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

Grant No. 700190

WP5 Harmonization of procedures considering all actors involved in lifetime of FCH products

D5.2 Report on feedback to new technologies and strategies and focus on new business model from FCH actors

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Executive Summary

This document, which is presented as deliverable 5.2 'Report on feedback to new technologies and strategies and focus on new business model from FCH actors', is part of HyTechCycling project, provides a second analyse on the needs and worries of the different FCH actors in life time of FCH products, validation and approval of WP3 results with focus on Business model and to collect information on re-adaptation of recycling centres for implementation of new strategies and technologies.

It is necessary in fact to underline that despite the Fuel Cells and Hydrogen (FCH) technologies are on the brick of having an important growth worldwide, there are still many obstacles that prevent a large commercialization of FCH. As underlined in previous reports and deliverables, principal obstacles are the lack of specific regulations, the recycling and dismantling stage, the lack of information on FCH technologies and their important potential market.

Continuous involvements of all FCH actors: from the industry manufacturer to the recycling centres, through the distributors and end-users allow to overcome these barriers and from their comparison allows the optimization and implementation of procedures related to the FCH end of life.

The second trip useful to collect feedback on new technologies and strategies and focus of new business model was done in the form of questionnaires - the document reports the main results from FCH manufacturers, recycling centres and end users – and through a Workshop organized in Mostoles, Madrid, at IMDEA ENERGY headquarter.

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Abbreviations

AB	Advisory Board
AD	Alcohol dissolution
AFC	Alkaline fuel cell
AP	Acid process
AWE	Alkaline Water Electrolyser
BoP	Balance of Plant
CHP	Combined heat and power generation
DMFC	Direct methanol fuel cell
EFCF	European Fuel Cell Forum
EoL	End-of-Life
EU	European Union
FC	Fuel Cell
FCH	Fuel Cell and Hydrogen
FCH-JU	Fuel Cell and Hydrogen Join Undertaking
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
MCFC	Molten carbonate fuel cell
MEA	Membrane Electrode Assembly
MR	Manufacturer/recovery center
OeM	original equipment manufacturer
PAFC	Phosphoric acid fuel cells
PCB	printed circuit boards
PEM	Polymer Electrolyte Membrane
PEMEC	Polymer Electrolyte Membrane Electrolyser Cell
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PEMWE	Polymer Electrolyte Membrane Water Electrolyser
PGM	platinum group metals
RC	Recylicng Center
REE	Rear Earth Elements
SED	selective electrochemical dissolution
SOEC	Solid Oxide electrolyte Fuel Cell
SOFC	Solid Oxide Fuel Cell
TD	transient dissolution

1. Introduction

The following deliverable report a second analysis of FCH actors' needs and worries concerning end-of-life, with a deep analysis on new recycling aspects related to FCHs. The previous deliverable D 5.1 Report on requirements from FCH actors[i] is the starting point for this second report. In order to collect additional information from the main actors a second round of questionnaires was launched.

The first surveys were proposed to the actors during the first period of the project.
The questionnaires were divided in different part as illustrated in Figure 1:

- general information for all- such as the location of the company, the number of employee and the main activity;
- regulation topic common to all actors: indeed, even at different scales, all actors need to obey regulations whether they are European or national;
- questions about the product, the Life Cycle Assessment (LCA), and the eco-design complete the survey intended to industrial manufacturers;
- general concerns and opinion about reverse logistics for distributors and logistics companies;
- concerns on end-of-life strategy for end users;
- questions focused on FCH recycling technologies and strategies for recycling centres..

Figure 1. First questions categories for each actor.

The second surveys, useful to identify their requirements and concerns, were spread among the actors of different stages of FCH products (manufacture, distribution, use and recycling). Moreover, the preliminary data and results collected during the two years of HyTechCycling project were presented during the second workshop in March 2018 (20th March 2018 at IMDEA ENERGY headquarter) with the involvement of the main FCHs actors.

This study and the workshop aim mainly to have a second outlook of needs from FCH actors and to prepare a document with requirements, inputs and preferences in new technologies and strategies with focus on business model. For these purposes, a second questionnaire for each FCH actors' category has been established (see Annex I, II, III attached). Indeed, each category has specific worries and needs depending on their main activity and their market position. Thus, the survey has been diffused among the Advisory Board (AB) and other stakeholder' contacts. The objective is to obtain a wide scope of answers that covers all the FCH technologies considered in the study and all the FCH technologies' uses as regards the end-users.

2. Survey definition

The keys to collect information on FCH technologies recycling and dismantling needs include distinguishing the different categories of actors. Indeed, in lifetime of FCH products, four categories of actors have been considered by the beginning of the activities:

- The industrial fuel cells and electrolysers manufacturers.
- The authorized distributors and logistics companies.
- The end-users of FCH technologies -who are customers of manufacturers-
- The recycling centres.

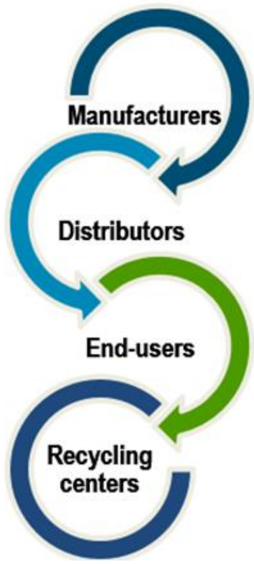

Figure 2. The four FCH actors considered in lifetime of FCH products.

For each questionnaire, a draft has been completed and approved by the other partners. Following the approval, the questionnaires were adapted to a Google Form format. The surveys were first sent by email to all stakeholders contacts and then direct calls were performed.

2.1 Survey premises

During the two years of the project, specific deliverables are produced and some results from them are used to analyse the needs of FCHs stakeholders, their approach on end-of-life and their approach on a EoL new business model.

The Deliverable 3.1[ii] on new end-of-life (EoL) technologies applicable to fuel cells and hydrogen (FCH) products, describes different types of novel methods applicable to the key FCH products (viz., proton exchange membrane fuel cells/water electrolysers, alkaline water electrolysers, and solid oxide fuel cells) for the recovery of key materials in more efficient, safer and potentially cheaper ways than conventional existing EoL technologies. Novel technologies are found to be mainly applicable to the recovery of precious metals used in the stacks as catalysts. Regarding balance-of plant (BoP) components, novel technologies focus on the recovery of valuable materials from printed circuit boards (PCBs). The identification of the novel EoL technologies, combined with the existing ones, leads to provide an overview of technology-oriented EoL strategies applicable to FCH systems for the recovery of critical materials. Novel EoL technologies for FCH stack materials are mainly oriented towards the recovery of precious metals. When compared to conventional EoL technologies, the main advantages associated with the reviewed emerging technologies are related to the possibility of recovering more than one valuable product (ionomer or carbon support for PEM-based systems) in addition to the precious metals.

A number of novel technologies are currently valid alternative for Pt and PEMFCs material recovery:

- Selective electrochemical dissolution (SED) for Pt and C support recovery;
- Transient dissolution through potential alteration (TD) for Pt recovery;
- Acid process (AP) and alcohol dissolution (AD) for nafion and Pt recovery

When compared to conventional EoL technologies such as pyro-metallurgical processes, transient dissolution (TD) generally shows a more favorable profile with relevant advantages in terms of versatility and economic performance. Selective electrochemical dissolution (SED) and Alcohol dissolution (AD) could also be considered promising EoL technologies, but their application is highly conditioned by the actual commercial deployment of PEM devices.

Furthermore, novel technologies are usually linked to enhanced technical performances (e.g., in terms of process duration), improved economic and environmental performances (thanks to the lower amount of energy required), and safer working conditions (thanks to mild operating conditions in terms of temperature, pH and voltage, as well as to the use of non-hazardous reactants).

Regarding BoP components, novel technologies are found to be applicable mainly to PCBs, which are rich in high-value metals and for which current recovery practices lead to significant environmental concerns. Although several emerging technologies could be applied, further research is still needed due to the low level of industrialization. In general, the main trend for BoP components is oriented towards the reuse of components such as pumps, blowers, compressors, etc.

The Deliverable 3.2[iii] has identified comprehensive strategies for EoL of FCH product in order to favour the deployment in relation to EU regulatory framework. The document reports a precise identification of the main actors involved in the FCHs supply chain and their role linked with three different scenarios: short, mid and long term for market deployment.

The role played by each of the actors is highly influenced by the development of the FCH market.

In the short term, FCH applications are expected to remain limited to a niche market. It is assumed that the importance of the hydrogen is expected to grow in the future across many sectors, such as industry, energy, transport, and residential ones.

The role of FCHs manufacturers, waste manager and end users is crucial. The manufacturer is involved in the production, in the trade and in the maintenance of the product.

In the mid-term horizon, a growth of the market and a higher number of FCH users is expected. Despite this growth, as usual for novel energy technologies, in the mid term the market volume would only be partly settled (with a wider deployment expected in the long term). In this scenario, the role of specialized recovery centers in the EoL phase is fundamental to boost and support the deployment of hydrogen technologies. In the mid-term horizon, the EoL of FCH devices would represent a new business for companies and would be likely stimulated by a growing economic relevance of FCH products.

In the long term scenario, with a high market volume, a higher number of transport of devices should be expected, thus requiring logistic optimization. In this sense, reverse logistics might be applied and could be convenient the FCH manufacturer with a dual role, recovery center and distributor. The multiple role of a single actor would mean a higher control of the company over the products' life cycle, facilitating a complete optimization of the supply chain.

However, the Eco-design Directive is identified as a key strategies to take in consideration during the design phase.

2.2 Survey structure

Each questionnaire is divided in several parts depending on the category of FCH actors it concerns. Refer to the appendix for the entire questionnaires. Why should the FCH actor spend time answering these questions? He needs to feel concern by the questionnaire. For this purpose, a general presentation of the issue -short but targeted- is given.

"***Fuel cell and hydrogen technologies are on the brick of having an important growth worldwide for they offer low level of emissions, high conversion efficiency, flexibility and silent operation. In Japan, FCE Vehicles have already conquered the mass market and it is spreading to Korea, China, Germany and the USA. Nevertheless, it remains some points that need clarifications that the European HyTechCycling project aims to bring to light. New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling are being developed to help face the issues of End-of-Life FCH technologies. As a result, by filling this present questionnaire, you can contribute in these advances."***

Figure 3. Introduction of the questionnaire.

Then for each category, specific questions have been developed. Nevertheless, they were mainly referring to the same section. As a result, the second questionnaires were divided in different part as illustrated in Figure 5. First, general information are required for all- such as the location of the company, the number of employee and the main activity.

