HyTechCycling

New technologies and strategies for fuel cells and Hydrogen Technologies in the phase of recycling and dismantling

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WP2 Regulatory analysis, critical materials and components identification and mapping of recycling technologies

D2.4 Recommendation and perspective on EU regulatory framework

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Executive Summary

The development of FCH technologies is nowadays widely extended and well-known all over the world. From its very beginning, several applications have been the ones that have had the most important growth, thus, nowadays: there are more than 540 FCEV already running, 120,000 micro CHP stationary fuel cells only in Japan and more than 80 HRS worldwide.

The first commercialization phase has already been proved and FCH technologies are currently overcoming the so-called Valley of Death in order to become a fact in all the sectors related to the electricity or fuel consumption. Fuel cells are environmentally and economically advantageous. They provide an immediate path to lower greenhouse gas (GHG) and air pollution emissions through increased energy efficiency, and this, in turn, leads to unique and substantial benefits for our planet, our personal health and our economy.

Compliance with environmental standards (implemented as policies and regulations) in the phase of end of life is reported and studied carefully in previous D 2.3, with a deep analysis of current barriers imposed in the legislative framework. One of the main barrier to the deployment of FCH technologies, as reported, is the lack of specific regulations during all of FCH life cycle. Starting from the barriers list from EU Regulations, recommendations and guidelines to provide the EC policy makers and national authorities a perspective of the changes and adaptations needed in the short to medium term will be report in the document.

Nevertheless, as changing legislative frameworks is challenging, the work will do strong efforts in making FCH technologies to comply with environmental standards, which may be one of the challenges limiting recycling and dismantling.

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Abbreviations

APU	Auxiliary power unit
AWE	Alkaline Water Electrolyser
BoP	Balance-of-Plant
CHP	Cogenerated Heat and Power
CRM	Critical raw material
D	Deliverable
EC	European Commission
EEE	Electrical Electronic Equipment
EoL	End of Life
ELV	End of life vehicles
EU	European Union
FCEV	Fuel Cell Electric Vehicle
FCH	Fuel Cell and Hydrogen
FCHV	Fuel Cell and Hydrogen vehicles
GHG	Greenhouse Gas
HRS	Hydrogen Refuelling Station
HTPEMFC	High Temperature Polymer Electrolyte Membrane Fuel Cell
ID	Innovation Deal
YSZ	Yttria Stabilized Zirconia
LCA	Life Cycle Analysis
LSCM	Lanthanum-Strontium-Chromium-Manganese
Ni	Nickel
PBI	Polybenzimidazole
Pd	Palladium
PEM	Polymer Electrolyte Membrane
PEMFC	Polymer Electrolyte Membrane fuel cell
PEMWE	Polymer Electrolyte Membrane Water Electrolyser
Pt	Platinum
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
REE	Rare Earth Elements
REFIT	Regulatory Fitness and Performance Programme
RoHS	restriction use of hazardous substances
SAE	Society for automotive engineers
SHVC	Substance with high concerns
SME	Small medium enterprise
SOFC	Solid Oxide Fuel Cell
STO	Strontium titanium oxide
TRL	Technology readiness level
WEEE	Waste Electrical Electronic Equipment

1. Introduction

This present section exposes the current situation of FCH legislations and the identified barriers for FCH deployment.

1.1 Study background

High deployment of Fuel Cells and Hydrogen technologies (FCH technologies) is expected in the near future in the EU to decarbonize energy and transport sectors. However, commercialization of FCH technologies (mainly PEM and alkaline electrolysers as well as PEM and Solid Oxide fuel cells) is not prepared for full deployment mainly concerning the recycling and dismantling stage. The main goal of the project is delivering the reference documentation and studies about existing and new recycling and dismantling technologies and strategies applied to Fuel Cells and Hydrogen (FCH) technologies. One of the key steps for the commercialization and market massive introduction of the technologies is a specific legislation regarding end of life and recycling of each fuel cell system component. In this report, specific recommendations and guidelines to adapt existing regulatory framework will be reported, analysed and delivered following the previous D2.3_Regulatory framework analysis and barriers identification (1).

