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Hydrogen Economy: the future for a sustainable and green society

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The increasing demand for sustainable energy efficiency and industrial decarbonisation leads researchers from different areas to seek alternative and more effective ways for attaining these goals. A hydrogen economy based on fuel cell and hydrogen technologies is a plausible and promising way to reach the European energy targets and improve the quality of life of society, providing independence and security of the energy supply across Europe. The need for rapid deployment of environment-friendly technologies implies for integrated policy measures and joint efforts of all Member States. This paper gives an overview of hydrogen and fuel cell technologies considering intensively their place in the European policy for decarbonisation and smart growth. The paper also discusses international initiatives in the field and suggests a pathway for greener society.

Key words: hydrogen, fuel cells and hydrogen, hydrogen technologies, hydrogen economy, sustainable development; long-term scenario, legal and administrative barriers removal, market deployment

INTRODUCTION

The hydrogen-based economy is a long-term dream of society and scientists for meeting the increasing demand for energy by using hydrogen as fuel in a clean energy system. The term "hydrogen economy" was introduced by the world-renown scientist John Bockris in 70s of the 20th century [1] evolving from the concept introduced by the British scientist J. B. S. Haldane [2].

The element hydrogen is the most abundant and lightest chemical element in the universe, as on Earth it is most commonly linked to molecules of water or organic compounds. The hydrogen gas is colourless, odourless and tasteless. It has a boiling point of -252.9 degrees Celsius and a melting point of -259.2 degrees Celsius. It is dissolved slightly in water, but occludes in significant amounts in certain metals as, for instance, palladium which may dissolve up to 3000 volume parts of hydrogen (occlusion is a term related to particular type of absorption of gases by metals).

In addition to its vast industrial applications in the chemical industry, metallurgy, glass industry and others, hydrogen is taking one of the leading positions in the energy sector as an energy carrier for both transport and stationary applications: as a fuel for motive power (including vehicles and waterborne vessels) and on-board auxiliary power, stationary power generation (for the energy demands involving household and industrial applications), as an energy carrier for storage applications medium, related to excess electric power generated off-peak, load levelling and balancing of the energy system, long-term energy storage [3]. Hydrogen does not exist naturally in convenient reservoirs with an exception regarding the actively investigated onshore natural hydrogen (H2) emissions [4] but nonetheless, it may be generated by water electrolysis, steam reforming of hydrocarbons, thermal decomposition of water or by other methods [5]. Some algae and bacteria, using sunlight as their main source of energy in certain circumstances also release hydrogen naturally.

Currently, the technologies with highest potential for producing hydrogen are divided in four categories: electrochemical, photo-electrochemical, thermochemical and photo-biological [6]. Some authors claim that one of the problems related to the production of hydrogen is that in the process a large amount of energy is consumed in comparison to the gained energy when using it as a fuel [7].

Fuel cell technologies are essential for attaining a carbon free hydrogen based economy. The fuel cell converts chemical energy from a fuel into

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electricity by an electrochemical reaction between hydrogen and oxygen from the air which brings to the production of electricity and heat, while the by-product is water [8]. Fuel cells need a source of fuel (hydrogen) and oxidizer to sustain the electrochemical reaction producing electricity continuously which is their significant advantage in comparison to batteries that need recharging. In similarity to batteries, the main active components of the fuel cells are two electrodes sandwiching the electrolyte. There are several different technologies for fuel cell such as: solid-oxide fuel cells (SOFCs), proton exchange membrane fuel cells (PEMFCs), alkaline fuel cells (AFCs), phosphoric acid fuel cell (PAFCs), solid acid fuel cell (SAFCs) and others.

The most promising technologies which are under intensive development are SOFCs and PEMFCs. SOFCs components are ceramics which have significant conductivity at elevated temperatures, thus having a high temperature operating mode which makes them suitable mainly for stationary applications. PEMFCs have no alternative for mobility applications. They are successfully used also for stationary applications. One of the serious problems faced is the large consumption of platinum. It should be marked that extensive research and development is conducted for the diverse application of all types of fuel cell. In general, the main hurdles for the large-scale market introduction of fuel cells and hydrogen technologies presently are their yet insufficient durability and high costs: two directions where common research and industrial efforts are concentrated.

