems, one in Spain, on Gran Canaria, and one in Greece, near Athens.	rural
14	RES2H2	Spain	ITC, INTA, ENDESA, OWK, Planet GbR, CRES		40 kW Solantis Energy electrolyser	2 225 kW windmills	finished 2007		Island
15	Bozcaada Hy-land	Turkey	ICHET, Çanakkale Governorship	ok	10 Nm3/h electrolyser; 20 kW FC; 35 kW H2 Genset	PV 20kW	under construction	H2 from RES on an Island	Island
16	H2SusBuild	Greece	CRES	ok	20 kW SOFC	40 kW RES (PV + wind)	oct 2008 - sept 2012	The main objective of this project is the development of an intelligent, safe, self-sustained and zero CO2 emission hybrid energy system to cover electric power, heating and cooling loads (tri-generation) of either residential, commercial and public buildings or districts of buildings.	
17	Halic H2 Filling station	Turkey	ICHET, Hydrogenics, Istanbul Municipality	ok	30 Nm3/h electrolyser	no	under construction	the Haliç hydrogen filling station will refill a bus and a boat	Urban
18	Hydepark	Turkey	Turkish SPO, TÜBITAK MRC Energy Institute...	ok	proton Energy HOGEN 5 kW	5 kW windmill & 12 kW PV	2005 - 2007	The main goal of this national project is to carry out R&D on hydrogen technologies and renewable energy applications. The project realises the	rural

3.4 Activity 2.3 -Project selection

Following the data collection in the activity 2.2, the activity 2.3 was dealing with the selection of the six projects that would be then used for the detailed analysis scheduled in Subtask 3. The six projects should then be selected from the consolidated list produced by activity 2.2 within the three identified categories of communities:

- Island or rural application
- Urban application
- Industrial and commercial application

In a practical way to select 6 projects out of the 18 projects listed by the task 2.2, the first two criteria to be developed are the following:

- **is the considered project really oriented towards hydrogen (H2) and communities?:**
  - ✓ is the project within the scope of the Task in terms of power range (considered below 500kW for the hydrogen system) ?
  - ✓ is the system used by or involving a real community living close and/or using the

hydrogen systems ? (or at least, is this one directly transposable to a real community ?)

- **is the project having enough available data to feed the modeling process in Subtask 3 ?** If not, the project cannot be considered as eligible. It means that the data should already be available, e.g. the project is implemented and the systems are running operationally – or at least being under implementation and confidently being able to feed with results before end 2012.

These first two criteria will contribute to a shorter list of project. These projects will then be compared, qualitatively, in terms of their potential regarding the success factors determined in activity 2.2

- Economic: market readiness, potential market application, market replicability, energy cost analysis
- Technology/Environment: acquired practical experience, emergence of large scale markets for hydrogen technologies, novel hydrogen applications, RES availability, plant availability
- community (social): economic development, innovation, training/education, involvement/commitment, social acceptance & awareness
- regulatory: sufficient legislative network, mandate/local policy measure for H2, codes & standards These qualitative marking will be able to determine which projects are suitable for the modeling.

In addition a last criteria to choose the six projects is to have a well balanced mix of projects in terms of

- Representiveness of the application distribution
- Balanced geographical distribution between Europe, Asia and America

After the above mentioned projects have been considered as difficult to integrate into the modeling task, then the remaining ones have been qualitatively analyzed through the success factors.

The results are the selection of the six following projects

<RURAL/ISLAND applications>

- HARP Project (CANADA) : off-grid application with real community involved in the project, and involving two energy storage technologies to be compared (H2 and redox battery)
- MYRTE Project (EU) : grid-connected renewable energy storage application on an island
- LOLLAND Project (EU) : combined heat and power (CHP) application with real community involved as well in a rural area

<RURAL/ISLAND applications>

- OCTAGON (US): green building application inside a city
- CHP Japan (JAPAN): CHP application in urban area. Access to data should be facilitated

by AIST

<INDUSTRIAL application>

- HyLog (EU) : Forklifts (industrial) application in a warehouse coupled with PV

The selected projects show a good balance in terms of geographical distribution: three projects in EU, two projects in America and one in Asia.

