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

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WP6 New business model and implementation roadmap

D6.2 Roadmap for recycling and dismantling strategies and technologies within FCH technologies

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Executive Summary

After explaining in the previous development of the HyTechCycling project the importance and needs, challenges, novel technologies, how the End-of-Life (EoL) affects all the actors involved in the FCH technologies market, and a variety of topics related to the implementation of the circular economy in the FCH technologies, the aim of this document is to present a roadmap of actions that should be taken from the year 2025 to the year 2050, to ensure a proper and efficient End-of-Life.

Starting from the 2025, this document presents a vision of how technologies market will evolve not only from roadmaps but also from industrial perspectives. After, the actions needed from now to the 2030 are presented.

Linked with previous work, the year 2030 has been set as a basis for the re-adaptation for the recycling centres, a key point in some cases as far as the business model developed has presented that the scope may vary from country to country.

Finally, the steps to follow in the definition and creation of a Producers Responsibility Organization (PRO) are explained. The author wants to especial thanks to the people involved in PVCycle, for their invaluable experience and information about the Extended Producer Responsibility and the Producers Responsibility Organizations.

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Abbreviations

AWE	Alkaline Water Electrolyser
ELV	Electric Vehicle
EoL	End-of-Life
EPR	Extended Producer Responsibility
FCH	Fuel Cells and Hydrogen
PEMFC	Polymer Exchange Membrane Fuel Cell
PRO	Producer Responsibility Organisation
SOFC	Solid Oxide Fuel Cell
USD	United States Dollar
WEEE	Waste of Electrical and Electric Equipment

1. Trends for the future

The Fuel Cells and Hydrogen (FCH) technologies market is expected to increase its size hugely. Linked with the objectives of the CO_2 emissions reduction [1], and thanks to it, hydrogen is expected to play a key role in the decarbonisation of the world. This perspective is not only based on the politicians' perspective, but also from the industrial point of view.

The biggest industrial efforts towards the hydrogen economy are represented by the Hydrogen Council, where different stakeholders that believe in hydrogen as a solution are involved. These actors have defined a huge diversity of roles and according to it, the roles where hydrogen will play a major role in the future are [2]:

- 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

From these industrial actors, hydrogen is the best solution towards a more sustainable future. The common vision of the members of the Hydrogen Council is presented in the "Hydrogen, Scaling Up" document [2]. From Hydrogen Council perspective, the hydrogen economy in 2050 will be able to cover the 18% of the final energy demand, saving 6 Gtonnes per year of CO_2 and having a total amount of 2.5 trillions of USD of annual sales.

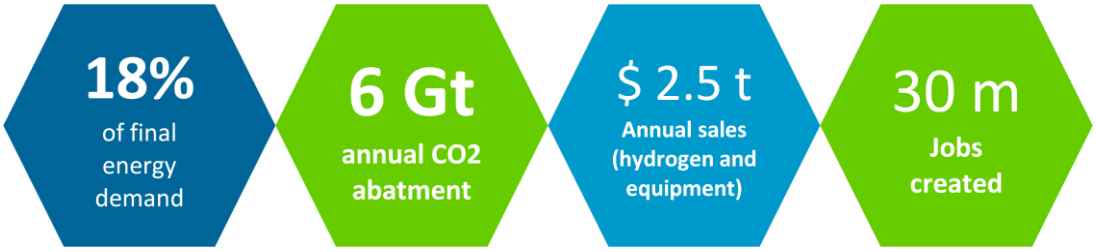

Figure 1. Future perspectives for 2050. Source: Hydrogen Council [2]

Among the different members of the Hydrogen Council, each of them has its own industrial vision. Shell has, in its Sky scenario [3], a scenario towards the emission reduction, and from its perspective, hydrogen will play a major role in the industry and also in the road transport sector.

In this scenario, it is also presented how the hydrogen will play a major role in the decarbonisation of the air transport where hydrogen and synthetic fuels are the best solutions to replace the current fossil fuels for a more sustainable and environmentally friendly solution. [4]

¡Error! No se encuentra el origen de la referencia.2 presents the annual demand of hydrogen and as equivalence, 1 EJ is provided by 7 million tons or 78 billion cubic meters of gaseous hydrogen and it is equivalent to 278 TWh of electricity.

