Implementation Roadmap

Deliverable D6.9

GRANT AGREEMENT
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D6.9 Implementation Roadmap

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I. Introduction

Deliverable D6.9 objective is to draw recommendations and propose an implementation plan to favor off-grid electrolysis applications deployment.

In a first part, main outputs from previous work carried in ELY4OFF are summarized.

In a second part of this report, main messages from two recent public reports are presented. Although these reports do not focus on off-grid electrolysers, they bring interesting vision of the opportunities and challenges of hydrogen future economy.

Finally, recommendations related to ELY4OFF technology are and made and an implementation plan is initiated to identify mains focuses for off-grid electrolysis.

II. Review of project related tasks

II.1.1 Deliverable 6.4: Assessment of Market potential

D6.4 presents the market assessment for the ELY4OFF project. Four main markets are evaluated.

The first market, ENERGY SYSTEM FOR ISOLATED AREAS, compares off-grid electrolysis to conventional solutions using diesel gensets of PV panels with batteries. ELY4OFF solution can primary avoid transport and diesel costs and reduce GHG emissions.

The second market focuses on OFF-GRID HDYROGEN REFUELING STATION.

Third market covers WEAK GRID AND BACK-UP GENERATORS, especially for less developed countries.

Finally, the hydrogen production for industrial feedstock is considered in the EU as GREEN HYDROGEN FOR NICHE INDUSTRIAL APPLICATIONS.

Based on assumptions that are fully described in D6.4, the following messages can be drawn:

- ENERGY SYSTEM FOR ISOLATED AREAS have presented that the gensets with batteries are still the most reasonable solution. This is due to the high investment costs, not only for FCH technologies but also from renewables resources.
- OFF-GRID HDYROGEN REFUELING STATION market has presented that off-grid production falls under an important issue. Due to the intermittency of the energy source, the electrolyser needs to be oversized to fulfil the demand. This lead to high cots. Nevertheless, with highly intensive energy sources such as wind power generation, off-grid systems can become economically feasible.
- WEAK GRID AND BACK-UP GENERATORS was identified as a promising market from an economic standpoint as, in developing countries, the higher part of the cost is related to the operational cost.
- GREEN HYDROGEN FOR NICHE INDUSTRIAL APPLICATIONS is also important, but face some concerns as OFF-GRID HDYROGEN REFUELING STATION market. In this specific application, the most developed countries should be targeted as they should be first to move towards the green hydrogen transition.

II.1.2 Deliverable 6.6: Commercial exploitation of results

D6.4 objective was to draw a list of exploitable results from ELY4OFF project to ensure commercial success. Following table summarizes identified exploitable results per item.

Exploitable Foreground (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial use	Patents or other IPR exploitation (licenses)	Final report update using knowledge gained from demonstration period
1. **Electrolyser stack design for low cross over membranes (ITM)**	Water electrolysers	Off Grid electrolysers	2020	Possible IP if significant stack modifications are needed	Stack efficiency has proven key to the hydrogen yield from the PV energy. Work which was started in this project has carried on into the FCHJU project "Neptune" where we are continuing to look at ways to use more efficient membranes to increase system efficiency
2. **Low Energy Balance of Plant for Electrolysers (ITM)**	Water electrolysers	Potentially some modifications applicable to all ITM systems	2020	Know how	Great knowhow has been gained from the first off grid BoP developed by ITM. Areas where further savings could be made have been identified and ITM will continue to develop these post-ELY4OFF. There have also been areas where power saving has resulted in more maintenance requirements which in remote locations might prove result in downtime which would lead to less hydrogen production than if the energy consumption was higher.
3. **DC/DC Converter (EPIC POWER)**	Converter for coupling PEM to PV panels	Off Grid electrolysers	2020	Possible IP	The DC/DC converters have behaved as expected during the demonstration period. The scope of the exploitable result provided in the first strategy plan remains without modificationn
4. **Peripheral component integration for managing essential back up power provision (FHA)**	Robust, efficient and optimised management of energy required for backup essential consumer	Off Grid electrolysers	2020	Possible IP	The system devised and tested during demonstration has offered excellent results. Although the most optimal configuration could not be tested, the alternative offered a suitable management of the energy coming from the PV. Due to the short period of demonstration (March to September) the rest of the year is required to stress the system performance in extreme weather conditions. The consortium has come to an agreement to follow the demonstration during some more time to gather information on the behaviour of the system also during winter time.
5. **Innovative Control systems to match PV output with electrolyser operation (INYCOM)**	Control system to balance changes in solar radiation with the changes in stack power requirements	Off Grid electrolysers	2020	Possible IP	
6. **Safety system management for off grid applications (ITM)**	Water electrolysis	Off Grid Electrolysers	2020	Potentially some modifications to allow very low and very high current densities which are needed for Off Grid systems	This is an area where a huge amount of development took place owing to the unique requirements of utilising the majority of the power available. This has been a joint development between ITM and INYCOM with the subsystems sharing information to ensure unusual (in an on grid scenario) voltage levels are differentiated between a system fault and lower power available from the PV