1.2 Methodology in the study

The main approach for developing the study was starting from the previous *D2.3_Regulatory framework analysis and barriers identification* (1) that has analysed the existing legislations on material design and end of life mainly related to fuel cell systems, and the barriers to innovation of the technology and its market entry. Recommendations for stakeholders and EU/national policy makers will be reported and analysed.

1.3 Legislations and barriers for deployment of FCH technologies

The Deliverable 2.3 analyses the legislation on material design and end of life mainly related to fuel cell systems, so specific Directives are reported and related to each part of the fuel cell system.

Life cycle of FCH	DIRECTIVES	FCH stack	BoP components	power conditioning	Batteries	Cabinet	FCH product	FCEV	CHP
Design	Eco Design Directive (2)	x	x				x	x	x
Materials selection	REACH Regulation (3)	x	x				x		
	RoHS Directive (4)			x			x		
End of life mana-gement	WEEE Directive (5)	x	x	x			x		
	Landfill directive (6)	x	x	x	x	x	x	x	x
	Hazardous waste Directive (7)	x	x						
	Batteries Directive (8)				x			x	x
	ELV Directive (9)							x	

Table 1 - Legislation reference to life cycle of a FCH system

- Eco design Directive has to be considered in the whole FCHs system design, but also for the materials selection both FC stack and BoP components.
- REACH Regulation is to be considered in stack and BoP materials selection.
- RoHS Directive is specific to material selection in power control systems.
- WEEE Directive is related to electric and electronic parts in a fuel cell system.
- Hazardous waste Directive has to be used for FC stacks and BoP components with hazardous materials.
- Batteries Directive is specific for EoL batteries installed in a FCH system.
- ELV Directive can be used for FCHVs.

The main barriers for the deployment of FCH technologies related to present legislations are here summarized:

- Barrier on system design: FCHs manufacturers have to implement and provide evidence of eco-design. Specific chapters in the eco-design Directive on FCHs technologies are required otherwise the FCH manufacturers may incur a negative impact of the product. Another fundamental aspect tied to eco design is related to the choice of materials during the design phase, it can impact positively on the cost of technology. Barrier related to Eco-design Directive.

- Barriers on materials selection: the present legislation on hazardous materials poses restrictions in the selection of substances. This implies the need for manufactures to take into serious consideration this requirement because it might preclude the marketing of these systems. Barriers related to REACH Regulation and RoHS Directive.

- Barrier on end of life management: recycling target could be too restrictive if the FCH developers will not put attention on them during the design phase and this could affect the technology's image. Barrier related to ELV Directive. However, the WEEE Directive poses an important issue due to the exclusion of large scale stationary industrial tools from the Directive. Therefore, FCH developers should focus on strategies for end-of-life management of the stack in order to limit landfill waste and following recovery and recycling procedures taking them into account during the eco design phase (10).

- Lack of a specific FCH Directive. Some current Directives include FCH products or have to be taken into account with a FCH system, but the creation of a more detailed FCH relevant regulatory is needed.

2. Implementation of existing regulatory framework and proposals for new laws

2.1 "Better regulation"

The EU, along with the Circular Economy concepts, and in strict cooperation with regional authorities, universities, stakeholders, innovators has detected preliminary barriers to innovation. The main objective of these actions was to help innovators to overcome the regulatory obstacles.

A "Better regulation" may help with innovation of the products, can support their market entry and can help providers and manufacturers of the technology to follow guidelines to better implement the technology in accordance with the existing and implemented regulatory frameworks.

However, regulations may also be an obstacle to innovation, delaying or complicating the entry of new products into the market, even if they are very innovative. The existence of *non-ad hoc,* even if applicable, too restrictive regulations are a first barrier to product innovation. The lack of specific regulations on the sector of interest is also a new product market restriction. Fuel cells fall into these specific frameworks of analysis.

They are innovative systems, a clean and efficient alternative to traditional systems (diesel generators, batteries) with environmental benefits during operation in line with current climate change concerns. The hydrogen and fuel cell sector represents a significant economic potential. A significant growth in Europe as a number of jobs, with an annual increase of 35% by 2020 is expected. In terms of transport, the global EU demand should reach over 0.4 Mt /year by 2020. Even though recently the hydrogen industry is in a commercial development phase, it is necessary to overcome some barriers before technology can deployed on a large scale: economic, financial, technical, social and legislative barriers.