4 Subtask3 – Model concept development

In ST3, the final goal is to develop three generic models of the distributed and community hydrogen system (DISCO-H2) concept so as to represent the three categories above. These concepts would be designed to be scaled up in light of concept replication and market penetration. Subtask 3 (ST3) – Model concept development, is the follow-up to subtask 2 (ST2). In ST2, based on the project survey and data collection, six projects were selected for detailed analysis in ST3; these focus on the following types of communities:

- two islands/rural
- two urban
- two industrial/commercial applications

However, facing to the difficulties of data collection for HARP Project and HyLog, the objective project was replaced by PURE project and FedEx forklift project, respectively. In addition, based on the discussion between the task members, PURE project was categorized in "industrial/commercial" applications together with FedEx forklift. The objective projects and the system components of those projects in ST3 are listed in **Table 2**.

Initially, based on preliminary information, a SWOT (strength, weakness, opportunity, and threats) analysis was performed for each project from the aspects of economic, environment/technical, community/social, and regulatory. Based on this analysis, the findings in community/social and regulatory aspects are summarized and reviewed here. Due to the lack of codes and standards in rural/island communities, it has taken a long time to obtain the permission of relevant authorities to proceed with installation. Fortunately, the community inhabitants were positive and friendly toward the installation and operation of hydrogen systems. The next step will be to show them the apparent benefits, such as reduced energy costs or increased employment. In urban communities, lack of codes and standards is also a problem in certain cases. In addition, education is important not only for engineers but for also users. In industrial/commercial communities, operational and maintenance support provided by suppliers were highly evaluated by the users.

Software analysis provided a host of findings relating to the economic and environment/technical aspects. In rural/island communities, the hydrogen storage system based on renewable energy sources (RES) is a major candidate. However, achieving economic feasibility with this kind of system is considerably difficult at present. In addition, the round-trip efficiency of the hydrogen system (electrolysis – storage – power generation) is about 40% at the highest, and the hydrogen system needs a specific objective such as load leveling or backup power. In urban communities, a small-scale FC-based CHP system has been commercialized and is close to achieving economic feasibility. However, using hydrocarbons as a fuel for CHP means that CO_2

emissions cannot be avoided, and the reduction of CO_2 emissions must be discussed carefully. In industrial/commercial communities, there are several applications where distributed hydrogen systems can be introduced, such as FC-based cogeneration, FC-based backup power and FC-powered forklifts. In the case of FC-powered forklifts in a warehouse, a lower charging frequency (longer driving distance per charge) and shorter charging (fueling) time are major advantages over battery-powered forklifts. A cost comparison of total ownership between these two kinds of forklift revealed that FC-powered forklifts are already competitive with battery-powered forklifts.

Table 2. Objective projects for subtask 3.

#	Project name	Country	Location	Outline	System components
Rural/Island community					
1	Lolland residential CHP	Denmark	Vestenskov, Lolland	Small-scale residential combined heat and power (CHP) application with real community involved as well in a rural area	• Wind turbine • Electrolyzer • Hydrogen pipeline • PEMFC (1.5 kW_{AC}) + Hot water tank
2	Myrte	France	Corsica island	Grid-connected renewable energy storage system with hydrogen in island	• PV (560 kWp) • PEM Electrolyzer (110 kW) • H_2 and O_2 storage tank (35 bar, 126 kg_{-H2}) • PEMFC (160 kW)
Urban community					
3	Japanese residential CHP	Japan		Small-scale residential CHP application using energy grid in urban area	• PEMFC (1 kW_{AC}) • Hot water tank
4	Octagon	USA	New York, NY	Large-scale CHP unit installation into an apartment building inside a city	• PAFC (400 kW_{AC}) • Hot water supply system
Industrial/Commercial community					
5	FedEx Forklift	USA	Springfield, MO	Utilizing a number of forklifts powered by fuel cell in delivery center	• FC-powered forklift ×40 • H_2 fueling system (NG reformed)
6	Hydrogen Office	UK	Methil, Scotland	Grid-connected renewable energy storage within a commercial building	• Wind turbine (750 kW) • Alkaline Electrolyzer (30 kW) • H_2 storage tank (12 bar, 10 kg) • PEMFC (10 kW)

In addition, “Project Follow-Up Questions” was prepared and delivered to each project respondent. This questionnaire focused mainly on the community/social and regulatory aspects. Unfortunately, only a few responses were received, and analysis of these aspects has not been sufficient.

Finally, subtask 3 concluded with proposals for model concepts for each community category: rural/island, urban, industrial/commercial. The model concept for rural/island communities was based on a small-scale grid and unstable RES such as wind and PV. A hydrogen system installed in such a scenario would play the role of peak shaving and peak shift so as to stabilize the electricity grid and increase the capacity of RES in the communities. Conversely, the model for urban community did not consider RES and relied fully on the existing electricity and gas grids. In this community, a natural gas–fueled FC-based CHP system was considered as a promising application, though this should not be called a hydrogen system in the strict sense. As for industrial/commercial communities, because the hydrogen application was distributed over a wide area, it was difficult to create a concrete concept. A cost-effective method of producing and delivering hydrogen would be critical regardless of application type.