Questions about the product are mainly related to industrial manufacturers:

- Power range of FCHs produced
- Logistic companies information to truck devices to end users
- Distributors used for selling the products
- Customers/end users categories

Questions about new EoL strategies identified in D3.2 are mainly related to the FCHs actors: industrial manufacturers, recycling centres and end users; questions on Eco-design new strategies are linked to the manufacturers work-design.

Furthermore, in the aim of dissemination and catching the actors' interest, the existence of the main public deliverables and the date of the Second Hytechcycling Workshop, were communicated through the questionnaires.

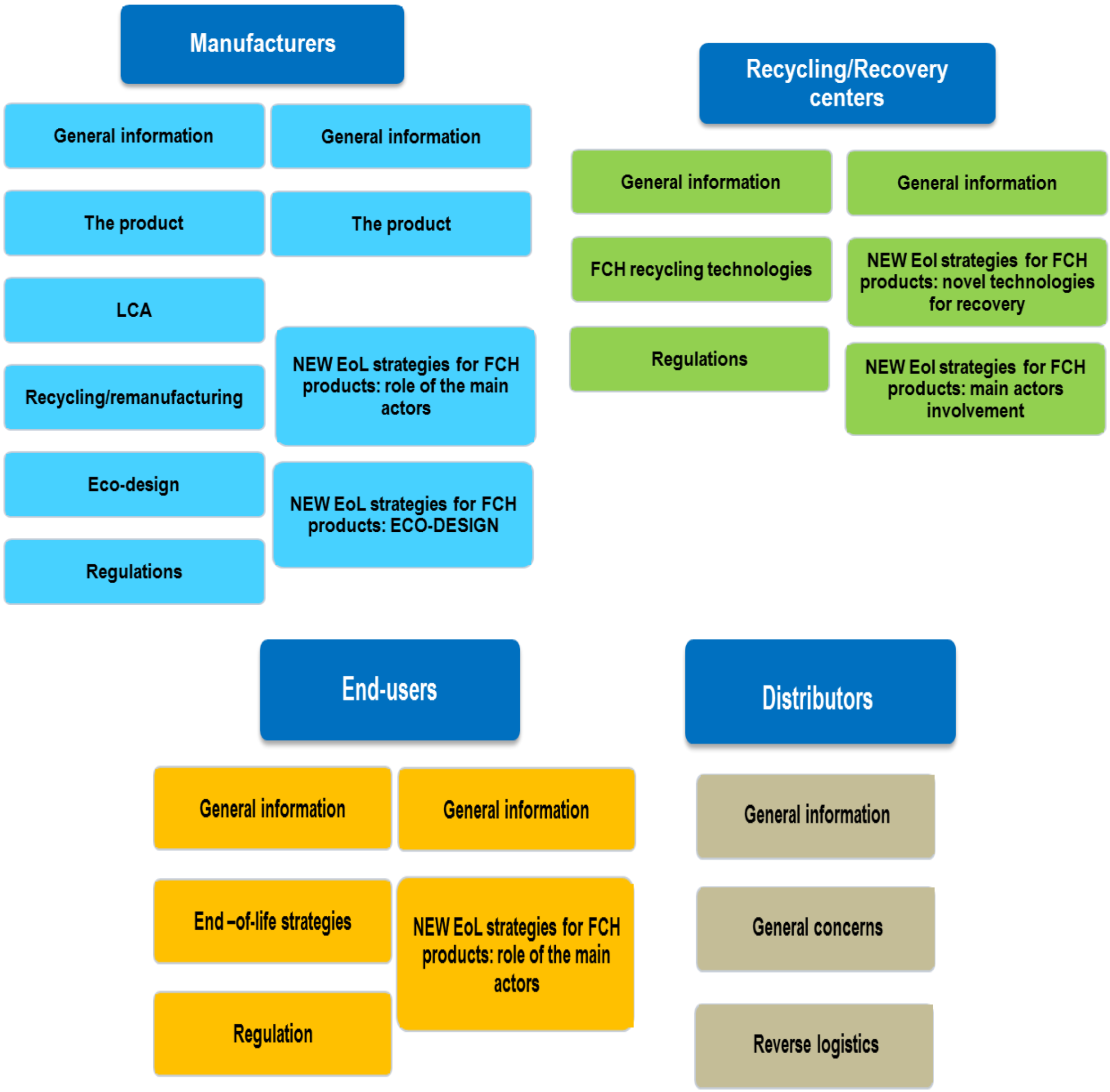

Figure 4. Questions categories for each actor (first and second questionnaires).

2.3 Survey target

The persons contacted for this survey members of the AB, and from the main stakeholders of the sector. The stakeholders list has been spread to all the partners in order to complete the list and continuously implemented with new contacts. As a result, the actors reached are from a wide range of European countries and they differ in their main activity. For these reasons, the results of the questionnaire are more relevant.

During the first trip of surveys among **63 companies** were contacted and increased to **75 companies** during the second trip. 54% of them were manufacturers, 24% were recycling centers, 16% end-users and 6% companies considered as other. The latter are mainly associations or organizations, directly or indirectly involved in Hydrogen Technologies and recycling -such as EFCF the European Fuel Cell Forum- through which it was possible to access to a broader network of manufacturers, recycling centers, end-users and distributors.

Figure 5. Distribution of FCH actors considered in the survey.

Different FCH actors, located in different countries, have been reached for the survey, Countries across the European continent have different national regulations that are important to be aware of to implement a good harmonization of regulations.

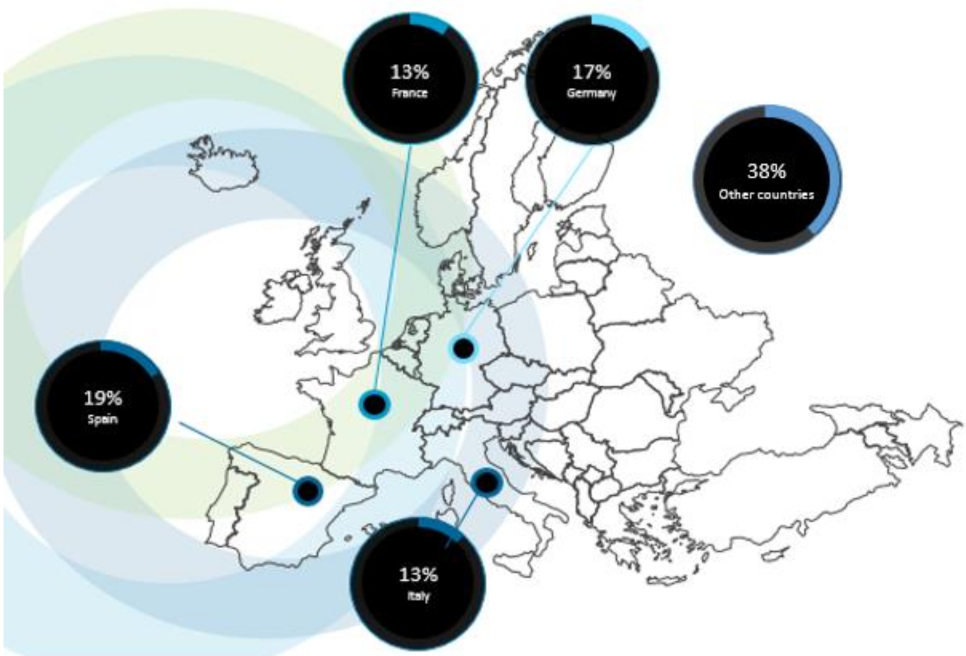

Figure 6. Geographical distribution of FCH actors considered in the survey.

Figure 6 gives the distribution of these actors depending on their country. As a result, it appears that the country more contacted during the survey is Spain -with 12 companies- followed closely by Germany, Italy and France with respectively 11, 8 and 8 companies. Thus, it may underline an uneven level of involvement among the European countries in the FCH technology development and their recycling and recovery. The important number of Spanish partners in this project also explains the high rate of Spanish companies.

3 Survey results

The survey covered main of FCH actors, and mostly companies near to the market concerning manufacturers. The data analyzed in this report was principally compiled from a Google Form platform and then treated on Excel.

Among **63 stakeholders** were contacted with the first round surveys -whether it is by e-mail and/or by phone-, 20 answered the questionnaire: 9 of them were FCHs manufacturers, 6 recycling centers and 5 end users. The end-users contacted until now are Energy Utilities, also involved in European Project.

Among **75 stakeholders** were contacted with the second round surveys -whether it is by e-mail and/or by phone-, 22 answered the questionnaire: 12 of them were FCHs manufacturers, 5 recycling centers and 5 end users. The end-users were contacted directly by AB manufacturers.

3.1 Manufacturers

Almost all the manufacturers who responded to the survey in the first round responded to the second, in addition to 5 new companies.

The questionnaire was divided into four topics (see Annex I_Survey for Manufacturers):

- General information.
- The product.
- New EoL strategies for FCH products: role of the main actors.
- New EoL strategies for FCH products: eco-design.

3.1.1 General information

This section aims to collect global information such as the name of the company, the location, the main activity and the number of employee. The objective was to reach at least one manufacturer per sector considered:

- PEMFC
- DMFC
- AFC
- PAFC
- MCFC
- SOFC
- AWE
- PEMWE
- SOEC

From all of them, 5 manufacturers are PEMFC developers, 2 are PEMFCs integrators, 2 are involved in SOFC development, 1 is involved in SOFC/SOEC assembling and integrations, and respectively 1 manufacturer develop AWE, 1 develop both PEMWE and AWE.

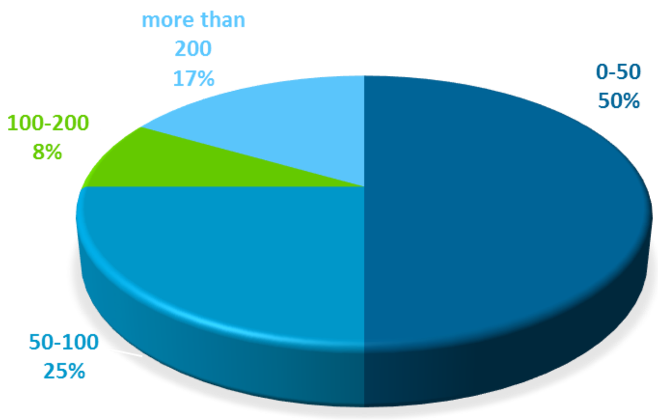

Figure 7. Manufacturers' enterprise dimension, number of employees: a) 0-50; b) 50-100; c) 10-200; d) more than 200.