Fuel cell and hydrogen technologies have already started to play a key EU role in contributing to the targeted reductions in greenhouse gas emissions together with the improvements in air quality and increased energy independence needs of the Community. Europe is facing serious challenges related to the production of energy which has key impact on its economy, environment, society and security. In the new package of measures “Clean Energy for all Europeans” [9], intended to support all European citizens and businesses with the means to maximize the benefits of the clean energy transition [10], an emphasis is given to the development of affordable and integrated energy storage solutions from renewable energy and fuel cells and hydrogen are foreseen as one of viable and sustainable problem solving solutions.

OVERVIEW

Advanced energy technologies are identified as an essential element for coping with climate change and securing energy supply. Europe’s ambitious climate and energy targets are foreseen in the Strategic Energy Technology Plan (SET-Plan) which has been the technology pillar of the EU Energy and Climate policy since its adoption in 2008 [11] but these targets cannot be met without deploying more efficient energy technologies. The plan was designed as a tool for supporting decision making in the energy policy field having several main goals [12]:

- to accelerate knowledge development, technology transfer and up-take;
- to maintain EU industrial leadership on low-carbon energy technologies;
- to foster science for transforming energy technologies to achieve the 2020 Energy and Climate Change goals;
- to contribute to the worldwide transition to a low carbon economy by 2050.

The implementation of the SET-Plan began with the establishment of the European Industrial Initiatives (EIIs) which bring together industry, the research community, the Member States and the Commission in risk-sharing, public-private partnerships aimed at the rapid development of key energy technologies at European level. In parallel, the European Energy Research Alliance (EERA) has been working since 2008 to align the R&D activities of individual research organisations to the needs of the SET-Plan priorities, and to establish a joint programming framework at EU level. The projected budget for the SET-Plan has been estimated at up to €71.5 billion [12]. The SET-Plan has two major timelines. For 2020, the SET-Plan provides a framework to accelerate the development and deployment of cost-effective low carbon technologies aiming to reach the 20-20-20 goals of a 20 % reduction of greenhouse gases (GHG) emissions, a 20 % share of energy from low-carbon energy sources and 20 % reduction in the use of primary energy in order to improve energy efficiency. For 2050, the SET-Plan is aimed at limiting climate change to a global temperature rise of no more than 2°C (by the end of the century) and more specifically to reduce EU’s GHG emissions by 80-95 % depending on the sector [12]. The SET-Plan objective in this regard is to establish a low-carbon energy technology and industry sectors by lowering the cost of low-carbon energy hence, providing energy security, environmental preservation and better quality of life.

Currently, the European energy system relies 80 % on fossil fuels which produce 80 % of all the Union’s GHG emissions thus, highlighting the importance of decarbonisation of the energy system. In line with the common objective of a competitive European economy and the accepted long term GHG emission reduction of 80-95% by 2050 compared to 1990 levels, the European Council agreed on a domestic greenhouse gas reduction target of at least 40% by 2030 compared to 1990 and set a target of at least 27% for renewable energy, binding at EU level, as well as an indicative target of energy savings [13].

The qualities of the energy system are very much linked to its energy supply. The Union and its Member States have set as a matter of high priority the development of a diverse, reliable and cost-effective portfolio of energy supply technologies to meet the EU climate and energy policy goals. Transforming the present system needs adequate and serious changes to the energy system in the medium and long term into an economic and industrial prospect for Europe. That cannot happen without extensive further research, development and deployment of new solutions and innovations to reduce the energy demand further, diversify and consolidate supply options (both external and local) attuned with Member States energy mix choices, and to develop a flexible and integrated energy system. Moreover, innovative business models and financial schemes that guarantee a diverse approach are also needed in order to do so.

The energy system is essential for every economy. Thus, the European Commission has set the energy sector as one of its main priorities. In accordance with the plan for modernisation of the current energy system, where two thirds of the greenhouse emissions result from energy production and use, an accelerated transition to a clean and efficient energy system is needed. That will have an impact on all Member States and will support the implementation of the developed the Energy package: "Clean Energy for all Europeans" with additional regulatory proposals and facilitating measures. The three principal objectives are [14]:

- energy efficiency first;
- Europe as the global leader in renewable;
- a fair deal to consumers.

The achievement of these 3 goals is strongly related to activities in 3 general directions [15]:

- investment in energy efficiency and renewable technologies;
- development of clean energy business models;
- embracing the new opportunities and consumer empowerment brought about by digitisation.