II.1.3 Deliverable 6.7 : Business models

An assessment has been done to identify the most appropriate model for off-grid applications, considering the key parties on the supply and demand sides.

A major key economic driver is the use of renewable energy to deliver green power to green gas. Using direct renewable energy that is off grid like the ELY4OFF project will demonstrate on a small scale that the deployment of large-scale off-grid electrolysis will allow developing countries with little to no electrification networks to produce a primary fuel source that can deliver heat, mobility and power; as well as manufacturing of fertilisers (ammonia) to allow continued to grow as well storing and selling the fuel commercially to other uses.

On the other hand there isn't a single business model to cover all off-grid hydrogen applications, there are several applications and each involves a set of stakeholders with a lead operator.

II.2 Recommendations from Deliverable 6.8 on specific business cases

First, it is worth bear in mind that within ELY4OFF project, considered hydrogen is fully green as it is produced from renewable energy only. Such hydrogen is of the highest quality in terms of decarbonisation potential as it avoids uncertainties concerning the actual carbon footprint of hydrogen produced by grid electricity, or by SMR+CCS. Green hydrogen appears to be more expensive but its potential in achieving zero emissions by 2050 and the associated value should be considered.

Although cost of full off-grid hydrogen remains high, each of the three evaluated applications from a techno-economic point might be interesting under certain conditions.

Off-grid hydrogen may represent benefits compared to competing technologies:

- For electrification of isolated site with high seasonality of renewable power is observed;
- For gas grid injection when renewable power factor is high and gas grid constraints are limited;
- For mobility when renewable power factor is high and low carbon mobility is valued.

Based on techno-economic evaluation carried out in task 6.6 and presented in deliverable 6.8, recommendations were proposed to facilitate development of off-grid hydrogen applications.

1- Consider off-grid electrolyzers at MW and GW scale

Due to the scale of the ely4off hardware demo development, the main focus of the project was on assessing kW scale deployments for early markets. It is recommended that further attention be given to the economics of multi-MW and GW scale off-grid hydrogen application. Indeed, since the project started new positions were taken on green hydrogen production at massive scale by Australia, Holland for the North Sea region, Saudi Arabia, with further potential contributions from Chile, North Africa, Norway, Iceland etc. Increase in hydrogen components manufacturing will also lead to large reduction of costs for hydrogen application that was not considered in this study.

2- Further R&D work on system components

It is also interesting to note that if the required hydrogen system consists primarily of a large electrolyser then the predicted levelized cost values are not too high. However, when the H2 application requires several other technologies as well as an electrolyser then the LCOH or LCE values are extremely high, due mainly to the high system capex. R&D work on system components such as gas grid injection or refueling stations must be carried out to contribute to cost reduction.

3- Focus on locations with high seasonality and PV + wind

Work carried out in the project shows that Off grid electrolysers can hardly compete economically at small (kW) scale. Further RD&D work must be undertaken at MW scale with a focus on regions exhibiting high seasonality and by employing both wind and solar power sources.