3.1.2 The Product: Information about the technology produced

The main objective is to collect information on the technologies manufactured and so specific details on: typical power range of the product developed, logistic companies' information to truck devices to end users, distributors used for selling the products, customers/end users categories.

Product power range

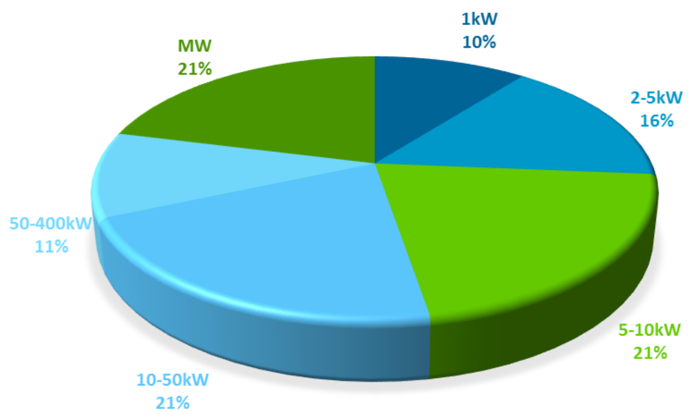

Figure 8. Manufacturers' product power range

Logistic companies and distributors information

60% of interviewed use logistics companies to truck devices to end users, mainly standard logistic companies as UPS and DHL.

80% sell directly the product without distributors. The distributors are mainly installation companies. Only one of them use distributors in out-of-EU States (China, India…). "*In our case it is very special as due to the size of the projects, there are no distributors. Take in mind that we deliver MWs electrolyzer plants which is not a final product to be distributed but it is a broad project depending in case by case due to the final application. Due to the limited market until now, we manage the projects by ourselves*".

Customers/end-users information

End users can be classified: 33% Energy Utilities; 25% automotive companies; 17% chemical industries; 8% telecommunication companies and mainly are system integrators, installation companies, gas supplier, OeM.

It was possible to have the activity sector of the end users but not their direct contacts, because they turn out to be confidential. "*Regarding the customers, we cannot give you details or names, but they are located mainly in the chemical industry (food, oil, hydrogenation fats, etc), refineries and steel industry more recently*".

3.2 Recycling centers

The new questionnaire was divided into 3 topics (see Annex II_Survey for recycling centers):

- General information.
- New Eol strategies for FCH products: novel technologies for recovery.
- New Eol strategies for FCH products: role of the main actors.

3.2.1 General information

The table below reports the five European recycling centers and one association that have answered the questionnaire, their main activities, location and the dimension (also figure 10):

Location	Main Activity	Number of employee
Spain	Industrial waste	50-100
Germany	Precious metal recycling	100-200
Spain	Spent batteries management and treatment	0-50
Switzerland	Industrial waste Plastic waste	0-50
Belgium	Electronic devices Industrial waste Automotive catalysts, industrial catalysts	200

Table 1. Recycling centres involved in the questionnaire.

3.2.2 New EoL strategies for FCH products: novel technologies for recovery

The starting points are the information collected during the first survey and during the 1st Workshop in Brussel (26th of September 2017) about the knowledge on hydrogen technologies. The proposed questions were useful in order to see if Recycling Centers (RCs) have the suitable technology for the FCH recovery at end of life, if there is interest and therefore also the willingness to invest on FCHs recycling and recovery, if there is a particular reluctance to deal with FCH end-of-life systems.

Mainly four RCs have already treated with FCHs, it has been asked which FCHs' type they have worked, from which manufacturers, what processes have been followed and whether specific difficulties have been experienced.

In addition, as many recycling centers are concerned with the recovery of precious metal from automobile sector, it is also possible to understand what are the quantities limit of Pt per cells economically advantageous in order to recover Platinum.

The first survey analysis improved with the second reports:

- 50% of the Recycling Centers (RC) have the technology required for FCH's recovery.
- Whereas, 66% has pyro-hydrometallurgical and 34% hydrometallurgical processes.
- 60% think about investing in technology for recycling FCH.
- Whereas, for the other 40%, it will depend on the market potential and the method employed.
- 84% of RC questioned have no reluctance in treating any material that composed FCH technologies.
- 40% thinks that the components should be distributed between specialized centers.

According to the RC questioned, the costs, the amount of material to treat in order to reach a sufficient plant size for profitability and the lack of logistics in place nowadays are factors that could prevent the recycling of FCH technologies. The cost for the treatment compare to the materials' value inside is one barrier for recycling FCH technologies. However, finding out another second application able to deal with whole or part of FCHs equipment could be one way for preventing the recycling.

Only one RC has already treated FCH technologies for a PEMFC manufacturer and it did not face any specific difficulty, with integrated smelting-refining.

As reported in section 2.1, the two previous deliverables D 2.2 Existing end-of-life technologies applicable to FCH products[iv] and D 3.1 New end-of-life technologies applicable to FCH products report detail on processes conventionally used to recover materials present also in a FCH system and novel technologies.
As also emerged from the interviews, current EoL strategies for PEMFCs, PEMWEs, AWEs and SOFCs are focused mainly on hydrometallurgical and pyrometallurgical recovery of precious metals used in the stacks as catalysts for the conversion process. Regarding BoP components, the literature also considers further recovery of valuable materials, such as metals and polymers for which mature recycling technologies are available. To face effectively the challenge of cost-competitiveness for the establishment of hydrogen economy, a full EoL strategy to reduce the costs of FCH devices is needed. However, there is a current lack of complete ecodesign and EoL strategies addressing exhaustively these FCH devices, which should include the recycling of valuable materials as well as reuse (or alternative use) options.

The Hytechcycling project has so detected some novel technologies for recovering PEMFC and PEMWE stack's critical materials. These novel technologies are mainly related to the possibility of recovery more than one valuable product of stacks and the precious metals: 60% of RCs interviewed is interesting in investing on them, but they need more information.

The main aspects to take in consideration with new implementations of existing plants/re-adaptation are:

- For new recycling processes implementation you have to obtain a new authorization
- Long time to receive authorization
- Main re-adaptations: For the recycling of this waste we should invest in new equipment, facilities and machinery / staff training

So the main problems that will incur with new recycling processes implementation are mainly linked with the bureaucratic aspects, request of authorization and who to submit, it depends on the type of residue that must be treated and it is strictly connected with the legislation that is not currently specific to fuel cell systems.
The first problem therefore is not technological but administrative and legislative.

Furthermore, the residue must be mapped and its identification unified in all member states. The non-correct identification of the type of waste, in this case also connected by a suitability of suitable legislation, can lengthen the time required for obtaining the authorization.
Similar residues can be treated according to different processes, so the correct identification is fundamental.

Once permission has been obtained, the recycler must then economically evaluate the optimal process and if it is possible to implement it with the existing one.

Furthermore, after having treated an end-of-life product, the important aspect is the percentage of the residual derived from the treatment and how efficient and productive it is for the recycler. This aspect must be very clear to the producer, since the product and so the product's residue is the extended responsibility of the producer and define how much can be recovered by a product.

3.3 End-users

The new questionnaire was divided into two topics (see Annex III_Survey for end users):

- General information.
- New EoI strategies for FCH products: role of the main actors.

3.3.1 General information

13 FCH end-users were contacted for the first survey; 7 of them agreed to answer the questionnaire. Table 2 gives a description of their location, number of employees and activities. In the second survey's trip, with the support of AB and manufactures, 5 end users were contacted, they cover all the technologies identified in Hytechcycling project (Table 3).

Location	Main Activity	Number of employees
Germany	Energy: combined heat and power generation (CHP)	0-50
Switzerland	Energy: CHP	
Denmark	Energy: Renewables (mainly wind)	200
Denmark	Transport Energy: CHP	0-50
France	Transport Industries Energy: CHP and injecting H in gas grid	200
France	Transport Energy: CHP and injecting H in gas grid	100-200
Germany	Energy: CHP	100-200

Table 2. End-users who answered the first questionnaire.

Location	Main Activity	Number of employees	customer of
Italy	Energy: CHP	0-50	SOFC producer
Croatia	Transport Energy: CHP and injecting H in gas grid	more than 200	PEMWE producer
Italy	other: sport facilities management	0-50	SOFC producer
The Netherland	other	0-50	PEMFC producer
Germany	chemical industries	more than 200	AWE producer

Table 3. End-users who answered the second questionnaire.

The way to collect end-of-life FCH technologies is important as regards logistics issues.

67% of end-users interviewed have starting to analyze end-of-life of the products, but they consider essential to analyze the extent to which system lifetime (max. linked to stack lifetime) is profitable, in order to have a good estimation of the minimum quantity of platinum per cell to reach rent-ability. Here above the explanation given to this statement:

"1. We are currently manufacturing in small volumes and plan a significant increase in the next years. If we achieve the planned 40 000 h stack lifetime and planned 15 years system lifetime, reuse does currently not make sense, because recycled components will always be < 10 % of totally produced volume.

2. We expect significant changes and improvements in the next 5 years in our technology. Therefore, a stack will at its EoL (i.e. after 40 000 h) be of a very status of technology and no one would like to buy a refurbished stack such an old version anymore. It's like a recycled mobile phone or television after 5 years. Therefore, one would have to go via the raw materials, where the suppliers say, that it does not make sense for them yet, as the raw materials are abundant and cheap and volumes are small, yet."

This statement raises numerous issues:

- The economic viability of FCH recycling and dismantling.
- The use of critical materials.

The other expectation as regards end-of-life deals with the recovery of precious metal from the product that is then recycled into a new product: "*Recycling of precious metals like Pt is an important factor to keep the cost low and guarantee availability when lager volumes are being sold. Furthermore the product itself needs to be designed in a way that a proper recycling of all material is provided for*".

The logistics behind such a process for the industry (e.g. critical volumes) is certainly key to the success of a recycling strategy.

25% of end users interviewed in the second trip, have already FCHs at end of life stage and return it to manufacturers, with specific agreements with manufacturers.

80% of end users interviewed in the second trip, think return to manufacturer is the best and more profitable way. ERP system can be the best practical means for improving these problematic recycling systems and avoiding the aforementioned problems. Producers must take responsibility for recycling their goods after the life cycle, either by direct recycling of their own waste or by subsidizing the resource recycling system.

"End users should not think about the recycling network and how it works. End users should pay an all inclusive fee (both O&M and recycling).It means customer loyalty and the end user will not cause any problem".

"The role of end users is to choose their favorite heating system among the market's products. In order to do so, the product should be inexpensive and in case of a tie, it should emit as less particulate matter as possible. Firstly the price, secondly the emissions. In order to boost their active participation, banks should allow them to apply for loans (white list) for a number of years close to product lifetime. If the amount of energy saving is greater than the amount of costs (loan instalments, fuel costs, other), end users will be more than happy to share their good deal with other close people".