As very clearly implicated in the Energy package the transition to a low-carbon energy-efficient and climate-resilient economy will require a decentralised open system with the involvement of all stakeholders. Traditionally, the energy system is marked by the dominance of large enterprises, incumbents and large-scale, centralised technological projects. Nevertheless, the future requires for the consumer to be in the focus of the energy system. As marked in the SET plan, for putting the active consumers at the centre of the energy system, they should be [13]:

- engaged in better understanding, information and market transformation;
- activated through innovative technologies, products and services – leading to innovative business models.

All these efforts (Fig.1) work hand in hand with other flagship initiatives such as the Digital Single Market, the Capital Markets Union and the Investment Plan for Europe in order to deliver on jobs, growth and investments for Europe [14].

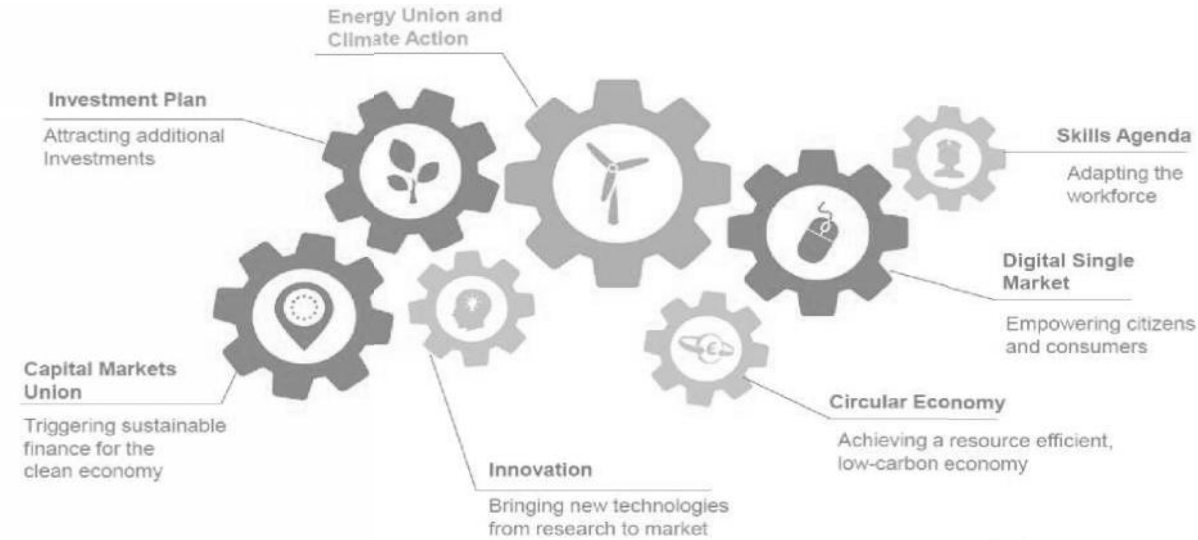

Fig. 1. Modernisation of the economy - role of the Energy Union and Climate Action [14].

Moreover, the package presents an opportunity to speed both the clean energy transition and growth and job creation. By mobilising up to an additional 177 billion euro of public and private investment per year from 2021, this package can generate up to 1% increase in GDP over the next decade and create 900.000 new jobs [16]. It will also mean that on the average the carbon intensity of the EU's economy will be 43% lower in 2030 than now [17], with renewable electricity representing about half of the EU's electricity generation mix [18].

Two complementary activities may also be taken into account for the implementation of the common goals:

- increasing public awareness – also in terms of national policy making, local authorities' activities and penetration of new legislation and educational and demonstration activities;
- integrated knowledge approach – expert knowledge bank focused on networking related to new technologies for overcoming the specifics in the different European countries.

Hydrogen has been accepted as a fuel / energy carrier together with advanced biofuels and other alternative liquid and gaseous fuels, including Liquefied natural gas (LNG), in the portfolio of sustainable means [13], therefore necessary to improve the EU security of energy supply and to achieve the ambitious European goals aiming to reduce the GHG emissions with respect to the overall EU 2020, 2030 and 2050 objectives in energy, transport, climate, economic and social policies. That leads to the need of advanced R&D for gaining advanced novel materials and components for fuel cell and hydrogen technologies accompanied with incentives and analyses of the key processes and mechanisms for hydrogen production and conversion and storage. On EU level there is sustainable collaboration for the acceleration of the market introduction on FCH technologies maintained by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) which concentrates the efforts of the European Commission, the FCH industries and the research community in the FCH sector in order to reduce dependence on hydrocarbons and to contribute to economic growth.