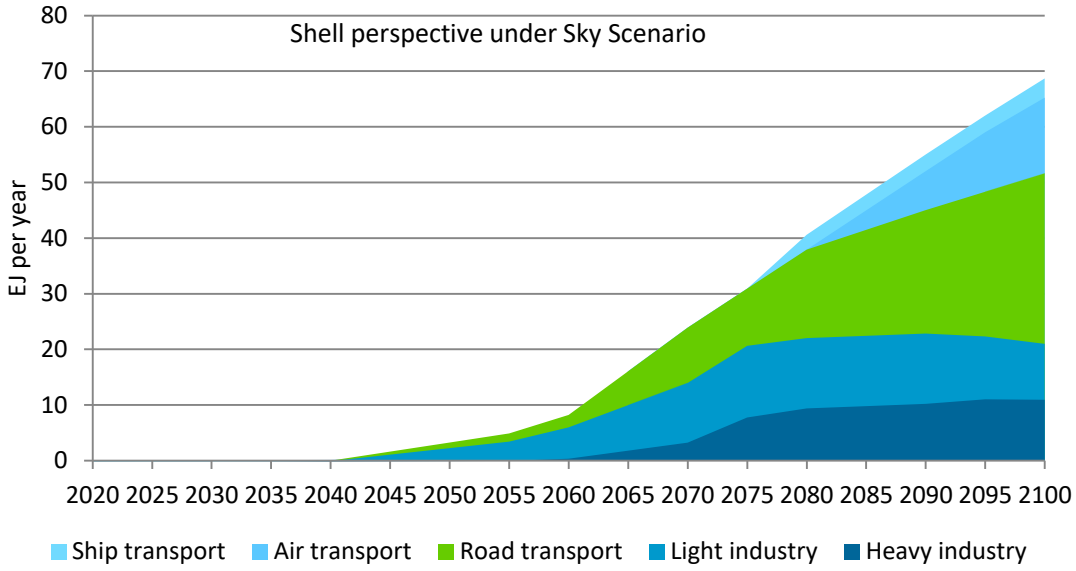

Figure 2. Sky trend for the hydrogen economy. Source: Shell [3]

In addition to this perspective, other actors who are not involved in the Hydrogen Council have also set in their perspectives towards a future where hydrogen will be an active member of the decarbonisation scenarios. As an example, DNV GL sets that hydrogen will grow in those markets whose gas grid can be used for hydrogen; in those market which has significant use of natural gas for heating and whose active fight against CO_2 is well known [5].

Due to it, hydrogen is expected to grow in Europe, North America and also in Asia. This outlook shows that the world hydrogen energy demand will be set as 2.5 EJ per year in 2050. DNV GL at its Energy Transition Outlook [5] has assumed that the hydrogen will be produced by electrolysis from the curtailment from renewable and also linked with hydrogen production with fossil fuel based production as steam methane reforming processes.