3.4 Distributors and logistics companies

As reported in the previous chapters, 60% of interviewed manufacturers use logistics companies to truck devices to end users, mainly standard logistic companies as UPS and DHL.
80% sell directly the product without distributors.
As also detected mainly along the new EoL strategies, the crucial actors involved in the short and mid-term supply chain of the FCHs are the manufacturers, responsible also in the trade of the systems, the recycling centers and end- users.
In a long term scenario, with a high market number, a higher number of transport of devices should expected, so it is needed a good optimization of distribution and logistics.
For this reasons, it was difficult to find responce from distributors and logistic companies.

3.5 New end of life strategies for FCH products

The definition of comprehensive strategies for the EoL of FCH products is pursued in order to favor their deployment in accordance with the EU regulatory framework. The main actors involved in the supply chain of FCH products are identified and their roles are defined in D3.2[1]. Subsequently, new strategies applicable to the EoL of FCH products are classified on the basis of the role that the actors may play in short-, mid- and long-term scenarios of the FCH market deployment. Strategies applicable at the design stage are also presented taking into account the Eco-design directive. As a key eco-design strategy, the potential reduction or replacement of critical materials is addressed for the different components of the devices addressed in the HyTechCycling project (i.e., PEMFCs, PEMWEs, AWEs, and SOFCs).

3.5.1 Role of the main actors involved in FCHs EoL

As reported in the section 2.1, Hytechcycling project has detected the role of the main actors linked with different scenarios.
In the short term scenario, Hytechcycling project has identified the role of FCHs manufacturers, waste manager and end users as crucial.
In the mid-term scenario, Hytechcycling project has identified the role of FCHs manufacturers, end users and recycling centers as crucial.

60% of FCHs manufacturers have already signed with the actors mentioned, in order to have profit for the Company:

- refund system for old systems is already in planning, contracts to PGM recycler
- platinum recycling agreement
- specifics agreement depending on the wastes
- they are include in the selling contract
- providing a discount on new materials if the older are returned.

RCs are interested in specific agreements with manufacturers, mainly frame Agreement for end-of-life FCH:

"The agreements between manufacturers and recyclers favor the correct management of the waste, enabling the amortization of investments to implement new treatments in a longer term. In addition, they stabilize cash flows by improving the economic returns of these businesses".

End users are interested in specific agreements with RCs and manufacturers.

- 40% evaluate the transport of old devices payed by manufacturer or recycling center economically advantages
- 60% evaluate economically advantages to pay directly the transport of old devices but with economic incentives: example a reduced price for a new or remanufactured device through agreements.

In the long term scenario Hytechcycling project has detected the manufacturer with a dual role: manufacturer and FCH recovery center (MR).

The manufactures agree it could be a business in the future, but not before two-five years.

- In the long run it will not only be profitable, but also necessary to recycle the expensive materials such as titanium, platinum and iridium. With the limited availability and high cost, FCH recovery will either become part of the manufacturer's business or the gap will be filled by dedicated companies.
- Nowadays the material recovery plays an important role and they expect the same also in future.
- At EoL they refund old stacks/systems and recycle them. Old MEAs will be sent to a PGM recycler. Other metals will be separated internally and recycled.

3.5.2 Eco-design

The Eco-design Directive is a framework directive that helps EU to achieve the 20-20-20 targets. The Eco-design Directive applies to energy-related products with a sales volume above 200,000 units per year through the internal European market. The eco-design is an important field in the study of end-of-life. Indeed, eco-design aspects must be taken into account for FCH technologies to be optimally recycled and disassembled. It must be taken into account in the total FCH technologies lifecycle. Among the manufacturers interviewed only 33% take into account the aspects of the directive, mainly because the volume is much less than 200,000 units/year.

The Eco-design Directive specifies the main parameters that must be considered to improve the environmental aspects when designing a product. In particular, when selecting materials, it must be considered:

i. Critical and hazardous materials

First, the material choice is a burning issue. FCH technologies require some critical and hazardous material.
According to the manufacturers questioned:
□ 83% of them have reduced the quantity of hazardous materials.
□ 30% of them have reduced the quantity by 30%.
□ the remaining part has inserted it as an objective for the next years

ii. Reduction in weight and volume of the product

The achievement of the adequate properties by using better construction techniques (at the material supplier level) should be prioritized over oversizing the component (at the component manufacturing level).
□ 34% of FCHs manufacturers can reduce of 30% of the total FCHs weight (and more)
□ 66% of FCHs manufacturers can reduce it between 10-20%
Reduction can be achieved:

- Applying new technologies and concepts

- Improving system integration
- Developing and producing product with less materials.
- System upscaling
- Increasing of performances
- Improving engineering and design (lightweight engineering, thinner cell-plated etc)
- Optimizing portable and containerized system
- Increasing the current density (a smaller system can be utilized for the same production capacity).

iii. Incorporation of used components

Another aspect linked with eco-design is the incorporation of used components in the FCHs, this imply a new design of the products in order to optimize the recycling and disassembling phases:

- all agree it can be sustainable as far as the reliability of the FCSs are guaranteed if compared with FCHs mounting new components
- all think it is easier for the BoP componets
- 80% of FCHs manufacturers already implement used materials in the design
- some of them are developing but mainly with the bipolar plates, but not yet developed it in the stacks
- 40% of them think as many components as possible are recycled or refurbished
- all agree the most important step is to find a suitable procedure to recycle the different components, this implies a non-significant modification of the design.

iv. Use of recycled materials, as secondary raw materials for stack components

What emerged from the surveys is that the manufacturers agreed that recycled material could be used. In terms of the PGM it is a closed cycle already, cell plates and platinum are already being recycled in some cases and also some mechanical components from bipolar plates, can be recycled after an intermittent cleaning step.

v. Design harmonization and standardization

The design harmonization and standardization provides multiple benefits. It simplifies the dismantling and recycling process, consequently it reduces the costs. In addition, it helps improve the products' quality and durability.

- 83% of FCHs manufacturers are interested in rethinking the design of their product in order to optimize the recycling and dismantling phases.
- 100% agree to standardize their fabrication process.

Eco-design for resource efficiency can benefit consumers by making products more durable or easier to repair. It can help recyclers to disassemble products in order to collect valuable materials. It can contribute to save resources that are valuable for the environment and economy. Market signals are, however, not always sufficient to make this happen, in particular because the interests of producers, users and recyclers are not necessarily aligned. It is, therefore, essential to promote and boost improved product design, while at the same time preserving the internal market and enabling innovation.

FCHs manufacturers and developers are required to implement and provide evidence of eco-design. The possibility to repair, remanufacture or recycle a FCH technology system and its components and materials depends on large part on the initial design of the product. It is therefore crucial that these aspects are taken into account when investigating possible eco-design implementing measures.

The design harmonization and standardization provides multiple benefits. It simplifies the dismantling and recycling process, consequently it reduces the costs. In addition, it helps improve the products' quality and durability.

4 Second workshop

The second workshop was organized the 20th of March at Institute IMDEA Energy, Mostoles-Madrid (see Annex IV_Workshop agenda).

Figure 9. Second HYTECHCYCLING WORKSHOP at IMDEA Energy, 20th of March 2018.

There were also relevant industry partners present at the WS highly interested on the project, on his results and willing to collaborate. Their attendance was mostly due to the interest the project represent for them, they wanted to know what we are working on. HyTechCycling is a pilot project in the field of hydrogen technologies recycling phase and there are great expectations on one side and huge responsibility on other hands for all partners included.

The FCH actors' answers provide some interesting directions and perspectives, useful to finalize the Hytechcycling identified new strategies and technologies and to proceed with the final business model.

5 Conclusions

The main aspects that emerged during the two years of the project and through the continuous interviews with the stakeholders is the need for continuous balance between:

i. **Cooperation between all the actors**, as we have seen so far on several fronts:
   - Cooperation in specific FCH regulations
   - Cooperation in Eco-design and harmonization in FCH fabrication process
   - Cooperation in implementation of new strategies and technologies in recycling and dismantling phase.

ii. **Agreements sign**
   - Engagement of the end users: a small bonus for end users should be double-checked in order to incentivize the active participation of some of the stakeholders, as end users;
   - “AGREEMENTS” between manufacturers and recycling centers to assure manufacturers to buy the recycling materials and reuse it.

iii. **Design and recovery,** where the role of the main actors involved in the FCHs end of life chain is crucial.

FCHs manufacturers: The role is crucial in 3 phases: materials selection, eco-design and end of life management. Mainly they are responsible to meet very strict environmental requirements:

- Restriction in use of certain hazardous substances;
- Materials selection in consideration of banned and restricted substances;
- Harmonize the design process in order to facilitate the dismantling stage;
- Improve the quality and durability of the FCHs;
- Implement a clear labelling;
- Increase the rate of reused components and materials;
- Guarantee a profitable “waste value” to recycling centres (Ballard guarantees that once a fuel cell stack has reached the end of life more than 95% of the precious metals in the MEA are reclaimed during this process[v];
- Guarantee to their customers a refurbishment program for FCHs that have reached end of life (linked with EPR legislation);
- Guarantee to Recycling centres critical mass of material to be recycled in order to guarantee profitability for the recycling business;
- Sign specific agreements with recycling centres in order to send them used materials for recovery (mainly stacks parts);
- Sign specific agreements with end users who return EoL FCHs and reuse recycled FCHs (save customers a percentage of the cost of purchasing new FCHs).

Recycling centres role:

- Sign “agreements” with manufacturers to assure manufacturers to buy the recycling materials and reuse it;
- Find another second application able to deal with whole or parts of the FCH equipment’s;
- Develop a more environmental friendly method;
- Guarantee the highest recycling ratio possible;
- Guarantee the origin of the material;
- Develop an economic analysis in order to compare the cost for the treatment compare to the materials’ value inside;
- New investments to implement novel technologies;

- After the business model evaluation, and if it is economically advantageous, start with the authorization's request permissions.

End users role:

- Return to the manufacturers the end of life product;
- Sign specific agreements with FCHs manufacturers.

iv. Regulation concerns.

FCH technologies represent a promising market in Europe; however; some regulations and legislations still affects its complete development. 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 complete new and different systems.

- Harmonization of transboundary waste movements;
- Harmonisation of waste regulation in EU countries. Clarification of the "waste" and "end of waste" status and its harmonisation within different countries it is necessary to develop the market. Once a material, device, etc is classified as waste, before being use as "raw material" again, it has to be declassified as a waste. Depending on the country, this step could be not possible;
- Clarification on the treatment of residues.