FCH technologies are expected to deliver economic benefits through job creation, improved balance of payments and long-term return on investments in the European economic area. It is acknowledged that the fuel cell and hydrogen industry sector has moved beyond the R&D stage and large scale investments have been made by the industry to deliver fuel cell and hydrogen products to end-users, including substantial financial resources allocated to research, development and demonstration by fuel cell and electrolyser suppliers, automotive original equipment manufacturers (OEMs), industrial gas companies, technology system integrators and grid energy network operators. These investments, together with the public sector funding at EU, national and regional levels, has placed the mobility, energy storage and stationary fuel cells sectors on the brink of commercial deployment that will deliver substantial macroeconomic and societal benefits on a Europe wide basis.

During the recent years FCH industry has achieved considerable progress toward meeting market based product performance, functionality, and cost improvement. Deployment for a range of applications such as mobility (including hydrogen refuelling infrastructure), stationary fuel cells (with/without on-site generation) and energy storage (with/without grid integration) in the energy systems of the EU.

A focus is taken to address non-technological aspects to facilitate deployment of FCH technologies, such as demonstration of their socio-economic effect, the environmental and energy benefits throughout the whole life cycle. At the moment there is no unitary regulatory framework in the EU in terms of FCH relevant regulations, codes and standards which represents of the barriers for large scale deployment.

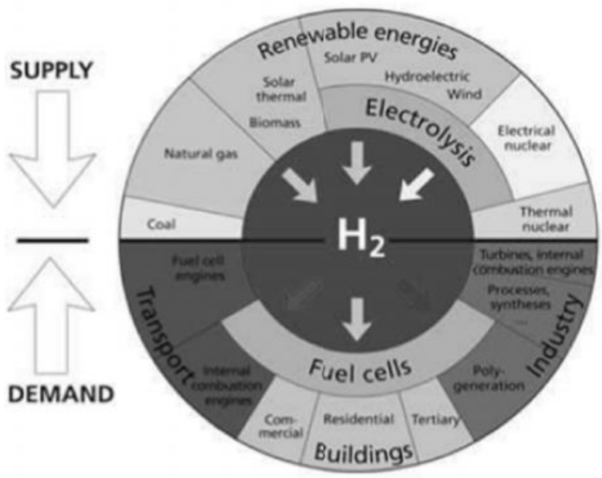

Fig. 2. Hydrogen economy [19].

The potential of hydrogen and FC technologies as an energy carrier is also becoming more and more plausible in economic terms as the need for integrated energy storage solutions grows rapidly and becomes more critical where renewable energy generation systems such as wind turbines and photo-voltaic that are already generating gigawatt hours (GWh) of electricity, often with a significant mismatch in grid power demand. In that sense, electricity storage becomes a key enabler of the large-scale deployment of fluctuating renewable energy (RE) generation capacity across Europe. Hydrogen as an energy carrier may be considered as a core element of the energy system of today – and will be even more so in the future: through stabilising power generation to make the best use of conventional and RE generation assets (Fig. 2).

From an economic point of view an extensive in-depth analysis of key trends, market drivers, and growth factors in the energy sector in Europe is needed – in order to clarify realistically the quantify of market supply and demand, taking into account relevant storage applications such as hydrogen with focus on regional, national and European specific regulations and standards. That would benefit the industrial and financial players in the energy sector as their return on investment (RoI) is closely related to the right setting and timing of market entry and is dependable on technology costs and low RE generation.

From a technological point of view, joint efforts of research, industry and society are focused and the efficiency of these actions is demonstrated by the activities and achievements of the Fuel Cells and Hydrogen Joint Undertaking – in synergy with the targets and goals implied by SET-Plan (Fig. 3.).