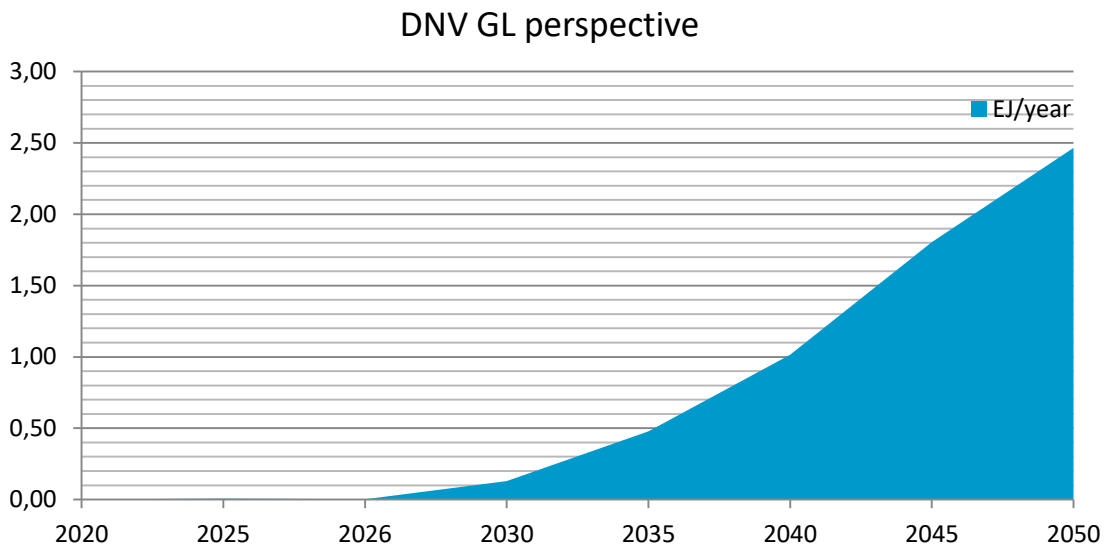

Figure 3. DNV GL perspective for the hydrogen economy. Source: DNV GL [5]

From the European Union perspective, further steps need to be followed to ensure hydrogen growth. Some of them extracted from the Hydrogen Roadmap Europe [6] are:

- Define a clear, realistic, long term and holistic decarbonisation pathways for all sectors and segments in which hydrogen is present.
- Begin to decarbonise the gas grid with forcing mechanisms as feed-in-tariffs.
- Encourage the use of electrolysers in the power system to balance the grid.
- Overcome the chicken-and-egg problems by setting a clear and credible roadmap for the refuelling infrastructure.

Linked with this growth that is expected in the near future, the circular economy should be considered. The more equipment sold, the bigger will be the waste produced. Modularity, replacement of critical materials and new strategies should be followed in order to control the possible concerns that may appear in the future related to this waste.

2. Needs, challenges and how to overcome them. The short term.

Based on previous work of the project [7] specific barriers needs to be overcome in order to promote the proper EoL and circular economy in the FCH technologies. Some of these challenges should be overcome in the short to medium term, as far as they are critical in order to establish a proper EoL. The time frame purposed to achieve a feasible solution for each problem is 2025. An indicative solution that may be neither the optimal nor the final applied one is presented below.

- To develop guidelines for the recycling centres, elaborated by manufacturers and recycling centres, in order to ensure the proper recycling process, with information related to the materials presented, where they are located physically and also safety related issues.

  Recycling centres in its majority have not faced yet the recycling processes of a FCH technology as far as these technologies are quite young in the market scale and have a long expected useful life.

  Recycling centres need information in order to work properly and to achieve its function in the best way possible. The HyTechCycling project has detected a lack of information about the materials, the technologies and the auxiliary equipment presented. Due to it, the recycling centre may face problems.

  A working group where recycling centres and manufacturers are involved may be a good option, in order to raise these questions and to solve all the possible issues that may appear with strategies that fit with all the actors.

- To attract all agents involved in the life of products to ensure that the processes employed are economically feasible in order to facilitate the implementation of FCH technologies and their EoL.

  As an example and after interviews with multiple manufacturers the recovery is not considered as a valuable option nowadays. Investigating how to reintroduce recovered components in the equipment could make economically attractive the promotion of the dismantling.

  Linked with the work performed in this project, the biggest costs from the EoL are related to the logistics and with the recycling process itself. Optimization of both processes is needed in order to achieve an economical EoL.

- To ensure that the processes employed are economically attractive to all agents involved in the life of products in order to facilitate the implementation of FCH technologies and their EoL.

  Regarding the recycling processes, costs as the electricity are critical and the benefits come from the reintroduction of the components in the market, a topic with special constraints as far as the secondary market is volatile.

  Additionally, it is needed to develop processes more efficient from the energy use consumption, as far as the operational cost of the recycling centres depends among other topics of the electricity price.