5 Subtask4 – Model concept development

This Subtask 4 (ST4) activity has drawn on work in the earlier subtasks to analyze the six projects from the viewpoint of their readiness for market replication. This report addresses two outputs:

- It assesses the market readiness of each of the projects under a framework developed by the Task participants by drawing on ST2 and ST3 results and additional analysis to draw market readiness conclusions across the six projects.
- it describes in some detail the framework which was developed for making consistent market readiness assessments across the six projects.

The cases study projects were selected and a SWOT analysis performed under ST 2. **Table 3** lists the projects under the three community classifications, along with the country of installation.

Table 3. Projects selected for analysis

	Type	Project	Country	Description
1	Rural/Island community	Lolland residential CHP	Denmark	Micro-CHP fuel cells powering urban/rural homes from piped renewable hydrogen
2	Rural/Island community	MYRTE, Corsica	France	Grid-connected renewable electricity storage using hydrogen
3	Urban community	Ene-Farm Residential H2 CHP	Japan	Micro-CHP fuel cells powering urban homes from NG
4	Urban community	Octagon Apartments, New York	USA	A distributed CHP fuel cell powering a green building from NG within a city
5	Industrial / Commercial	Fedex Distribution Centre	USA	Hydrogen fuel cell powered forklifts - distributed industrial application
6	Industrial / Commercial	Hydrogen Office	UK	Renewable hydrogen to power a building office – distributed commercial application

The techno-economic performance of the projects was analyzed for under Subtask 3 [1]. Some projects were closer to the market than others, and have further advanced subsequently. Delay in the completion of Task 29 has inadvertently allowed a reality check to be undertaken of the market readiness assessment results - observations are included in this report.

In drawing the conclusions about maturity of the technologies several qualitative assessment tools were used to create a “Market Readiness” framework with which to assess each project. These were drawn from a range of different sources and the framework was developed specifically for this study. A review of literature in the area did not reveal any suitable pre-developed methodology which could be used to assess, at a qualitative level, the “market readiness” of the range of hydrogen energy projects selected. The approach is described in Section 3 and also discussed at some depth in the Appendix as the methodology may be a useful as a basis for assessment of other new technologies and products.

To achieve a consistent (although largely qualitative) assessment of the market replication status and potential, an extended Technology Readiness Assessment (TRA) approach was taken. The aim was to determine the maturity in the market place of the combinations of technologies utilized in the six case study projects. This process is described in Section 3. As part of this assessment, the technology learning potential for cost reduction of the systems comprising the technologies was estimated. Gaps between current status and commercial application were identified. The results are qualitatively presented in the form of “at a glance” bar graphs for each project. An example of the format is given in **Figure 3** below.

In this Market Readiness assessment score card, the 1 to 9 index of the TRL technology maturity assessment scale (columns) was followed for all fields or dimensions (rows). These dimensions were grouped under the five categories determined as being relevant to market readiness by the Task participants: technical, environmental, economic, user/community, and regulations, codes and standards (RCS). The intent is to create an overall picture of progress towards commercialization in the chosen assessment dimensions.

The colour of the bar provides an indication of the status for this dimension or field – green implies that the level has been met, orange indicates some issues or uncertainties, red indicates that the level is not reached or tested Grey indicates that insufficient data or evidence is available, while white is unscored or not relevant.