4- Diversity of applications

Due to the diversity of applications and the impact on cost of optimized design, it is important to note that manufacturers should not simply make a 'one size fits all' solution for off grid hydrogen systems but adapt system to specific application.

5- Include avoided cost of grid expansion

Considering an off-grid implementation in practice means that the cost of connecting to the grid would be very high. So there is an avoided cost of grid connection and of grid fees, which theoretically contributes to reduce CAPEX and OPEX costs, but was difficult to assess in this study.

6- Include avoided cost of carbon emissions

Avoided cost associated to the reduction of carbon emissions (taxes, incentives…) should be taken into account and would contribute to reduce the existing economic gap between off-grid electrolyser and competing technologies.

III. Analysis of specific literature

Two recent public reports are analyzed.

III.1 IEA report Key recommendations

IEA report "The Future of Hydrogen", published in 2019, identifies opportunities and challenges for hydrogen future. This report does not specifically focus on off-grid applications but clearly illustrates IEA future vision for H2 applications.

Although this report does not specifically focus on off-grid applications, it specifically identifies 4 near-term opportunities for hydrogen:

1- Make industrial ports the nerve centers for scaling up the use of clean hydrogen.

Today, much of the refining and chemicals production that uses hydrogen based on fossil fuels is already concentrated in coastal industrial zones around the world, such as the North Sea in Europe, the Gulf Coast in North America and southeastern China. Encouraging these plants to shift to cleaner hydrogen production would drive down overall costs. These large sources of hydrogen supply can also fuel ships and trucks serving the ports and power other nearby industrial activities like steel plants.

2- **Build on existing infrastructure, such as millions of kilometers of natural gas pipelines.**

Introducing clean hydrogen to replace just % of the volume of countries' natural gas supplies would significantly boost demand for hydrogen and drive down costs.

3- **Expand hydrogen in transport through fleets, freight and corridors**

Powering high mileage cars, trucks and buses to carry passengers and goods along popular routes can make fuel-cell vehicles more competitive.

4- **Launch the hydrogen trade's first international shipping routes**

Lessons from the successful growth of the global LNG market can be leveraged. International hydrogen trade needs to start soon if it is to make an impact on the global energy system.

It also draws 7 key recommendations to scale up hydrogen, as a roadmap for the future:

1- **Establish a role for hydrogen in long-term energy strategies**. National, regional and city governments can guide future expectations. Companies should also have clear long-term goals. Key sectors include refining, chemicals, iron and steel, freight and long-distance transport, buildings, and power generation and storage.

2- **Stimulate commercial demand for clean hydrogen**. Clean hydrogen technologies are available but costs remain challenging. Policies that create sustainable markets for clean hydrogen, especially to reduce emissions from fossil fuel-based hydrogen, are needed to underpin investments by suppliers, distributors and users. By scaling up supply chains, these investments can drive cost reductions, whether from low-carbon electricity or fossil fuels with carbon capture, utilisation and storage.

3- **Address investment risks of first-movers.** New applications for hydrogen, as well as clean hydrogen supply and infrastructure projects, stand at the riskiest point of the deployment curve. Targeted and time-limited loans, guarantees and other tools can help the private sector to invest, learn and share risks and rewards.

4- **Support R&D to bring down costs**. Alongside cost reductions from economies of scale, R&D is crucial to lower costs and improve performance, including for fuel cells, hydrogen based fuels and electrolysers (the technology that produces hydrogen from water). Government actions, including use of public funds, are critical in setting the research agenda, taking risks and attracting private capital for innovation.

5- **Eliminate unnecessary regulatory barriers** and harmonise standards. Project developers face hurdles where regulations and permit requirements are unclear, unfit for new purposes, or inconsistent across sectors and countries. Sharing knowledge and harmonising standards is essential, including for equipment, safety and certifying emissions from different sources. Hydrogen's complex supply chains mean governments, companies, communities and civil society need to consult regularly.