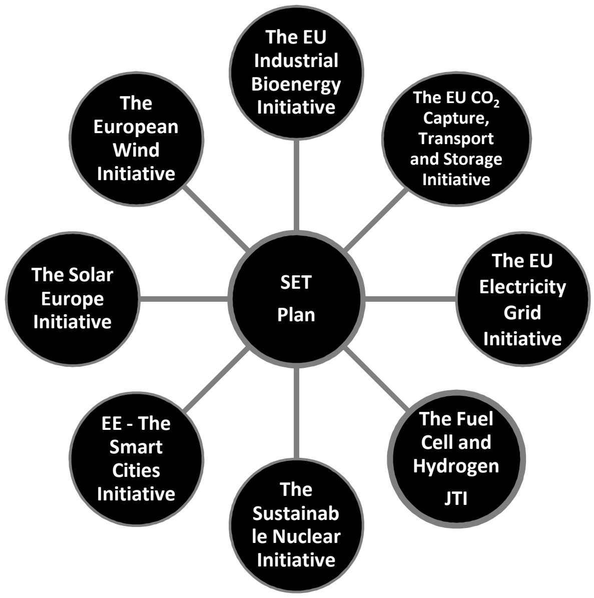

Fig. 3. European Strategic Energy Technology Plan [20].

The Fuel cell and Hydrogen Joint Undertaking (FCH JU) has a Multi-Annual Implementation Plan (MAIP) as primary strategic document which sets out the scope and details for basic, breakthrough and applied research and demonstration activities according to five main ‘application areas’ [21]:

- Transport and refuelling infrastructure;
- Hydrogen production and distribution;
- Stationary power generation and combined heat and power;
- Early markets;
- Cross-cutting issues.

According to the latest available data from the FCH JU Annual Activity Reports and the H2020 portal 204 projects were supported by the FCH JU to date, of which 155 originated under FP7 and 49 as part of Horizon 2020. They are distributed between the three main pillars of the programme [22]:

- Transport;
- Energy;
- Cross-cutting activities.

The first pillar (Transport) aims to accelerate the commercialisation of FCH technologies in the transport sector (which has an important role in the GHG emissions) through support of demonstration and research (RTD) projects across Europe.

The demo projects’ focus is directed to proving technology readiness and public acceptance while increasing the number of fuel cell electric vehicles (FCEVs) and the hydrogen refuelling network across Europe. There are six targeted segments: cars, buses, material handling vehicles (MHVs), auxiliary power units (APUs) and refuelling infrastructure [23]. The demo activities involving cars concern more than 1,500 vehicles, 250 of which are already in operation while the rest are planned within currently running projects. Also, a network of hydrogen refuelling stations is being created across Europe covering 8 countries and in 2015 it delivered 130,000 kg of hydrogen in 17,500 refuelling operations at 96% availability. Demonstration activating related to buses involve 67 vehicles in 12 European cities as 41 buses in 7 cities are already in operation while demonstrations of material handling vehicles have involved 48 vehicles (covering 6 models) from 3 manufacturers on 10 sites [22].

The research and innovation projects target a cost-efficient increase in the performance of fuel cell systems and hydrogen refuelling station (HRS) system. More specifically, the RTD projects in transportation relate to new materials and components development, improvement of performance levels, optimisation, reduction of costs and novel modelling in 8 technological segments [22]:

- Membrane electrodes assembly (MEA);
- Catalysts;

- Gas diffusion layer (GDL);
- Bipolar plates;
- Manufacturing and process development;
- Methodologies and tools;
- System and balance-of-plant (BoP) components;
- Advanced refuelling developments;

The second pillar (Energy) aims to accelerate the commercialisation of FCH technologies related to stationary fuel cells and the production of “green” hydrogen as an energy carrier. More specifically it targets reduction in costs while increasing the efficiency and the durability of fuel cells for energy production and at the same time also making the best use of the deployed of renewables in the European energy system. The FCH JU programme supports activities in three main areas [24]:

- stationary fuel cells (power and heat) demonstration and proof-of-concept activities related to technology capability and readiness;
- Stationary fuel cells (power and heat) research and innovation for performance, durability and cost improvements;
- Hydrogen production pathways from renewable energy sources, handling, distribution and storage technologies to enable hydrogen as a key energy carrier in the EU.

Until now around 40 projects have been funded by the FCH JU in the Energy pillar. It is notable to mention that the demo projects related to combined heat and power (CHP) are structured in different topic areas:

- Micro-CHP (< 5 kW)
- Mid-size CHP
- Large size CHP (>400 kW)
- Off grid/back up

So far, around 700 μ-CHP systems for residential applications have been installed in 11 European countries by 10 manufacturers. The generation of own electricity allows home owners to cut energy costs by 800-1,300 € per year [22]. The aim is to reach 3,000 units installed by 2020 and to increase their market competiveness. As a comparison it may be noted that Japan’s ENE-FARM program has supported the deployment of well over 120,000 residential fuel cell units [25] as plans are to reach 1.4 million units by 2020 and 5.3 million units by 2030 [26].