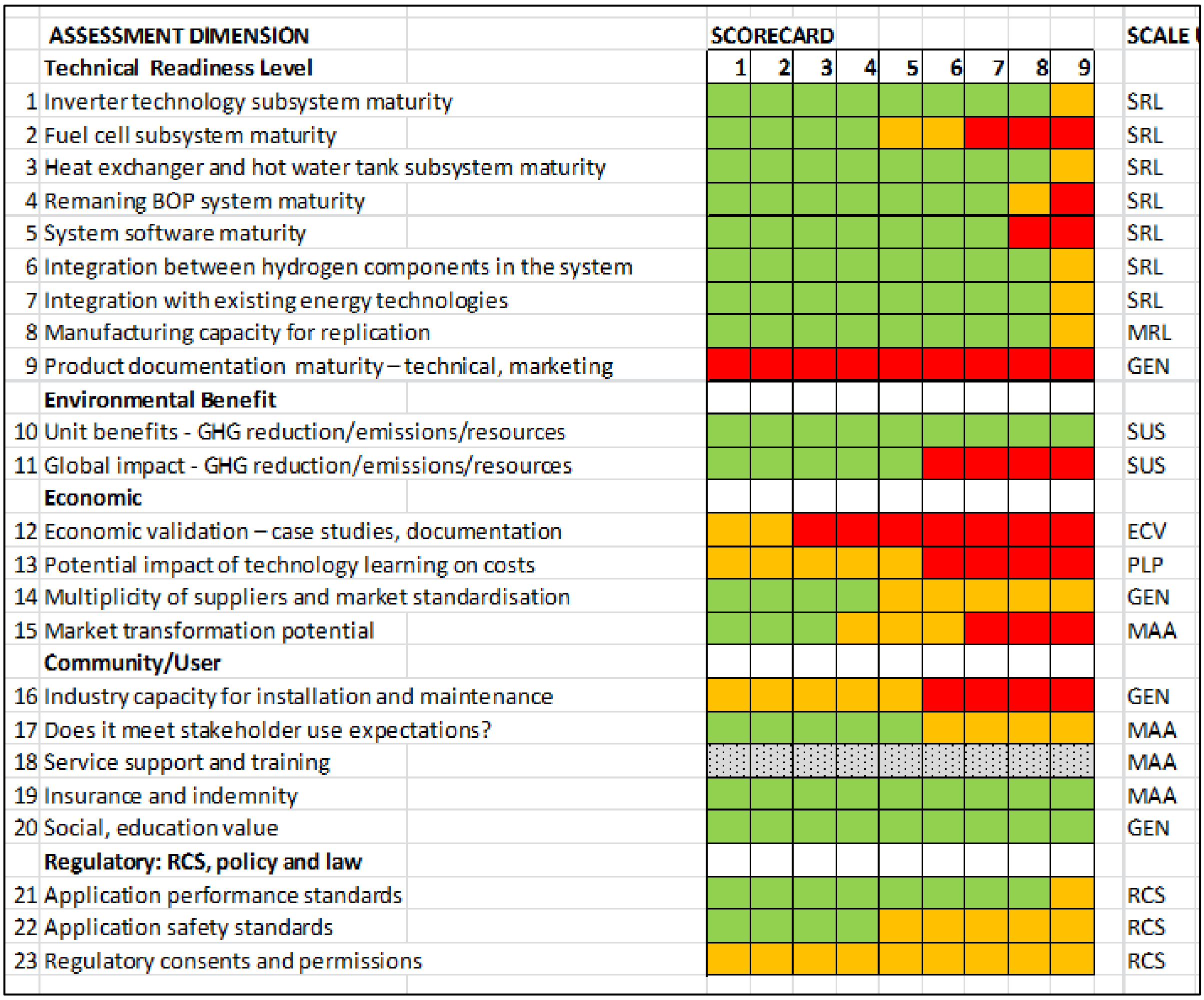

Figure 3. "At a glance" matrix presentation of project market readiness assessment results

In Section 4, each project has been separately addressed under this market readiness framework.

Specific comparisons are drawn in Sections 5 and 6. The overall results are summarized in Section 7 and given in **Table 4** below. The table indicates where the various projects excel (+), have both strengths and weaknesses (±), or are found wanting (-). The assessment scorecards for each project are provided and explained in more detail in Section 3.

From this summary, it can be seen that no project illustrates a high success signature in all market readiness dimensions. Projects that offer good economic value are less positive in environmental benefits, and the converse is also true. Commercially advanced projects do not necessarily show a positive economic signature, as they may still be supported by government policy and subsidies of some kind. Standouts in ongoing commercialisation progress to date are the Residential CHP systems (Enefarm) and the MHE (Fedex Distribution Centre).

Table 4. Comparison of the main Market Readiness features across the six projects.