6- **Engage internationally** and track progress. Enhanced international co-operation is needed across the board but especially on standards, sharing of good practices and cross border infrastructure. Hydrogen production and use need to be monitored and reported on a regular basis to keep track of progress towards long-term goals.

7- **Focus on four key opportunities** to further increase momentum over the next decade. By building on current policies, infrastructure and skills, these mutually supportive opportunities can help to scale up infrastructure development, enhance investor confidence and lower costs.

III.2 H2 council markets vision

Hydrogen council report "hydrogen scaling up", published in 2017, presents its vision of the long term (2050) potential of hydrogen.

Although this report does not specifically focus on off-grid applications, the vision presented in this report is summarized by seven roles that can play hydrogen in the future:

"Hydrogen is a central pillar of the energy transformation required to limit global warming to two degrees Celsius. To achieve the two-degree scenario, the world will need to make dramatic changes year after year and decrease energy-related CO2 emissions by 60% until 2050 – even as the population grows by more than 2 billion people2 and billions of citizens in emerging markets join the global middle class. Hydrogen can play seven major roles in this transformation:

- Enabling large-scale renewable energy integration and power generation
- Distributing energy across sectors and regions
- Acting as a buffer to increase energy system resilience
- Decarbonizing transportation
- Decarbonizing industrial energy use
- Helping to decarbonize building heat and power
- Providing clean feedstock for industry.

In all seven application areas, hydrogen can offer economically viable and socially beneficial solutions."

Figure 1 from this report illustrates the role that can play hydrogen in 2050 through the total hydrogen demand.

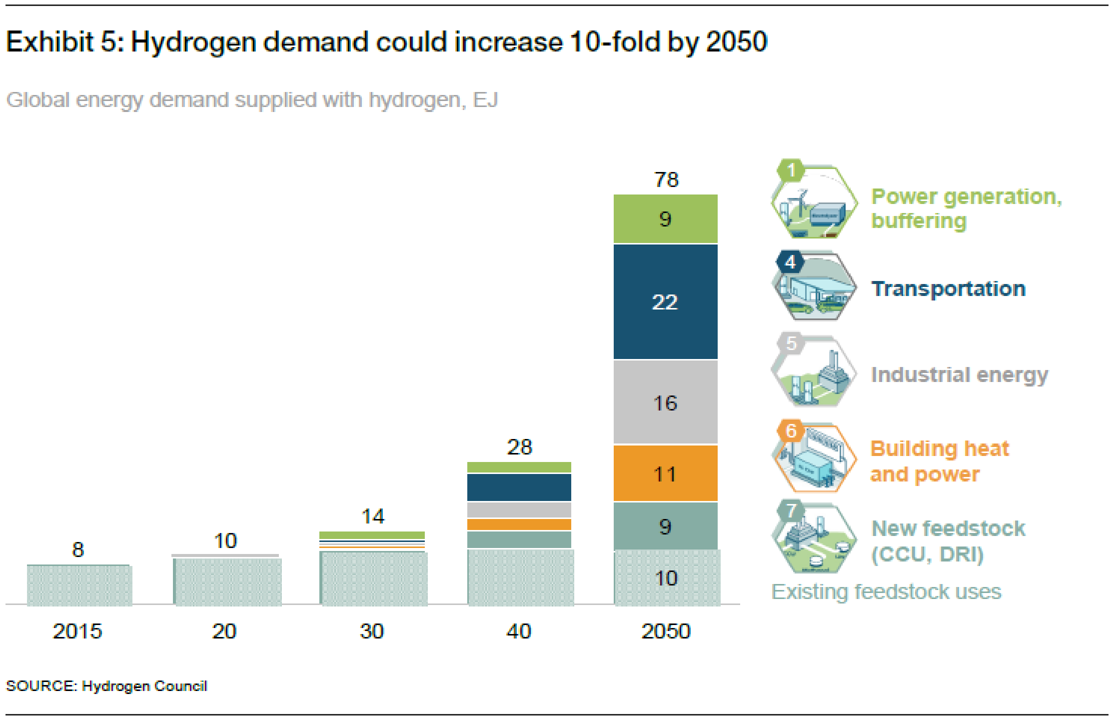

Figure 1 – Hydrogen demand increase by 2050

Figure 2 illustrates the deployment of hydrogen markets from today until 2050.