The ability to demonstrate compliance with the existing regulatory framework and the recommendation for new legislations are necessary for a successful market entry (11).

Moreover, over the years, different interpretations of the transposition of legislation by Member States and a growing number of thematic areas have led the European community to review regulatory plans that do not often support innovation and to introduce new thematic areas of interest.

In order to overcome mainly regulatory barriers faced by SMEs, the EU developed a REFIT Programme (Regulatory Fitness and Performance Programme) through stakeholder consultations and developed a “Better regulation for better results” in May 2015 in order to give more collect information (12).

Better regulation covers the whole EU policy cycle (Figure 1) (13). The EU Policy cycle can be divided in two steps:

- Planning of new laws or review through stakeholder consultation, monitoring and evaluation, impact assessment (blue part).
- Policy design: preparation and adoption; implementation (transposition, complementary non-regulatory actions), application (including enforcement), evaluation and revision (grey part).

Figure 1 – EU Policy cycle (13)

2.2 “Innovation Deals”

A further approach to be explored is inserted in the new EU Action Plan and it introduces the definition of “Innovation Deals” with the objective to detect the main barriers to innovation and quickly addressing legislative barriers, shortening the time for a market uptake (14).

Innovation deals (IDs) are “*a pilot approach to help innovators facing regulatory obstacles (e.g. ambiguous legal provisions), by setting up agreements with stakeholders and public authorities*”, a “*new way to address EU regulatory obstacles to innovation in an open and transparent manner, in the form of a voluntary cooperation between innovators, national/regional/local authorities and Commission services to better achieve EU policy objectives”* (15).

“*Innovation Deals would not support 'normal' business activities, but would be <u>restricted to innovative initiatives that have only a recent and limited or even no access to the market with the potential of wide applicability.</u> Through <u>involvement of the European Commission and the relevant Member State</u>*

authorities, together with stakeholders Innovation Deals would seek to find ways to avoid potential innovation barriers arising from existing EU law or Member State implementation.

They may concern actions which EU law already allows, but where confirmation or clarification of the legal position is sought, for example exploring existing flexibility within the legislative framework, eventually leading to testing and/or application of the innovation, fully complying with existing legal requirements. The outcome of Innovation Deals, therefore, will be considered by relevant Member State authorities for their policy and legislative actions, and will be monitored according to national schemes. Member State Authorities may be asked to report data in order to assess the impact of these Deals on economy, environment, growth and job creation (11)".

Some points have to be put into evidence in order to describe the role of IDs:

- An innovator or a group of innovators can apply for an ID. Innovator is "any physical or legal person who introduces new methods, ideas or products";
- IDs are related only to innovative solutions, with a recent, limited or even no access to the market, with broad opportunities to penetrate the market in the short term;
- Innovation and limited or no access to the market must be demonstrated (TRL 8-9);
- ID has to be in line with Circular Economy;
- ID does not violate any EU legislation and principle;

During the first phase, the EU Commission collected 32 expressions of interest from 14 Member states and some topics which identified the major barriers to innovation.
In 2017 two Innovation Deals will be focused on: regulatory barriers on sustainable wastewater treatment and e-mobility and recycling of batteries. The IDs must be in accordance with the REFIT Programme.
In this phase of innovation and re-working of legislations, specific studies on FCHs can be allocated through a strict cooperation of stakeholders, innovators, regional authorities, universities, EU Commission.

2.3 Proposals for new laws

As explained in the section 1, FCH technologies have no specific regulations, but are associated to some existing regulations' scope. Nevertheless, for a broad development of these promising technologies, new laws and regulations related to FCH technologies must arise.

This report is intended to policy makers so as to propose some new regulations. This part gives important points on which the new laws should focus. Indeed, as regards FCH technologies, it exists some hot spots. As a result, they can constitute the beginning point for new laws.