Project		Market Readiness Dimension*						
		1	2	3	4	5	6	7
1	Octagon Apartments	++	+	-	±	+	±	++
2	Enefarm Residential CHP	+++	-	+	+	±	+++	+++
3	MYRTE	--	+	---	±	-	+	-
4	Lolland residential CHP	---	++	--	±+	+	++	-
5	Fedex Distribution Centre	+	±	++	+	+	+	+++
6	Hydrogen Office	-	++	--	±	±	+	-

*** Key to Market Readiness Dimensions:**

1. Technical
2. Environmental
3. Economic
4. Community/User
5. Regulations, Codes and Standards
6. Potential for cost Reduction
7. Post-Project Commercialisation Progress

Of the case studies themselves, our hope is that these representative examples of distributed hydrogen technology applications will contribute to the development of "a how to guide" that informs professionals (planners, architects, engineers), policymakers (especially at sub-national levels) and businesspeople as to utilize the process and the "need to know" aspects of utilizing hydrogen solutions for their respective remote/island, urban, and industrial applications. The aim is to increase awareness of the market maturity of the different attributes of these hydrogen projects, and support the progress of similar hydrogen technologies and systems through to commercialisation.

6 Summary - General findings

General findings about the projects and the subsequent status of the technologies are listed below.

- Two projects, Lolland (Denmark) and Hydrogen Office (UK) have been terminated following several years of operational study and assessment.
- One project, MYRTE (Corsica) is ongoing as a platform for continuing research into hydrogen energy storage system technologies.
- One project, Octagon Apartments is operating commercially, although replication to other sites is slow which indicates either marginal economics or limited market acceptability.
- Two projects, Residential CHP (Japanese Enefarm) and fuel cell powered Forklift Trucks (USA Fedex) are successful commercially and production is expanding quite rapidly.
- These two projects which have advanced to volume production have had consistent long-term government support of one form or another, coupled with well set up market supply and service chains.
- Performance of the technologies in all the projects ranged from very good to adequate (ie met operational expectations relative to the maturity of the technology), but some projects evidenced low technology maturity through high costs for initial bedding in and ongoing maintenance.
- While these hydrogen technologies offer environmental benefits, they struggle to compete with existing solutions on present day economic basis, ie where little account is taken of the environmental effects of incumbent technologies.
- If more financial emphasis were placed on environmental benefits, particularly to mitigate climate change, the hydrogen energy solutions will become more competitive.
- CHP fuel cell systems which offer higher efficiency but still consume fossil fuels are the most economically viable, but achieve the least specific CO_2-e reduction benefits (/kWh). However, large scale uptake will still produce substantial overall GHG reductions.
- The three renewable hydrogen projects all implemented hydrogen storage in some form. Round trip electricity to electricity conversion efficiency was therefore low, which makes competing with modern batteries challenging.
- Cost effective and convenient hydrogen storage for stationary applications is still a major challenge, as is the round trip efficiency of conversion. To maximize the value of the stored hydrogen, applications that use hydrogen for CHP or thermal uses may become more attractive due to the higher efficiency achieved over purely electrical loads.
- All projects required substantial government capital contributions and support, and at present technology costs still need this investment to varying degrees. However, technology learning cost reduction projections are promising, particularly for the small fuel cell based

projects. Large cumulative sales volumes are required to bring costs down to a point where assistance is not required.

- At present the common benefit from the uptake of distributed hydrogen in the six projects is the mitigation of greenhouse gas emissions, rather than a clear economic benefit. This may change with some of the technologies, as market volumes increase and cost is reduced through economies of scale and production learning.
- The ability to monetarise the environmental benefits of hydrogen energy depends on the application, and on the value placed on GHG and pollution reduction in the relevant jurisdiction. The fossil energy based systems do not show high GHG savings per unit, but may have greater overall impact than renewable energy based systems if the uptake is substantially higher.
- In three of the projects (Lolland, MYTRTE, Hydrogen Office), we consider that some technologies were introduced to operational field trials before they were technically ready (as viewed under the TRL R&D maturity scale). This is attributed to overly optimistic demands from the funding agencies, and corresponding promises by developers to protect their funding opportunity, which and resulted in delays and additional costs. Problems were often discovered or rectified at the sharp end of these projects, when the full scale project was already delivered or installed. More realistic technical expectations and targeted funding based on application of TRA qualification levels may have avoided substantial costs. Both funders and developers need to commit to TRA advancement principles.
- Market networks to grow and support sales and operations are very costly, and the timeframe to set up and achieve brand goodwill is often long. It is much easier to form alliances with incumbents who have the experience and infrastructure already set up. This is particularly evident in the successful Japanese residential CHP project.
- Renewable energy based projects (offering hydrogen storage) need more pilot and demonstration scale funding for these technologies to be proven, costs reduced and the products to become market ready.

Three of the technologies have since advanced to various stages of commercialization, providing an opportunity to compare the results from the ST4 Market Readiness project assessments. The project assessments (Section 4) indicated a likelihood of success in these cases (Japanese Residential CHP, Octagon Apartments CHP, Fedex Forklift Trucks). In the three which have not yet advanced to replication (Lolland Residential CHP, MYRTE PV- Hydrogen Storage, Hydrogen Office Wind-Hydrogen CHP), the assessments identified substantial issues with regard to readiness for the market.