6 References

[i] S. Fiorot, D. Damosso, A. Ferriz, "D5.1 Report on requirements from FCH actors"
[ii] A. Valente, D. Iribarren, J. Dufour, "D3.1 New end-of-life technologies applicable to FCH products"
[iii] A. Valente, D. Iribarren, J. Dufour, "D3.2 New end of life strategies for FCH products"
[iv] A. Valente, M. Martín-Gamboa, D. Iribarren, J. Dufou, "Deliverable 2.2 Existing end-of-life technologies applicable to FCH products"
[v] Ballard, Technical note, Recycling PEM fuel cells, End of Life management

Annex I_ Survey Manufacturers

HyTechCycling: questionnaire for manufacturers

Fuel cells and hydrogen technologies are on the brick of having an important growth worldwide for they offer low level of emissions, high conversion efficiency, flexibility and silent operation. In Japan, FCE Vehicles have already conquered the mass market and it is spreading to many other countries such as Korea, China, Germany and the USA.

Nevertheless, it remains some points that need clarifications that the European HyTechCycling project aims to bring to light. New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling are being developed to help you – as manufacturers facing the issues of End-of-Life FCH technologies. As a result, by filling this present questionnaire, you can contribute in these advances and you will be able to benefit from the deliverables and the business models that the project aims to deliver.

*Required

COMPANY GENERAL INFORMATION

1. **Name of the company** *

____

2. **Location** *

____

3. **Main Activity** *

Tick all that apply.

- [ ] PEMFC
- [ ] DMFC
- [ ] AFC
- [ ] PAFC
- [ ] MCFC
- [ ] SOFC
- [ ] AWE
- [ ] PEMWE
- [ ] SOEC
- [ ] Other: _______________

4. **Number of employees** *

Mark only one oval.

- ( ) 0-50
- ( ) 50-100
- ( ) 100-200
- ( ) +200
- ( ) Other: _______________

PRODUCT INFORMATION

5. **Please give us information on your product. Typical power range of your FCH systems are:** *

Tick all that apply.

- [ ] about 1 kW
- [ ] 2-5 kW
- [ ] 5.1-10 kW
- [ ] 10.1-50 kW
- [ ] 50-400 kW
- [ ] order of MW

6. **Do you use logistics companies to truck your devices to the end users?** *

Mark only one oval.

- ( ) yes
- ( ) no

7. **Do you have distributors or you directly sell your product?** *

Mark only one oval.

- ( ) yes, we have distributors
- ( ) no, we directly sell our product

8. **Please give us some information on the two cathegories, if you use one of them: logistics companies and distributors. We would contact them in order to collect some information.** *

9. **Who are your customers/end users?** *

Mark only one oval.

- ( ) Energy Utilities
- ( ) chemical industries
- ( ) private customers
- ( ) automotive companies
- ( ) telecommunication companies
- ( ) other

10. **Who are your customers/end users?Please give us some information and contacts.** *

NEW EoL strategies for FCH products: role of the main actors

Hytechcycling Project has identified existing and novel technologies for recovering materials from stacks and BoPs components. The involvement of all the FCHs actors in order to validate the EoL strategies is crucial, as specific agreements between Manufacturers and recycling centers.
Hytechcycling project has identified 3 different scenarios:
1) short term with FCHs limited to a niche market;
2) mid-term with the market volume only partly settled;
3) long term with the massive introduction of FCHs.

11. **Until now, what is your position regarding EoL devices? Do you have collected some of them from your end users?** *

Mark only one oval.

- yes
- no

12. **If your previous answer is yes, how many old devices do you have received?**

Mark only one oval.

- only one
- 2-5
- 6-10
- more than 10

13. **Internally, do you have a specific area that work on EoL devices?** *

Mark only one oval.

- yes
- no

14. **Do you think could be profitable for you having internally a EoL dedicated sector?** *

Mark only one oval.

- yes
- no

15. **In the long term scenario we have detected the manufacturer with a dual role: manufacturer and FCH recovery center. It could be profitable for you? please describe your vision** *

16. **Scenario 1: we have identified the role of FCHs manufacturers, waste manager and end users as crucial. Do you have already specific agreements with them in order to have profit for your Company?** *

Mark only one oval.

- yes
- no

17. **If your previous answer is yes, what kind of agreements have you signed?**

18. **If your answer is no, what kind of agreement could be economically advantages for your business?**

NEW EoL strategies for FCH products: ECO-DESIGN

The Eco-design Directive is a framework directive that helps EU to achieve the 20-20-20 targets.
The Eco-design Directive applies to energy-related products with a sales volume above 200,000 units per
year through the internal European market.
The Eco-design Directive specifies the main parameters that must be considered to improve the environmental aspects when designing a product.

19. **Do you take into account the eco design directive?** *

20. **One aspect to take in consideration is the weight and volume reduction of the FCHs. How much could you reduce it?** *

Mark only one oval.

- no reduction is possible
- 5% of the total
- 10% of the total
- 20% of the total
- 30% of the total
- more than 30%

21. **How can you reach a good reduction? please explain** *

22. **Another aspect is the use of recycled materials, as secondary raw materials for stack components. What is your position?**

23. **Another aspect linked with ecodesign is the incorporation of used components in the FCHs, this imply a new design of your products in order to optimized the recycling and disassembling phases? What is your position?** *

24. *Mark only one oval.*

- ( ) Option 1

Second Hytechcycling Workshop

Date: Tuesday, 20th March
Time: 9:30 – 13:30 (registration starts at 9:00)
Location: Parque Tecnológico de Móstoles, Avda. Ramón de la Sagra, 3
28935 Móstoles Madrid

RESULTS FROM THE SECOND YEAR OF THE PROJECT! HyTechCycling project partners are pleased to invite you to learn more about FCH technologies' issues as regards recycling and dismantling. The aim of this workshop is to inform participants of the HyTechCycling projects findings up to now and to validate the new technologies and strategies for recycling and dismantling identified.

25. **Would you be interested in participating to a workshop with other manufacturers, recycling centers, FCH technologies end-users and some distributors ?** *

Mark only one oval.

- ( ) Yes
- ( ) No

26. **link for registration**
https://docs.google.com/forms/d/e/1FAIpQLSeQDdBL19LORAIBu2b-nm0djifEKwlAhKZdlmaJCvU7orDdsg/viewform?usp=sf_link

Comments

27. **Feel free to add some comments, questions or suggestions !**

Thank you for your time !

Powered by Google Forms

Annex II_ Survey Recycling Centers

HyTechCycling: questionnaire for recycling/recovery centers

Fuel cell and hydrogen technologies are on the brick of having an important growth worldwide for they offer low level of emissions, high conversion efficiency, flexibility and silent operation. In Japan, FCE Vehicles have already conquered the mass market and it is spreading to Korea, China, Germany and the USA.

Nevertheless, it remains some points that need clarifications that the European HyTechCycling project aims to bring to light. New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling are being developed to help you – as recycling centers- face the issues of End-of-Life FCH technologies. As a result, by filling this present questionnaire, you can contribute in these advances.

*Required

COMPANY GENERAL INFORMATION

1. **Name:** *

2. **Location:** *

3. **Main Activity** *

Tick all that apply.

- [ ] cars
- [ ] electronic devices
- [ ] industrial waste
- [ ] plastics
- [ ] precious metals
- [ ] batteries
- [ ] Other: ______

4. **Number of employees** *

Mark only one oval.

- ( ) 0-50
- ( ) 50-100
- ( ) 100-200
- ( ) +200

NEW EoI strategies for FCH products: novel technologies for recovery

Hytechcycling Project has identified existing and novel technologies for recovering materials from stacks and BoPs components.

5. **Until now, what is your position regarding EoL FCH devices? Do you have collected some of them?** *

Mark only one oval.

- yes
- no

6. **What FCHs do you have received?** *

Mark only one oval.

- PEM fuel cell
- SOFC fuel cell
- AWE (alkaline water electrolizer)
- PEMWE (proton exchange water electrolizer)

7. **If yes, do you have the technology required for Fuel Cells & Hydrogen technologies' recovery?** *

Mark only one oval.

- Yes
- No

8. **What kind of technologies do you have for recovery?** *

Mark only one oval.

- HTM hydrometallurgical
- PMT pyrometallurgical
- Hydrothermal

9. **The Hytechcycling project has detected some novel technologies for recovering PEMFC and PEMWE stack's critical materials. What do you think could be easily implemented in your RC?** *

Mark only one oval.

- SED (selecttive electrochemical dissolution)
- TD (transient dissolution)
- AP (acid process)
- AD (alcohol dissolution)
- Other: ____________________

10. **These novel technologies are mainly related to the possibility of recovery more than one valuable product of stacks and the precious metals. Do you think about investing on them?** *

Mark only one oval.

- yes
- no

11. **In order to implement novel technologies in your RC what kind of re-adaptation you need to implement? please give us details on new equipments or updates on existing machinery you have.** *

12. **In order to implement novel technologies in your RC what kind of re-adaptation you need to implement? please give us details on investments you will have to face.** *

NEW Eol strategies for FCH products: main actors involvement

The involvement of all the FCHs actors in order to validate the EoL strategies is crucial, as specific agreements between Manufacturers and recycling centers. The main actors involved are: recycling/recovery centers, FCH manufacturers, end users (customers of manufacturers).
Hytechcycling project has identified 3 different scenarios:
1) short term with FCHs limited to a niche market;
2) mid-term with the market volume only partly settled;
3) long term with the massive introduction of FCHs.

13. **In the mid-term scenario we have identified the role of FCHs manufacturers, end users and recycling centers as crucial. Do you have already specific agreements with them in order to have profit for your Company?** *

Mark only one oval.

- yes
- no

14. **If your previous answer is no, would you be interested if a « convention » is instituted between recycling centers and manufacturers to assure the manufacturer to buy the recycled materials?** *

Mark only one oval.

- Yes
- No
- Other:

15. **What kind of agreement could be economically advantages for you business? please give details** *

16. **If you are in contacts with FCHs manuyfactures, what kind of agreements have you signed?**

Second Hytechcycling Workshop

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Time: 9:30 – 13:30 (registration starts at 9:00)
Location: Parque Tecnológico de Móstoles, Avda. Ramón de la Sagra, 3
28935 Móstoles Madrid

RESULTS FROM THE SECOND YEAR OF THE PROJECT! HyTechCycling project partners are pleased to invite you to learn more about FCH technologies' issues as regards recycling and dismantling. The aim of this workshop is to inform participants of the HyTechCycling projects findings up to now and to validate the new technologies and strategies for recycling and dismantling identified.