- To develop proper tracking strategies with the involvement of the manufacturers, integrators and recycling centres, in order to avoid improper recycling processes and the speculation of black markets with some specific materials as platinum.

  The control of the equipment during its EoL is crucial in order to achieve a circular economy. Manufacturer, via its maintenance service or another method, must ensure where its technology is. Moreover, and based on the "polluter-pays-principle", the manufacturer should participate also in the EoL. Specific labels in FCH products with information about the materials or a way that allows to the recycling centre to contact the manufacturer if it receives components that do not know how to recycle are important.

- To develop recycling technologies to recover the maximum amount and type of materials.

  Even if it is true that some technologies have demonstrated its high level in the industry, as the pyro-hydrometallurgical processes, novel processes are believed to be a good option in the recycling of the FCH technologies. Some of these novel processes have been studied in the HyTechCycling project [8] and even if some of them could be an option, there is a need to scale this processes from pilot to process level.

  The benefits of these new recycling processes are not only related to the FCH technologies as far as the materials have in most of the cases a second possible use[1]. Additionally, it has to be considered that they evolve (in some technologies as Polymer Exchange Membrane Fuel Cell (PEMFC) more than in other as Alkaline Water Electrolyser (AWE)) and due to it, their components and materials may change.

  Special attention should be given to the solid oxide technologies, as far as the HyTechCycling project has detected a lack of suitable processes for most of the materials presented in these technologies.

  Research and development of novel technologies, and how to scale up the technologies for high volumes is a key topic to address in order to properly develop the future recycling of the FCH technologies.

[1] In this sense, energetic valorisation is considered as a use. Nevertheless, the HyTechCycling project envisages to looks for closed loops in the recycling chain, or at least in open loops which are needed in components as the ceramics.

- To promote the use of treated waste of FCH technologies by manufacturer companies so that recycling processes can be useful and flow can be generated between these companies and the recycling centres.

  If the recycled material has quality enough, in some cases it could be used for the manufacturing of the raw components for new generation FCH technologies. This loop needs to be optimized, as far as if the recycled material is able to compete against the raw ones in price, the use of recycled materials will decrease unnecessary emissions related with the mining process.

- To boost the participation of end users, by creating guidelines, promoting the importance of the recycling, and creating a direct link between end users, recycling centres and manufacturers.

  The involvement of the end user is also important, and to promote them, this project purposes to inform to the end user about the way to return the waste, or at least provide to the customer with information of a phone number to obtain the information needed.

  Dissemination activities are currently being developed to promote the technologies. Even if this dissemination is hugely important to boost the hydrogen economy, additional dissemination should be performed by the actors involved in the EoL in order to give clear information for end-users and avoid leakages in the reverse logistics chain. It has to be remembered that the end-user is the end and the beginning of the direct and inverse logistics chain, causing that the beginning of the second is mainly related to end-user behaviour.

- To promote the modularity and the reuse of the components in the FCH technologies at the same time that the markets for the secondary raw materials are detected and boosted.

However, and being all these actions needed for the future, the legislation also needs to be adapted to the FCH technologies. Projects as HyLaw[2] have currently identified which are the barriers that should be faced by the legislators in order to promote the hydrogen economies towards Europe. The fields identified here cover broadly all the applications of the FCH technologies as the production, the grid services, transport and also the gas grid legal concerns.

Based on the work performed by this project in its legal analysis, there are some actions that should be performed in the short to medium term to ensure proper development of the FCH technologies and its proper EoL implementation.

Information related to the complete legal recommendations can be found in the previous work of the HyTechCycling project [9] but some of the most important ones are the following ones:

[2] The HyLAW project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 737977. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe Research

- From material selection, regulators should find a way to promote the use of recycled materials in a certain amount. However, this promotion should consider also the quality requirements that these technologies require.

- From EoL perspective FCH technologies do not fall under the scope of a specific directive, so they move among different regulations as Waste of Electrical and Electric Equipment (WEEEs) Directive [10], Batteries Directive [11], Electric Vehicle (ELV) Directive [12] and others. It is required that the FCH technologies regulation becomes more detailed in order to create the proper atmosphere to its market implementation.