Due to Europe's high dependence on import, there is growing concern about the supply of particular materials. The use of scarce or critical materials could jeopardize the development of FCH technologies. Furthermore, due to hazardous materials used in some FCHs, the main points in which this new laws should be focused are:

- limiting the amount of critical and hazardous materials such as nickel used in SOFC.
- establishing the recycling of some part mandatory such as precious metals used in AWE's anode for instance.

Thus, these policies will dissuade the use of critical and hazardous materials, while they encourage innovation and the development of efficient and viable technologies.

2.3.1 Recyclability chart

The automotive market is one of the most developed one for FCH technologies. As a result, some organizations have started to consider the end-of-life issue. Indeed, herein some proposals for new laws or regulations based on a study carried out by the SAE International (Society of Automotive Engineers) (16) are presented.

FCH technologies are quite complex by the numerous components they are made of. Nevertheless, three sub-systems can be defined:

- BoP components
- Fuel supply
- Cell stack

For each sub-system, a new regulation should propose a recyclability chart which provides specific recyclability data on major FCH sub-systems components. This chart will help to define better the material types recycling issues, disassembly, reuse or alternative uses, technical issues, infrastructure issues, environmental issues such as resource depletion and end-of-life environmental issues.

"This chart serves as a quick reference, supported by the text of the standard, to evaluate specific choices by design engineers and determine the implications of those choices for reuse, recyclability and landfill potential".[16]

As in the case of FCE Vehicles, another idea could involve implementing dismantling and recyclability ratings for each sub-system. This proposal should pave the way for better awareness of recycling and dismantling issues among the FCH actors.

Moreover, this proposal can be completed by a new label regulation. Components -or at least sub-systems- could be tracked with a specific label which provides important information such as the components materials and the end-of-life strategy appropriate for the concerned sub-system.

2.3.2 Design harmonization

A better standardization and a modular conception of FCH technologies aim to improve the products' quality and durability. In coordination with the European Standards Organization, minimal standards should be applied to the FCH technology. Indeed, this design harmonization and standardization provides multiple benefits. It simplifies the dismantling and recycling process and consequently reduces the costs of the task. Modular conception would also facilitate the dismantling stage and allow reusing components as much as possible. The design should be adapted to the recycling scenario. Even more, a regulation can impose the manufacturers to demonstrate proofs of a design adapted to recycling and dismantling before the product is launched.

Furthermore, in this design harmonization process, a regulation should impose a minimum quantity of recyclable materials used in manufacturing phase. For instance, the use of thermoplastic is common in PEMFC, PEMWE and AWE. The use of a minimum percentage of recycled plastic should be fulfilled until reaching 100% of recyclable plastic used.

Thus, a clear labelling of the product is also expected for the end-user to be aware of durability of the product. Manufacturers which are able to produce more durable and with higher rate of recycled materials should assure their clients to be aware of it. For this purpose, a clear labelling of product is required. In the same time that it promotes products' durability, it ensures a fair and transparent competition between manufacturers.

2.3.3 "Agreements"

Another interesting proposal concerns implementation of "agreements" between recycling centers and manufacturers as it is illustrated in the Figure 2. Those agreements should assure the manufacturer to buy the recycled materials from recycling centers which have treated their products. It will facilitate the recycled material logistic and increase the rate of reused components and/or materials. Benefits of these agreements should impact both manufacturers and recycling centers. In fact, manufacturers would be able to buy materials and/or components at low price and recycling centers are assured to profit from recycling FCH technology.

Figure 2 – Agreements between FCH manufacturers and recycling centers

3. Recommendation on EU Regulatory framework for stakeholders and EU/national policy makers

As it was previously said, even if there are no specific regulations on FCH technologies, some regulations can be extended and improved in order to fit to FCH technologies. As a result, this section exposes some recommendations on existing EU regulatory framework.

3.1 Recommendations on REACH Regulation

The first barrier to innovation and commercialization of the FCHs that comes from the REACH restrictions is the presence of hazardous materials in the stack that could affect the deployment of FCHs systems. The Annex XVII of the REACH Regulation (3) includes substances restricted for which manufacture, placing on the market or use is limited or banned. The REACH reports also information on SHVC (Substance With High Concern).