17. **Would you be interested by participating to a workshop that will gather many european recycling centers, FCH manufacturers, end-users and distributors ?** *
Mark only one oval.

- ( ) Yes
- ( ) No

18. **link for registration**
https://docs.google.com/forms/d/1tfjy8bHx3WbZCX34HMcnRoxwa79mxMWd-dWsp36u_mM/edit

Comments

19. **Do you have any comments, suggestions, questions ?**

____

____

____

____

____

Annex III_ Survey End-users

Questionnaire for FCHs end users

Fuel cell and hydrogen technologies are on the brick of having an important growth worldwide for they offer low level of emissions, high conversion efficiency, flexibility and silent operation. In Japan, FCE Vehicles have already conquered the mass market and it is spreading to Korea, China, Germany and the USA.

Nevertheless, it remains some points that need clarifications that the European HyTechCycling project aims to bring to light. New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling are being developed to help face the issues of End-of-Life FCH technologies. As a result, by filling this present questionnaire, you can contribute in these advances.

*Required

COMPANY GENERAL INFORMATION

1. **Name of the company** *

____

2. **Location (Town, COUNTRY)** *

____

3. **Main activity** *
Tick all that apply.
- [ ] Transports
- [ ] Industries
- [ ] Energy: CHP
- [ ] Energy: Injecting H in gas grid
- [ ] Other: ______________________________

4. **Number of employees** *
Mark only one oval.
- ( ) 0-50
- ( ) 50-100
- ( ) 100-200
- ( ) + 200
- ( ) Other: ______________________________

5. **Are you customer of a** *
Mark only one oval.
- ( ) PEM system manufacturer
- ( ) SOFC system manufacturer
- ( ) AWE (alkaline water electrolizer) system naufacturer
- ( ) PEMWE (proton exchange membrane water electrolyzer) system manufacturer

6. **How many systems have you bought in the last 2 years?** *
Mark only one oval.

- 0-10
- 10-50
- 50-100
- 100-200
- over 200

7. **How many FCHs suppliers do you have ?** *
Mark only one oval.

- only 1
- 2-10
- 10-15
- 15-20
- +20

NEW EoL strategies for FCH products: role of the main actors

The role of end users is crucial in the identification of a NEW BUSINESS MODEL CONCEPT for end of life FCHs.

8. **Do you have FCH systems at EoL stage?** *
Mark only one oval.

- yes
- nor yet

9. **If your previous answer is yes, how do you collect end-of-life FCH technologies ?**
Mark only one oval.

- return them to FCHs manutacturer
- return them to recycling centers

10. **Do you already have specific agreements with FCHs manufacturer or recycling centers?** *
Mark only one oval.

- yes
- no

11. **If you don't have yet FCHs at EoL stage, are you thinking what to do next?**
Mark only one oval.

- yes
- no

12. **What do you think could be more profitable for you** *
Mark only one oval.

- return to manufacturer
- return to recycling center

13. **In which terms could it be economically advantageous for your business?** *
Mark only one oval.

- transport of old devices payd by manufacturer or recycling center
- transport of old devices payd by you but with incentives

14. **If you will pay the transport of old devices, what kind of incentives could be more profitable?**
Mark only one oval.

- reduction of taxes
- economic incentives: example a reduced price for a new or remanufactured device

15. **Please describe your scheme of business model in the EoL chain. What kind of tax aides could be applied?** *

16. **How can an end user be introduced in the recycling network? How to facilitate your interaction?** *

17. **What is your opinion about logistics related with this issue? Is there any kind of past experience that you think it could be useful in a situation like this one, where there is neither a responsible nor a defined chain of actions?** *

18. **Interested in being involve in a working group to think about business models, regulations etc.?** *

19. **Which is the role of end users and how to boost an active participation and how are they going to be engaged in a business model?** *

____

____

____

____

____

Secon Hytechcycling Workshop

Date: Tuesday, 20th March
Time: 9:30 – 13:30 (registration starts at 9:00)
Location: Parque Tecnológico de Móstoles, Avda. Ramón de la Sagra, 3
28935 Móstoles Madrid

RESULTS FROM THE SECOND YEAR OF THE PROJECT! HyTechCycling project partners are pleased to invite you to learn more about FCH technologies' issues as regards recycling and dismantling. The aim of this workshop is to inform participants of the HyTechCycling projects findings up to now and to validate the new technologies and strategies for recycling and dismantling identified.

20. **Would you be interested in participating to a workshop with other manufacturers, recycling centers, FCH technologies end-users and some distributors ?** *

Mark only one oval.

- ◯ Yes,
- ◯ No

link for registration

https://docs.google.com/forms/d/e/1FAIpQLSeQDdBL19LORAIBu2b-nm0djifEKwIAhKZdImaJCvU7orDdsg/viewform?usp=sf_link

21. **Please feel free to add any suggestion or comment:**

Thank you for your time !

Annex IV_Workshop agenda

20 MARCH

HyTechCycling

DISSEMINATION WORKSHOP

PUBLIC ENTRY

Location:

Institute IMDEA Energy

Parque Tecnológico de Móstoles Avda. Ramón de la Sagra, 3. 28935 Móstoles Madrid

FCH

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HyTechCycling

www.hytechcycling.eu

Workshop Programme

20 March 2018

9:00 – 09:30
Welcome coffee and registration

09:30 – 09:40
General presentation of the project.
Ms. Ana Férriz, Foundation for the Developtment of New Hydrogen Technologies in Aragon.

09:40 – 10:10
The HYTECHCYCLING project till now
PhD. Sabina Fiorot, Environmental Park

10:10 – 10:30
Results from "New recycling technologies applied to FCH products"
PhD Javier Dufour, IMDEA Institute

10:30 – 10:50
Results from "New strategies for FCH technologies in the phase of recycling and dismantling"
PhD Javier Dufour, IMDEA Institute

10:50 – 11:00
Questions and/or comments

11:00 – 11:30
Coffee break

11:30 – 12:00
Results from "Life Cycle approaches"
Phd Mitja Morit, UNIVERZA V LJUBLJANI

12:00 – 12:20
Results analysis of the questionnaires to FCH manufacturers, recycling centers, distributors and end users
PhD. Sabina Fiorot, Environment Park

12:20-12:40
Approach to a "New Business Model"
Mr. Alfonso Bernad, Foundation for the Developtment of New Hydrogen Technologies in Aragon.

12:40 – 13:20
Roundtables discussion divided by groups

13:20 – 13:30
Conclusions the discussions and next HYTECHCYCLING steps
Ms. Ana Férriz, Foundation for the Developtment of New Hydrogen Technologies in Aragon.

HyTechCycling

Annex V_ppts of 2nd WS

20 MARCH

HyTechCycling DISSEMINATION WORKSHOP

PUBLIC ENTRY

Location:

Institute IMDEA Energy

Parque Tecnológico de Móstoles Avda. Ramón de la Sagra, 3. 28935 Móstoles Madrid

FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HyTechCycling

www.hytechcycling.eu

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10:50 – 11:00
Questions and/or comments

11:00 – 11:30
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HyTechCycling

HyTechCycling

HYTECHCYCLING project introduction

2nd Workshop

Madrid, 20th of March 2018

Summary

- Nowadays, the development of the FCH technologies isn't take into account their **recycling and dismantling**, nor their possible re-uses inside a future context of commercialization.

- Some **critical materials** that are used are:
  - PEMFC and PEMWE: **Platinum group materials as Iridium, Platinum or Ruthenium.**
  - SOFC: **Rare-Earth compounds as Lanthanum and Yttrium**.
  - Alkaline electrolysers: **Platinum** and **Asbestos**

- A lack of strategies around the End of Life of this technologies exists. There is also an absence in the reuse of this products.
- There is a markets for business models derivate from material saving and recycled raw materials.

University of Ljubljana

Project introduction

MAIN OBJECTIVE

HyTechCycling aims to deliver **reference documentation** and studies about existing and new recycling and dismantling technologies and strategies applied to FCH technologies, paving the way for **future demonstration actions** and advances in legislation and **business models**.

- First European project related with FCH technologies recycling.
- Involves the hole FCH technologies life's cycle.

University of Ljubljana

FOUNDATION FOR THE DEVOLOPMENT OF NEW HYDROGEN TECHNOLOGIES IN ARAGON

ENVIRONMENT PARK Parco Scientifico Tecnologico per l'Ambiente

HyTechCycling in numbers

5 European partners

3 years long

0,5 M€

Topic **FCH-04.1-2015 Recycling and Dismantling Strategies for FCH Technologies**, dentro de la **Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU)**

Partners

Work Packages

WP 1. Project Management & Coordination.

WP 2. Regulatory analysis, critical materials and components identification and mapping of recycling technologies.

WP 3. New strategies and technologies.

WP 4. LCA for FCH technologies considering new strategies & technologies in the phase of recycling and dismantling.

WP 5. Harmonization of procedures considering all actors involved in lifetime of FCH products.

WP 6. New business model and implementation roadmap.

WP 7. Dissemination & Exploitation.