- Legislators should also find a way to promote the Extended Producer Responsibility (EPR) in these FCH technologies, in order to ensure that the circular economy will be present in the market.

Linked with all these measures, the technologies will be benefited for the economy of scales as far as the market will exploit. With these revenues, the companies will uptake and ramping up the production, while the process is optimised and the costs are reduced. In Figure 4, it is presented the cost as a function of the year units manufactured for the Solid Oxide Fuel Cell (SOFC) technologies [13], and it is possible to see how the increase of the market will allow producing a cost reduction and will increase the revenues of the companies.

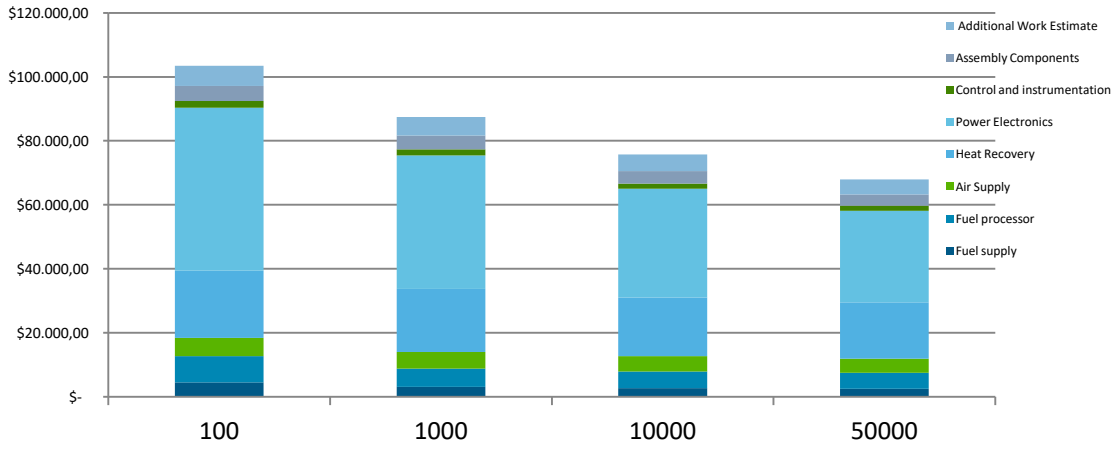

Figure 4. SOFC costs reduction [13]

Finally, recycling centres should readapt in some cases. The *D.6.1 New business model* [14] has demonstrated that the FCH technologies' waste is able to be treated from the national perspective or the European one. Based on the perspectives raised from this source and the D.5.3 *Guidelines on re-adaptation of existing recycling centres* [15], the year 2030 set a basis for the re-adaptation of the recycling centres in the nations which do not have the structure ready and wants to treat internally this waste.

Before 2030, what HyTechCycling purposes are to use the existing recycling centres that are able to cover completely the recycling, or to split it into mechanical treatments as grinding and separation, and chemical treatments as the ones that may replace or work together with pyro-hydrometallurgical processes based companies.

This re-adaptation process may follow different steps, but its first stage should be considering the market in the country. If the recycling centre sees the market as interesting it should plan the introduction of these FCH technologies as waste to recycle. An evaluation should be performed firstly considering:

- **A proper analysis of the materials composition of the FCH technology that will be treated**: With this analysis, equipment needs and procedures to develop may be detected. This information should be performed in the same way that the protocols explained previously. Additionally, linked with the national focus, the technology that will grow may be different, and thus the recycling needs also may differ from one situation to another.

- **Market study:** This market study will focus not only on the input of new materials to recycle but also on how to sell the recycled raw materials that may appear. Future applications, current replacing applications or even the reintroduction in closed loops must be studied and evaluate as far as has D6.1 [14] demonstrates, the recycling process and the revenues of it are the higher importance economic force that may push the FCH recycling.

- **Cost study**: The investment needed and also the operational costs should be evaluated in order to assess how the recycling centre is going to face the re-adaptation.