The third pillar (Cross-cutting activities) is closely related to the first two as it supports the commercialisation efforts in the energy and transport areas through a range of market preparation and readiness support measures. More specifically [22]:

- providing new knowledge to develop and improve regulations, codes and standards (RCS);
- preparing the European workforce;
- increasing public awareness and social acceptance;
- ensuring FCH technologies are environmentally sustainable.

Since 2014, projects addressing portable applications, previously classified within the ‘early markets’ application area, have also been categorised as cross-cutting. Until now more than 30 projects have been undertaken in the third pillar [22]. Efforts have been directed in order to gather knowledge and support the stakeholders in the FCH and energy fields thus, allowing that knowledge to pave the way for further regulations, codes and standards. Identification of economically viable niches for the FCH technologies has also been a priority in the joint efforts of the industry and research stakeholders.

On European level joint activities have also been directed towards support for the market penetration of fuel cells and hydrogen applications through a Horizon 2020 flagship project HyLAW which has already started as of January 2017 and will run until December 2018. HyLAW stands for “Hydrogen Law and Removal of Legal Barriers to the Deployment of Fuel Cells and Hydrogen Applications” [27]. It aims at boosting the market uptake of hydrogen and fuel cell technologies providing market developers with a clear view of the applicable regulations whilst calling the attention of policy makers on legal barriers to be removed. The project brings together 23 partners from Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Hungary, Italy, Latvia, Norway, Poland, Romania, Spain, Sweden, Portugal, the Netherlands and United Kingdom (Fig. 4.) and is coordinated by Hydrogen Europe [27].

Fig. 4. HyLAW project partners [27].

The HyLAW partners will first identify the legislation and regulations relevant to fuel cell and hydrogen applications and legal barriers to their commercialisation. They will then provide public authorities with country specific benchmarks and recommendations on how to remove those barriers.

HyLAW's main outputs will be [27]:

- an online and publicly available database compiling legal and administrative processes applicable to hydrogen and fuel cell technologies in 18 countries across Europe;
- national policy papers describing each legal and administrative process, highlighting best practices, legal barriers and providing policy recommendations;
- a pan-European policy paper targeted towards European decision makers;
- national and European workshops for dissemination of the findings and convincing public authorities to remove barriers.

The database will be maintained by Hydrogen Europe for minimum three years after the end of the project.

The HyLAW project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 737977.

From a boarder perspective, international efforts have also been directed to support of the deployment of FCH technologies for cleaner and safer future. The International Energy Agency (IEA) Hydrogen Implementing Agreement (HIA), which is a leader in the management of coordinated hydrogen research, development and demonstration activities, has launched a specific task (Task 38) entitled: "Power-to-Hydrogen and Hydrogen-to-X: System Analysis of the techno-economic, legal and regulatory conditions" with aim to examine hydrogen as a key energy carrier for a sustainable and smart energy system [28]. The IEA–HIA has long-term and vast experience in facilitating and managing an inclusive range of Research, Development & Demonstration (R, D&D) and analysis programs (over 40) among its international members – including international organisations, industrial and research partners, non-profit organisations [30]. The "Power-to-hydrogen" concept implies that hydrogen is produced via electrolysis as the electricity supply may be either grid, off-grid or though mixed systems while "Hydrogen-to-X" implies that the hydrogen supply concerns a large portfolio of uses. More specifically [29]:

- Transport (hydrogen for fuel cells, biofuels, synthetic methane for transport etc.);
- Natural gas grid (by mixing hydrogen directly with natural gas or synthetising methane and injecting it into the natural gas grid);
- Re-electrification through hydrogen turbines or fuel cells;
- General business of merchant hydrogen for energy or industry, especially refinery, steel industry, ammonia, etc.
- Ancillary services or grid services for the electricity grid, transport or distribution grid. Hydrogen provides flexible energy storage and carrier options which could defer the need for new lines and would alleviate the transmission difficulties

Task 38 has a lifespan of 4 years (2016-2019) and ambitions goals [31]:

- to provide a comprehensive understanding of the various technical and economic pathways for power-to-hydrogen applications in diverse situations;
- to provide a comprehensive assessment of existing legal frameworks;
- to present business developers and policy makers with general guidelines and recommendations that enhance hydrogen system deployment in energy markets.