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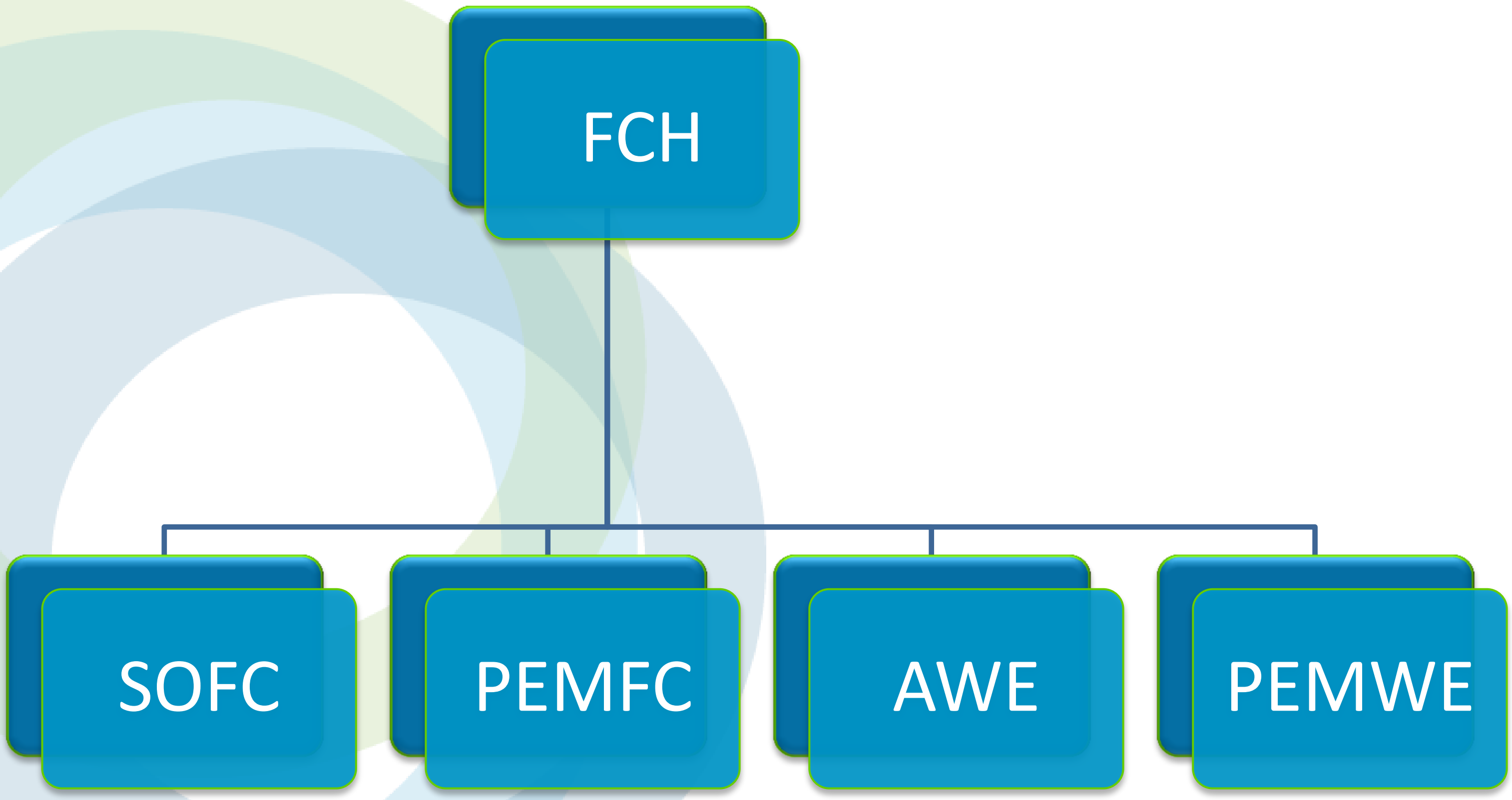
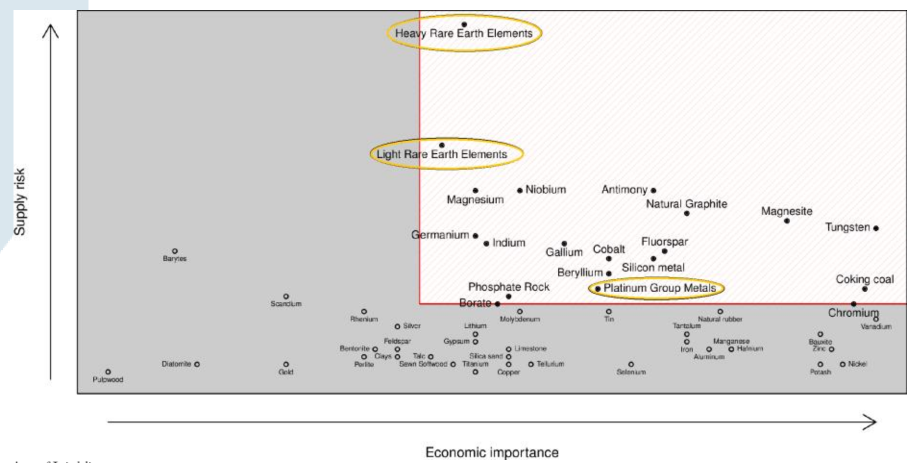
Technologies analysed



Project introduction

IDENTIFYING THE PRESENT. LOOKING TO THE FUTURE:

- Identification and characterization of critical materials.
- Current End-of-Life technologies and strategies.
- Regulatory framework and barriers.
- Needs and challenges in the End-of-Life.



This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme from and Hydrogen Europe and N.ERGHY.

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Thank you for your attention.

More info:
www.hytechcycling.eu

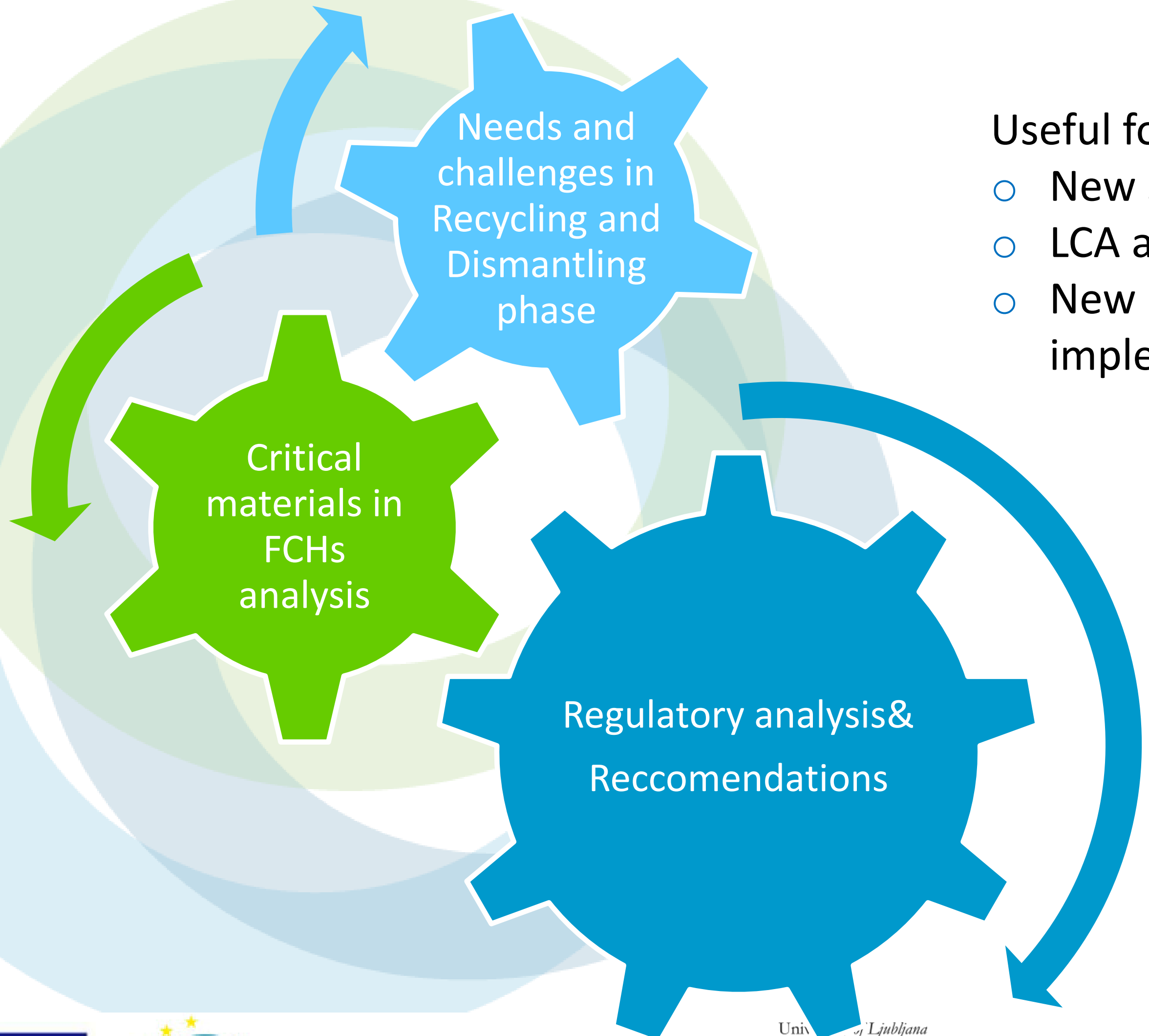
HyTechCycling

The Hytechcycling project till now

Speaker: Federico Cartasegna
Environment Park

Location:
Institute IMDEA Energy
Parque Tecnológico de Móstoles Avda. Ramón de la Sagra, 3. 28935, Móstoles Madrid

Objectives



Useful for identification of

- New strategies and technologies
- LCA analysis
- New business model and implementation roadmap

Objective

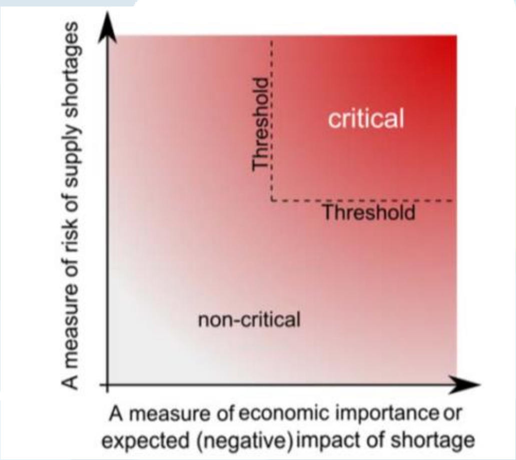
Identification of critical materials used in the manufacturing of FCH products according to different criteria: their **function** as component, **environmental** aspect as material classification, **cost** as material value, **criticality/scarcity** as material criticality and current recycling and dismantling technologies.

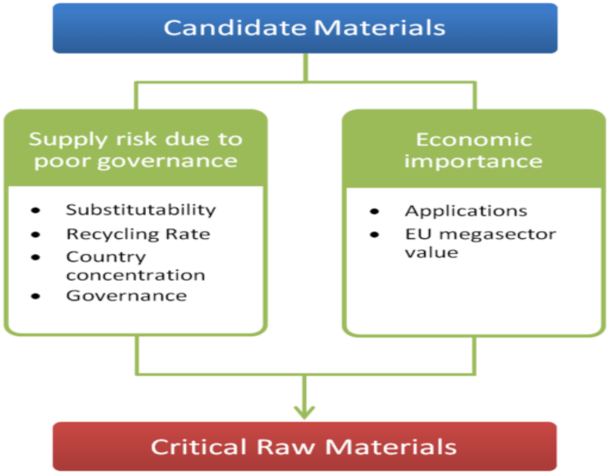
Main results

- **SOFCs** materials mainly consist of **Rare Earth Elements** (REE), classified as critical, costly and hazardous.
- **PEMFCs** materials are mainly low-to-medium in cost with the exception of **Pt or Pt-alloy catalysts**. Concerning critical materials, Pt and graphite are significant in weight and volume in the stack.
- **PEMWEs** materials are more expensive compared to the PEMFCs. The oxygen evolution reaction catalysts are based on **REE** while the hydrogen evolution reaction catalysts are based on **Pt**.
- **AWEs** materials are mainly cheap with the exception of anode and cathode catalysts, which are also classified as critical for the EU states. **Ni-based catalyst** and asbestos diaphragms, used in older types of AWEs, are classified as carcinogen.