With all the information raised for the evaluation, if a recycling centre aims to be re-adapted from the mechanical treatments to cover the new technology, the permissions must be obtained. Permissions will require a detailed analysis per country to assess the delays and the costs that the recycling centre will need to wait, but this time may be productive if the recycling centre uses it to contact with manufacturers and start to create agreements with them.

After all the process, the recycling centre re-adapted will start its new activity and benefit for it.

3. Roadmap for the introduction of an Extended Producer Responsibility (EPR) system in 2050. Long term

Assuming the trend in the market that all the different scenarios presented, it is easy to see that the market volume will increase at a higher speed after 2050. As has been explained previously, the more the market grows, the more important the recycling needs will become. There is no need on reinventing the wheel so the use of currently existing structures that have demonstrated their operation should be considered.

Due to the huge amount of materials that will be recycled in the future, and based on the EPR strategies, a reasonable option to manage all the waste streams is the creation of a Producer Responsibility Organization [16]. The Producer Responsibility Organization (PRO) will be the organism that will manage all the waste and ensure that the objectives are achieved.

The process to set the PRO will be longer than it is presented in this document.This PRO will be a representation of all the actors and will help to optimize all the fluxes.

During the first year of the EPR definition and creation, there are four different working groups that should be created and thus, all the different points of view are covered. The frame idea here is to split the meetings among the time, having time enough to evaluate all the possible concerns.

The groups will be:

- **General group**: Basically is based on manufacturers and distributors. In this meeting, a key point to set the proper objective is to clarify that the efficiency or the technical benefits or one technology against the others is a topic without importance. The importance of this business model resides in the materials that the technologies have, and the possible synergies that they have.

- **Collection group**: Group whose aim is the definition of the proper collection strategy. Municipalities for small scale groups and even industry tranportists should be invited in order to motivate the proper strategy and to reduce to the minimum exponent the costs related to it.

- **Recycling group:** This group should be based on recycling centres, where all the different technologies could be managed. It is a proposition of the HyTechCycling project that not only WEEEs recycling centres but also batteries centres take part in this group. The recycling centre could be helpful to set the recycling objectives, split the technologies among the centres, and evaluate which are the solutions that each material needs in order to close the recycling chain.

- **Funding group:** The last group that should meet, and also one of the most critical under the business model perspective. The funding group will set if the recycling costs should be covered at the selling moment, or if the costs should be paid in the future when the technology arrives at its EoL, among other topics.

It is important to set a realistic target during the first steps of the EPR strategy creation. Ambitious targets will be difficult to achieve and without the proper evolution and tracking, the results will be far away from

the planned ones. The recycling target, as an example, should evolve from a small value to a bigger one yearly, in order to correct the possible failures that appear.

The proposition here is to start with the creation of the PRO from the perspective of the manufacturers with the technologies with a higher amount of kilograms in the market, and testing with them firstly. The model could be replicable if it works then by other technologies whose market share is smaller.

Finally, the scope of the PRO presented here should be European. The market shares among the different countries will differ hugely even in 2050, as far as the introduction of FCH technologies in some countries will be still low. Due to it, a general system should be promoted, and from that system, which ensures the basic management, a divisional structure could be created in the countries with a higher amount of recycled equipment.

4. Conclusions

The future must become greener and greener if the society expects to leave a better world for future generations. This movement should be promoted with technologies like hydrogen, which is a key component for the future playing a role in the balance of the grids, as an industrial feedstock and is a way to promote a real and efficient decarbonisation of the transport sector.