As reported in the previous *D2.3_Regulatory framework analysis and barriers identification* (1), the FCHs technologies present some hazardous materials such as: nickel and nickel based oxides used in SOFCs and raney-nickel in AWEs (a); asbestos used in AWEs (b) and potassium hydroxide in the electrolyte of AWEs (c). Starting from the hazardous materials, a correct analysis of the components, analysing if some of them can be substituted, is necessary.

a) Nickel oxide used in the anode side of a SOFC stack is classified as SHVC (Substance With High Concern) and this classification could lead to a potential prohibition. Research activities on new potential materials are ongoing but nickel based catalysts are the most active until now. Also the presence of nickel based alloys, mainly in the balance of plant of Solid Oxide fuel cells, always takes the issue with hazardous materials and so the evaluation of alternative materials.

Nickel or its compounds are included in REACH ANNEX XVII restricted substances list (entry 27) (17).

Analysing the state of the art of SOFCs and the materials used as anodic catalysts, the most efficient materials are based on Pt and Pd. The nickel recovery is cheaper and the Ni-YSZ anode presents excellent electrochemical catalytic performance. Therefore, it is essential to develop alternative anodes providing high performance in the operating conditions in order to replace Ni-YSZ cermet for SOFC applications.

Much of the research into cermet- alternatives for both anodic and cathodic application has focused on the production of perovskite-type compounds. The first example of an efficient and fully redox stable anode material, (La0.75 Sr0.25) Cr0.5 Mn0.5 O3 (LSCM), was developed in 2003. Due to the conductivity in both oxidizing and reducing atmospheres, LSCM can be utilized as both anode and cathode in a symmetrical SOFC. Another material which has been under extensive investigation is strontium titanium oxide, $SrTiO_3$ (STO) with a high sulphur tolerance. The main difficulty with the use of pure STO is low electronic conductivity in a reducing atmosphere. Both pyrochlore and tungsten bronze structured compounds were the focus of investigations into suitability for its utilization as an anode material.

Researches in the last years demonstrated that with Ni-YSZ and Ni-CeO_2/YSZ at least the 25% wt of Ni was necessary to prevent high ohmic resistance and the mixture Ni-CeO_2 reduces the cell polarization. Perovskite are also other investigated materials (18). Until now Nickel catalysts seem to be the most efficient and economic.

Another aspect to consider about the nickel and so any other hazardous materials is that the law is in the early stages and so its implementation. In this phase, the fuel cell manufacturers should present a socio-economic assessment to justify the need to use nickel and other hazardous materials, showing how in many cases there is no reasonable substitute for nickel-containing materials and overcoming the banning of the material.

Socio economic analysis from the stakeholders have to include considerations on (19):

- Job opportunities, starting from a total estimation on the number of jobs in EU of 1.25-1.5 million, around the 55% is covered by nickel industry jobs.
- Market of nickel, EU is a global leader in the production of nickel-containing alloys, such as stainless steel and super alloys.
- Nickel based materials are present in many strategic sectors of the EU economy.
- The technologies based on nickel helped the industries and the users to create new products and a new strategy of work.

Moreover nickel-based alloys used in the high-temperature components of SOFC cells are difficult to replace because they have high benefits including durability.

The EU and National policy makers are requested to consider these socio-economic aspects that will allow to overcome some barriers to market.

b) Asbestos fibres mainly present in the AWEs membrane are included in REACH ANNEX XVII restricted substances list (entry 6) (20).The recycling of asbestos cells should be limited to the old alkaline electrolysis plants located in developing countries. Removal of asbestos can disturb the fibers of which it is made, and it is know that prolonged inhalation of asbestos is harmful (provoking lung cancer and other diseases). For these reasons, the use of this mineral is forbidden in the EU since 2005. As reported in the Annex (20) *"by 1 June 2011 Member States making use of this exemption shall provide a report to the Commission on the availability of asbestos free substitutes for electrolysis installations and the efforts undertaken to develop such alternatives, on the protection of the health of workers in the installations, on the source and quantities of chrysotile, on the source and quantities of diaphragms containing chrysotile, and the envisaged date of the end of the exemption. The Commission shall make this information publicly available".*