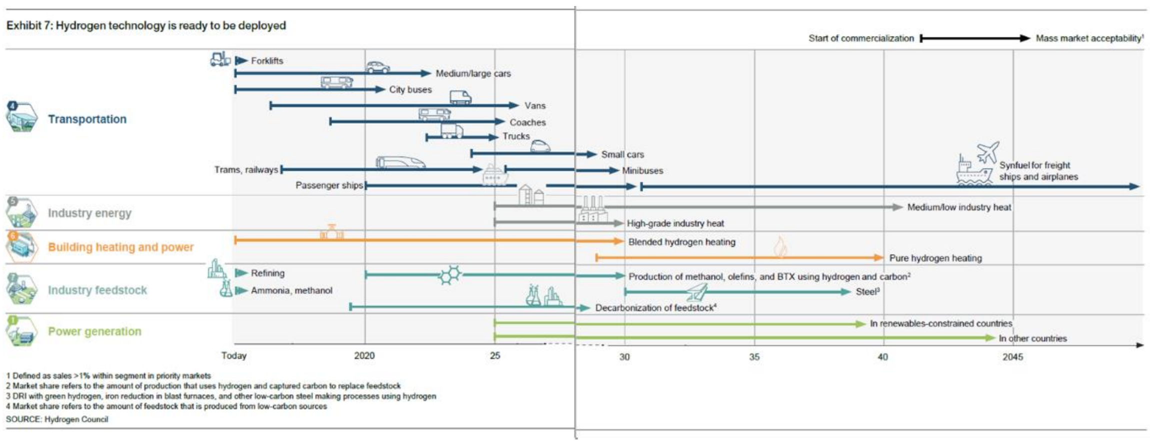

Figure 2 – Hydrogen technology deployment by 2050

IV. Recommendations and implementation roadmap

IV.1 Recommendation to favor off-grid electrolysers deployment

From work carried out in ELY4OFF, and latest literature on hydrogen presenting opportunities and challenges, ELY4OFF partners for off-grid electrolysers make following recommendations.

1- Consider off-grid electrolyzers at MW and GW scale
2- Further R&D work on system components
3- Focus on locations with high seasonality and PV + wind
4- Include avoided cost of grid expansion
5- Include avoided cost of carbon emissions
6- Favor international cooperation and green hydrogen market
7- Eliminate regulatory barriers and/or harmonize between countries

IV.2 Implementation Roadmap

The plan sets possible scenarios for 2020, 2030 and 2050 for penetration of off-grid RES installation with electrolysers.

- **2020**

➔ Focus on existing niche markets for off-grid electrolysis;
➔ Fund R&D to reduce cost of system ;
➔ Work on the identification of positive externalities.

- **2030**

➔ Focus on gas grid injection in remote areas with large renewable potential
➔ Focus on industrial markets for which Green hydrogen for green chemistry is valued or is favored by Europeans directives ;
➔ Focus on applications favored by cost of carbon emissions (taxes, incentives…)

- **2050**

➔ Focus on Mobility application ;
➔ Focus on Electricity storage and power applications to increase share of renewblae in the energy mix ;
➔ Include avoided cost for grid extension and other positive externalities.

References

[1] ELY4OFF Grant Agreement (Grant Agreement number: 700359)and ELY4OFF deliverables

[2] “The future of Hydrogen – Seizing today’s opportunities”, *report prepared by the IEA for the G20, Japan,* June 2019

[3] “Hydrogen scaling up – A sustainable pathway for the global energy transition”, *Report by Hydrogen* Council, November 2017