The IEA-HIA Task 38 involves more than 50 experts in different fields from 15 countries. It is coordinated by the French Commissariat à l'énergie atomique et aux énergies alternatives / Institut de Technico-Economie des Systèmes Energétiques (CEA/I-tésé) and supported by the French Environment and Energy Management Agency (ADEME). There are also 15 participating IEA HIA ExCo Members: Australia, Belgium, European Commission, France, Germany, Japan, The Netherlands, New Zealand, Norway, Shell, Southern Company, Spain, Sweden, United Kingdom, and the United States [31].

The ongoing work conducted in Task 38 shows that an international joint effort is needed to analyse strategic studies in the FCH field, archive external synergies, and manage existing knowledge in order to identify possible pathways and niches together with all stakeholders for the successful market deployment of FCH technologies leading to a carbon-free and sustainable economy.

CONCLUSION

The establishment of sustainable European expert knowledge network arises as a necessary component for the further market integration of FCH technologies in the EU, being a specific knowledge niche emerging from a combination of resources from the European Research Area and from the established public private partnerships. Thus, its role in the total package of measures is quite important. Presently, novel technologies are needed in order to ensure energy efficiency and integration of renewables in the energy mix. A large number of the innovative technologies are in a pre-commercial stage. On EU level serious efforts are devoted for commercialisation of research and innovation above Technology Readiness Level 4 (TRL), and that in fact, somewhat brought to an underestimation of fundamental research in specific areas which were left to be developed on national level. However, in some new Member States that does not happen with the same pace and leads to fragmentation on European level. Fortunately, in the results from the currently performed analysis, introduced in the set of measures “Clean Energy for all Europeans”, all those issues have been taken into account and an updated strategy has been proposed. Thus, it is the right time to start the development of the next generation through breakthrough research with multi-fold benefits.

Currently, the existing regulatory and legal and administrative processes (LAPs) covering areas such as local and national planning, safety, installation and use/operation do not reflect adequately the use of FCH technologies. The limited awareness and coverage of FCH technologies in LAPs creates complications and requires substantial time, incurs additional costs and resources therefore, representing a barrier for rapid deployment. In this way, the financial resources are not directly targeted to the technology deployment leading to relative inefficiency and restricting quick access to the potential market. That hot topic of the European policy in the field will be supported by the planned and on-going activities of European HyLAW project and the International Task 38 of the IEA/HIA. The synergy of those activities would also support the growing necessity for the setting up of a distinct guild of highly-trained technical personnel needed for the newly created FCH infrastructure in Europe and worldwide.

The joint efforts of science, industry and policy-makers on European and international level have shown considerable success during the recent years for the implementation and market penetrations of FCH technologies. FCH technologies in a pre-commercial state have already been developed (above TRL 7). It can be highly been acknowledged that they will not only serve as transitional technologies during the decrease of fossil fuels utilisation but also as end point technologies for the efficient production and utilisation of hydrogen, and more generally in the global energy system as well.

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ВОДОРОДНА ИКОНОМИКА: БЪДЕЩЕ ЗА ЕДНО УСТОЙЧИВО И ЗЕЛЕНО ОБЩЕСТВО

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(Резюме)

Нарастващата нужда от устойчива енергийна декарбонизация на индустрията кара изследователите от различни области на науката да търсят алтернативни и по-ефективни начини за достигането на тези цели. Икономика основана на технологии, използващи горивни клетки и водород, е един приемлив и обещаващ начин за постигането на заложените европейски цели и подобряването на качеството на живот на гражданите, осигурявайки независимост и сигурност на енергийната система на Европа. Съществува належаща необходимост за ускорено въвеждане на технологии, опазващи околната среда, както и интегрирани мерки и съвместни усилия на всички страни членки на ЕС. В тази статия се дава общ преглед на технологиите на база водород и горивни клетки и се разглежда обстоятелствено тяхното място в общоевропейската политика за декарбонизация и интелигентен растеж. В статията, също така, се обсъждат и международни инициативи в областта като се предлага възможно развитие за едно по-зелено общество.