The recycling process of asbestos is well known and is based on its transformation to harmless silicate glass. It is a thermal process at 1000 – 1250 ºC (21). Other industrial process transforms asbestos and waste containing asbestos into porcelain stoneware tiles, porous single-fired wall tiles, and ceramic bricks by means of microwave thermal treatments (22). FCHs manufacturers are requested to consider asbestos replacement, already to be taken into account during the design phase of the cell. The new generation of alkaline electrolysers (non-asbestos membrane based) has been developed during the last few years (23).

c) Potassium hydroxide is used in order to enhance the conductivity of the solution, electrolytes which generally consist of ions with high mobility are applied in the electrolyser. Potassium hydroxide is preferred over sodium hydroxide due to higher conductivity of electrolyte solution. Most commonly 25–30% alkaline solutions are adopted in commercial electrolyser. The recycling technologies used for this equipment are well known. Purge precautions and mainly procedures have to be considered in the recycling of KOH solution (for mixtures and components have to be removed from any separately). For the treatment of KOH and power electronics chemical waste treatment and WEEE legislation are nowadays considered respectively.

3.2 Recommendations on WEEE and RoHS Directives

As reported in the previous *D 2.3_ Regulatory framework analysis and barriers identification (1)*, the main power conditioning, electric and electronics components in a FCHs system comply with the WEEE and RoHS Directives.

According to Annex IB of the WEEE Directive, “large scale stationary industrial tools”, falling under category 6, are exempted from the scope of WEEE. They are “*machines or systems consisting of a combination of equipment, systems, finished products and/or components, each of which is designed to be used in industry only, permanently fixed and installed by professional at a given place in an industrial machinery or in an industrial building to perform a specific task. Not intended to be placed on the market as a single functional unit*” (6).

The Figure below reports the concept of “large scale installation” reported in the WEEE Directive (Article 3 and 4).

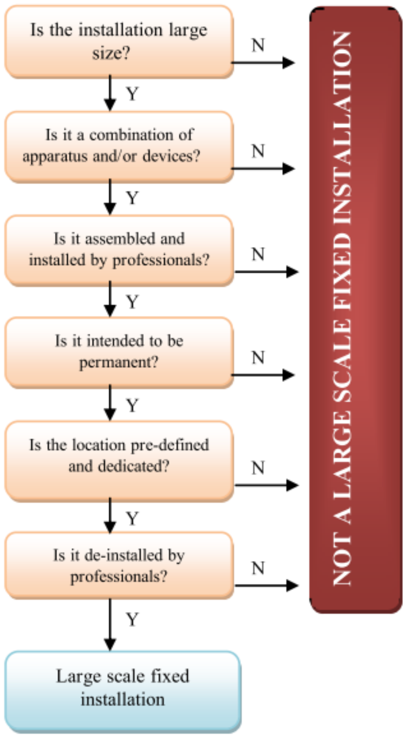

Figure 3 – Large scale fixed installation concept (21).

Large stationary fuel cell market includes different systems: large-scale systems for prime power, large backup power or combined heat and power.

Stationary power generation systems, based mainly on PEMFC and SOFC technologies, are characterized by efficient fuel utilization, reduction on pollution emissions, CO_2 and other greenhouse gases. They provide clean, efficient, and reliable off-grid power to homes, businesses, telecommunications networks, utilities. The market is growing, so it is necessary for the fuel cell developers to collect the main information on the product and to propose the inclusion of "large stationary power generation systems" in the WEEE Directive product list.

Starting from the stakeholders´ recommendations on EU Regulatory framework, the role of EU policy makers is to change to the scope of the Directives, in order to include "large stationary power generation" in the scope of the Directive, order to help and mainly simplify the market entry for FCHs technologies.

RoHS Directive 2002/95/EC drives the manufacturers to avoid the use of some components (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers). In order to meet the requirements and a national implementing legislation, the substitution of these hazardous materials is needed.

The use of certain substances often creates a complex supply chain, mainly due to the need to redesign the product and so to re-adapt the production system of the same. This entails higher costs for the product more closely related to adaptation of the processes. The Eco-design Directive must be considered.