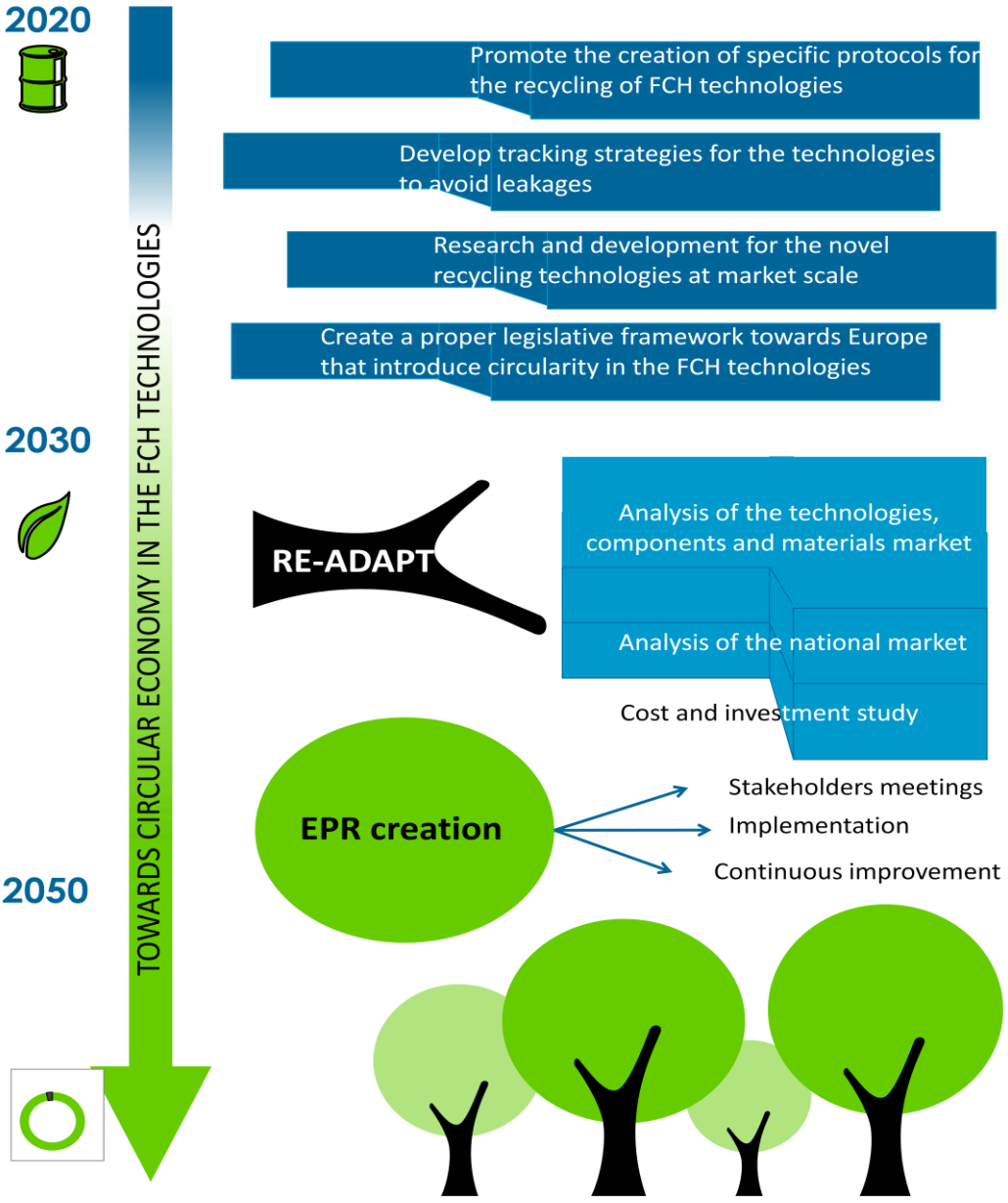

Figure 5. Towards circular economy in the FCH technologies roadmap.

The trend towards a hydrogen economy in the medium to long term is present in most of the predictions towards a sustainable future, but in order to ensure this future, legislators and industry should work together in order to promote the FCH technologies and to facilitate the market introduction.

In the short term, some barriers in the field of the regulation of the EoL, the recycling strategies and the recycling centres should be overcome. For the future, where the volume of FCH technologies will be higher, the PRO creation, the adaptation of the recycling centres and the changes in the technology related with materials will be a key point in order to ensure that a future with a huge implementation of the technologies will be sustainable.

The sustainability of the technologies, linked with its sustainable use, led the path for a greener future.

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