The major barrier to market growth of both the fossil fuelled and renewable energy hydrogen systems studied is cost. For a system to be economically viable, the combination of capital cost and ongoing maintenance and fuel or feedstock costs must be competitive with existing options in use. Where the costing of a renewable hydrogen energy storage system includes the energy supply technology (eg solar PV), the system will have a high up front cost compared with fossil fuel based systems.

Although the cost of the "fuel" (eg, renewable electricity) may be negligible, the up-front cost of the conversion technology must still be amortised over the life of the system. It is therefore difficult to compare like with like, because globally most electricity generation is still fossil based, with low embedded costs. Also, since the renewable energy storage systems generally operate at a low capacity factor, both the storing energy and retrieving energy duty cycles are low. Coupled with this, electricity recovery ("round trip") efficiency is also low. This means that capital cost recovered on an energy processed basis (ie $/kWh) is low compared with a high availability source such as gas.

The use of batteries for renewable energy storage faces the same low duty cycle issue. On this basis, it is probably no surprise that the three project technologies capable of being fueled with natural gas have advanced towards commercialisation more rapidly than the renewable energy sourced projects. This trend is likely to continue until higher value is attributed to the greater GHG reduction potential of renewable energy resources over natural gas. Overall, the cost of storing electricity by either hydrogen gas or chemical batteries is relatively high. Hydrogen storage is further disadvantaged by an insurmountable efficiency barrier in reconversion to electricity. If the heat of conversion associated with hydrogen storage can be utilized, the poor efficiency penalty can be greatly reduced. The Hydrogen Office and Lolland projects potentially exploit this opportunity, but MYRTE does not, since a high value thermal load is not available. In the longer term, as the value of renewable energy grows relative to fossil fuels, renewable energy sourced hydrogen storage systems should become more cost effective.

Technology Learning analysis shows that as cumulative sales volumes rise, cost can be dramatically reduced through competitive manufacture of the products. Smaller scale products with large market potential therefore have opportunity for substantial cost reduction if cumulative market volumes are high. Larger scale technologies which have a slow production growth rate will generally suffer from slow or limited learning ability. Within these distributed hydrogen energy applications, systems using small scale fuel cells and electrolysers have most potential for cost reduction through technology learning.

Early market government support can create sufficient volume for market competition to accelerate the downward trend. Of the case studies undertaken, two technologies have been notably provided with this kick start and are well on the way to becoming fully cost competitive. These are the Japanese Enefarm residential CHP systems, and the USA materials handling vehicle (fork lift truck) systems.

Overall, in the short term fossil fueled technologies have more chance of reaching competitiveness within energy infrastructures that presently use these fuels. A higher value must be placed on storage of renewable energy than at present, for fully renewable hydrogen energy systems to be cost competitive.

The renewable energy systems assessed tended to be pre-market pilot projects and less technically mature - this impacts negatively on user acceptance, maintenance costs and ongoing use. A perceived objection to hydrogen may really be objections to other parts of a project (e.g. a wind turbine).

Most countries have a well-developed regulatory framework for fuel gas supply and use. These frameworks have been developed for safe operation of gas networks using natural gas, butane, propane and LPG and in some cases biogas. For example, many jurisdictions define gas quality requirements only for the common gases NG, LPG etc., so technically hydrogen cannot be used as a distributed fuel gas without regulatory changes. Many regulations are not well suited to hydrogen distribution. Hydrogen, manufactured and used locally in a closed loop primarily for its energy storage characteristics or conversion efficiency in fuel cells does not necessarily require the same safety rules. Pilot projects will meet high compliance costs as they will often be used to test and develop more hydrogen-friendly codes of practice and regulations.

The scale of hazards associated with a project should be assessed in relation to potential impact. Generally the larger the scale of the storage hazard (hydrogen), the more stringent the operating controls (hazard notices, exclusion zones, fire fighting equipment, trained operators, written safety, maintenance and emergency plans, etc.) need to be. Hydrogen fuelled appliances will generally need to be safety certified if sold in commercial quantities.

The local regulatory authorities for the environment and for gas safety should be engaged very early on in the development of a project. Invariably the response will be positive, but tempered with caution and lack of knowledge about the safety implications of changing or relaxing the operating conditions. Education about hydrogen as a fuel is often necessary.