Although in the second version, the RoHS1 and RoHS2 laws tend to expand the list of hazardous substances, they are simpler so, if the manufacturer demonstrates that there are no alternative solutions available, they improve the exemption mechanism. Even in this case the producer has to present a socio-economic analysis that must be acknowledged by EU policy makers.

3.3 Recommendations on Hazardous waste and Landfill Directive

Waste legislation and mainly Hazardous Waste Directive identifies the wastes with hazardous properties.

As reported in the D2.3 the FCHs systems and mainly SOFC stacks are made of hazardous materials and so in the waste classification it is necessary to determinate if it is hazardous or not.

So, the FCHs manufactures have to provide a detailed life cycle assessment in order to stay below the limits and prevent damage to the technology image.

The main recommendations are strictly linked with a correct choice of materials in the design phase of technology, following the objectives of the eco-design directive and, if some materials cannot be replaced, performing a careful LCA in the design phase, in order to prevent concentration limit in the final waste.

Landfill Directive presents the barrier related to the need of a pre-treatment prior to the disposal to landfill. The recommendation is for developers to find a solution for the main parts of the FCHs system and mainly the stack in order to comply with the law and enter in the market with large volumes.

3.4 Recommendation on critical raw materials

The use of critical raw materials, mainly Pt based and REE, poses problems mainly due to an increasing cost of materials and a decreasing availability that could impact in the system production and could limit its commercialization. This is an assessment that manufacturers must consider during the design-phase.

Recommendations are mainly related to the substitution or reduction of critical raw materials to evaluate during the eco-design phase and in accordance with the Directive.

Different replacing techniques of critical raw materials have been analysed in the framework of "The Critical Raw Materials Innovation Network (CRM_InnoNet)", an initiative of the European Commission which aims to create an integrated community that will drive innovation in the field of critical raw materials substitution (22). The EC is really aware of the benefits that the substitution of critical raw materials can provide to the EU industry. The most promising techniques for CRM InnoNet are:

- Direct replacement of one substance or material for another (e.g. in solar panels: indium tin oxide for organic polymers)
- Replacing a material with an entirely new technology (e.g. bio-enzymatic processes replacing metal catalysts)
- Services (e.g. a leasing model for electric car batteries could allow batteries to be swapped for a charged one rather than recharged, allowing for longer recharge times needing smaller quantities of critical raw materials).

The reduction techniques are more commonly applied by optimization techniques in the use of material resources in the R&D departments of the manufacturer companies. As an example, Toyota has reduced platinum loadings to around 30 g over the recent few years before presenting their commercial Fuel Cell Electric Vehicles (FCEV) (around 4 to 5 times more platinum than the one present in the catalyzer of a diesel equivalent class car, representing the cost in platinum less than 3 % of the total vehicle cost). Current improvements in nanotechnology are allowing reductions in metal loading without a loss of performance or durability (24).

3.5 Recommendations on End-of-Life Vehicles Directive

There will be the need to include electro-mobility in a sustainable transportation concept, to develop a more environmental friendly method of mining main metals and to promote recycling.
This could be implemented through a more detailed research on recycling methods and optimization and through an implementation and amendment of the EU and regional legislations.
Recommendations are proposed to the manufacturers in design-phase in order to reach the Directive recycling and recovery targets. With the recycling targets set up to 85% by weight of the vehicle, FCH manufacturers have to consider the target and transpose it mainly to the Fuel cell stack.

3.6 Recommendations on Eco-design Directive

The technology providers in order to comply with future requirements should be able to demonstrate life cycle thinking, and therefore should dedicate resources to addressing these issues. They have to encourage the technology.

Eco-design aspects must be taken into account for FCH technologies to be optimally recycled and disassemble.

Eco-design Directive must be taken into account in the total fuel cell life cycle:

- Material selections and substitution in order to comply REACH Regulation;
- Fuel cell manufacture and construction, in order to comply REACH Regulation, RoHS Directive for the EEE;
- Fuel cell manufacture and construction in order to reach the End of life management targets;
- End of life management to guarantee the main requires from Hazardous Waste and landfill Directive.

4. Guidelines for EU polices and regulations

FCH technologies represent a promising market in Europe. However, some regulations and legislations barriers remain. The technology is evolving quickly, and the legislation should follow the rhythm otherwise, important market and development perspectives will be missed. Indeed, FCH technologies require a specific regulation as they are quite complex systems.

Thus, this section sums up the main ideas developed in the present report. Recommendations on EU regulatory framework and proposals for new laws are the main points summarized here above.

- Hazardous and critical materials:
    - Reduce their use by imposing a limited amount, otherwise imposing a socio-economic assessment to justify their use.
    - At the end, prohibit the use of hazardous materials.

- Eco-design:
    - Harmonize the design process in order to facilitate the dismantling stage.
    - Improve the quality and durability by imposing a minimum standard.
    - Modular conception.
    - Imposing a rate of recycled materials used.
    - Clear labelling.

- Recyclability charts:

    - For each sub-system, apply a dismantling and recyclability rating.

- Agreements:
    - Develop a strong network between FCH manufacturers and recycling centres.
    - Win-win: manufacturers buy materials and components at a low price, and the recycling centres assure to have a new market.

Thus, considering its complexity, new regulations are required for this type of technology. Those new regulations must be adapted to the actual situation, be helpful to the development of this market. At the same time, they must ensure a good practice -such as the reduction of hazardous and critical materials. As a result, they must promote innovation and breakthroughs in this field.

5. Perspectives and conclusions

Fuel cells have the potential to become a substitute in a widely range of applications and the technology is next to the mass market. The total amount of fuel cells deployed between 2009 and 2014 all around the world have been 239,460 units from which 152,600 are associated to stationary fuel cells in which, as it has been mentioned, CHP, APU and back-up fuel cells are included. These markets have represented $1.2 billion in 2013 and $ 14.3 billion are projected in 2020(25). In this sense, CHP stationary fuel cells penetration is expected to reach 24 MW (12,000 units) by 2020, 130 MW (42,000 units) by 2030, 401 MW (178,000 units) by 2040 and 464 MW (200,000 units) by 2050 in the conservative scenario, and 62 MW (21,000 units) by 2020, 263 MW (68,000 units) by 2030, 1,244 MW (882,000 units) by 2040 and 4,953 MW (1,676,000 units) by 2050 in the high pathway scenario (26) both in the European frame. Additionally, the ENE-FARM project has predicted 389,491 shipments by 2020 in Japan (27).

Based on that data, the market will reach 1,986,238 units shipped by 2050 in the conservative scenario and 2,635,755 units in the optimistic one (28). An important niche market appears for fuel cells within the frame of the telecommunication applications, specifically in the telecommunication base stations, where 5,000,000 units will be installed by 2020 (29), considering a 50 % fuel cell penetration in an optimistic scenario and a 5 % in the conservative one, 2,500,000 and 250,000 FC telecom base stations will be replaced by 2020. When talking about APU; 13, 996 units are expected to be reached by 2020; 25,436 by 2030; 36,924 by 2040 and 48,412 by 5050 in the conservative scenario and 23,643 by 2020; 65,666 by 2030; 127,525 by 2040 and 208,430 by 2050 in the optimistic scenario (30, 31).

As has been widely described, environmental product legislation plays a crucial and relevant role in order to ferry the fuel cell systems to the mass market. However, it requires a thorough work on both materials during design and end of life management by the stakeholders to ensure that some legal barriers can be overcome or arranged through a thoroughly socio-economic analysis. In addition to EU policy makers is required to perceive the existing difficulties and barriers exist and to incorporate any changes of regulations. In some cases, the restrictive directives may limit the development and commercialization of technology.

The best approach is to create new “Innovation deals” and “working groups” on FCHs involving stakeholders of the sector, policy makers, universities, through which the FCHs providers will present the barriers listed above, presenting some proposals arising from recommendations and leading policy makers to analyse in more detail the new technology.

In end-of-life management, FCHs providers have to focus on waste management strategies stemming from the stack, in order to implement and make easier recycling processes in the short term. This will lead to greater environmental awareness and will allow developing sensitivity to the product. This must be taken into account when starting the product design, following the good eco- design standards.

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