Three main criteria were defined to obtain list of critical materials:

1. **Hazardousness** – Material properties that make it dangerous, or capable of having a harmful effect, to human health or the environment [1], [2].
2. **Scarcity or criticality** - The **EU Criticality Methodology** [3] is a combination of two assessment components:
   - Economic importance or expected (negative) impact of shortage,
   - Risk of supply or poor governance.





[1] Agency for Toxic Substances and Disease Registry (ATSDR): Methodology Used to Establish Toxicity/Environmental Scores for the Substance Priority List.
[2] W. M. Liu J, Goyer RA, "Toxic effects of metals.," in Casarett and Doull's toxicology: the basic science of poisons., 2008, pp. 931–979.
[3] European Commission, "Report on critical raw materials for the EU: Report of the Ad hoc Working Group on defining critical raw materials," 2014.

Results of 20 EU critical raw materials:

Antimony	Beryllium	Borates	Chromium	Cobalt	Coking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural Graphite	Niobium
PGMs	Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten	

EU-20 critical raw materials.

3. **Price** - Prices of elements and their compounds list was estimated from actual price on the market.

[1] Agency for Toxic Substances and Disease Registry (ATSDR): Methodology Used to Establish Toxicity/Environmental Scores for the Substance Priority List.
[2] W. M. Liu J, Goyer RA, “Toxic effects of metals.,” in Casarett and Doull’s toxicology: the basic science of poisons., 2008, pp. 931–979.
[3] European Commission, “Report on critical raw materials for the EU: Report of the Ad hoc Working Group on defining critical raw materials,” 2014.

List of critical materials-SOFC

Solid Oxide Fuel Cells

Component	Material	Material classification	Material value	Material Criticality
Electrolyte	Yttria-stabilised zirconia	Non-hazardous	Medium	High
Anode	Nickel-based oxide doped with YSZ	Hazardous (Cat. 1 carcinogen)	Medium	High
	Nickel	Hazardous (Cat. 1 carcinogen)	Medium	High
Cathode	Strontium-doped lanthanum manganite	Hazardous (Irritant)	Medium	High
Interconnect	Doped lanthanum chromate	Hazardous (Irritant, harmful)	Medium	Medium-High
	Inert metals/alloys	Non-hazardous	High	Medium-High
Sealant	Glass/Glass-ceramic	Non-hazardous	Low	Low
	Mineral	Non-hazardous	Low	Low
	Precious metals	Non-hazardous	High	High
Substrate	Ceramic	Non-hazardous	Low	Low

Main results

- **SOFCs** materials mainly consist of **Rare Earth Elements** (REE), classified as critical, costly and hazardous.

List of critical materials-PEMFC

Polymer Electrolyte Membrane Fuel Cell

Component	Material	Material classification	Material value	Material Criticality
Electrolyte	Perfluorosulphonic acid (PFSA)	Non-hazardous	Medium	Medium
	Sulfonated polyether ether ketone (s-PEEK)	Non-hazardous	Medium	Low
	polystyrene sulfonic acid (PSSA)	Non-hazardous	Low	Medium
	polybenzimidazole (PBI) doped with H_3PO^4 *	Hazardous (corrosive)	Medium	Low
Anode and Cathode - GDL	Carbon cloth or paper treated with hydrophobic agent	Non-hazardous	Low	Low
	Metallic mesh or cloth (e.g. stainless steel)	Non-hazardous	Low	Low
Anode and Cathode (catalyst layer)	Platinum or Pt-alloys	Non-hazardous	High	High
	Catalyst support (carbon, metal oxides, carbides, etc.)	Non-hazardous	Medium	Low
Interconnect	Synthetic graphite or graphite composites	Non-hazardous	Low	Medium
	Stainless steel	Non-hazardous	Low	Low
Sealant	Thermoplastic	Non-hazardous	Low	Low
	Elastomer	Non-hazardous	Low	Low

* used only in HT PEMFC

Main results

- **PEMFCs** materials are mainly low-to-medium in cost with the exception of **Pt or Pt-alloy catalysts**. Concerning critical materials, Pt and graphite are significant in weight and volume in the stack.

List of critical materials-PEMWE

Polymer Electrolyte Membrane Water Electrolyser

Component	Material	Material classification	Material value	Material Criticality
Electrolyte	Perfluorosulphonic acid (PFSA)	Non-hazardous	Medium	Medium
	Sulfonated polyether ether ketone (s-PEEK)	Non-hazardous	Medium	Low
Catalyst layer - Cathode	Pt or Pt-alloys	Non-hazardous	High	High
Catalyst layer- Anode	Iridium and Ir-alloys	Hazardous (irritant, harmful)	High	High
	Ruthenium and Ru-alloys	Hazardous (toxic, carcinogen)	Medium	High
Anode and Cathode - GDL	Thermally sintered Ti	Non-hazardous	Low	Medium
	Ti or stainless steel mesh	Non-hazardous	Low	Medium
	Synthetic graphite or graphite composites (only possible on cathode side)	Non-hazardous	Low	Medium
Interconnect	Coated titanium or Ti-alloys	Non-hazardous	Low	Medium
Sealant	Thermoplastic	Non-hazardous	Low	Low
	Elastomer	Non-hazardous	Low	Low

Main results

- **PEMWEs** materials are more expensive compared to the PEMFCs. The oxygen evolution reaction catalysts are based on **REE** while the hydrogen evolution reaction catalysts are based on **Pt**.

List of critical materials-AWE

Alkaline Water Electrolyser

Component	Material	Material classification	Material value	Material Criticality
Electrolyte	Potassium Hydroxide	Hazardous (corrosive)	Medium	Low
Anode	Precious metals	Non-hazardous	High	High
	Plastic	Non-hazardous	Low	Low
Cathode	Raney-Nickel	Hazardous (carcinogen)	Medium	High
	Plastic	Non-hazardous	Low	Low
Interconnect	Plastic	Non-hazardous	Low	Low
Sealant	Thermoplastic	Non-hazardous	Low	Low
	Elastomer	Non-hazardous	Low	Low
Diaphragm (membrane)	Asbestos	Hazardous (carcinogen)*	Low	Low
	Polymers	Non-hazardous	Medium	Low

* only in older types of AWEs

Main results

- **AWEs** materials are mainly cheap with the exception of anode and cathode catalysts, which are also classified as critical for the EU states. **Ni-based catalyst** and asbestos diaphragms, used in older types of AWEs, are classified as carcinogen.

REGULATORY FRAMEWORK: ANALYSIS BARRIERS AND PERSPECTIVES

ELV Directive

- Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.

Batteries Directive

- Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC.

Packaging Directive

- Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste

Landfill Directive

- Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

Eco Design Directive

- Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of Eco Design requirements for energy-related products.

REGULATORY FRAMEWORK: ANALYSIS BARRIERS AND PERSPECTIVES

WHEE Directive

- Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast).

RoHS Directive

- Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast version).

REACH

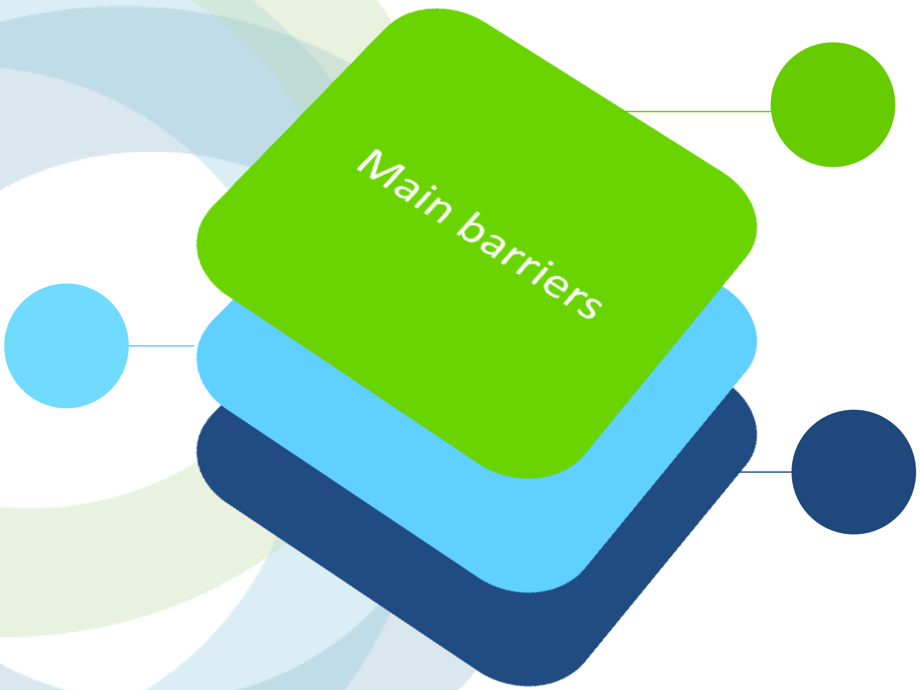
- Regulation (EC) no 1907/2006, of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency.

Waste framework Directive

- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

Hazardous waste Directive

- Council Directive 91/689/EEC of 12 December 1991 on hazardous waste



Hazardous materials in FCHs and barriers on REACH Regulation

- affect the deployment mainly in relation to future restriction on use of hazardous materials

Critical raw materials

- Eco-design Directive
- Pt based & REE

Lack of specific legislation on FCH

- ELV Directive
- WEEE Directive

REGULATORY FRAMEWORK: ANALYSIS BARRIERS AND PERSPECTIVES

Hazardous waste and landfill Directives

- damage the environmental beneficial image promoted by FCH manufacturers and developers
- delay the market entry

WEEE and RoHS Directives

- large stationary systems out of scope
- avoid use of some components

Eco-design Directives

- interests of producers, users and recyclers not aligned
- promote eco-design

End-of-Life Vehicles

restrictive targets:

- reuse&recovery: 95%
- reuse&recycle: 85%

of the vehicle by weight, so the FCHs developers have to guarantee the achieving goals in the end of life

RECOMMNEDATIONS AND PERSPECTIVES ON EU REGULATIONS AND POLICIES

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 the 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, recycling centres assure to have a new market

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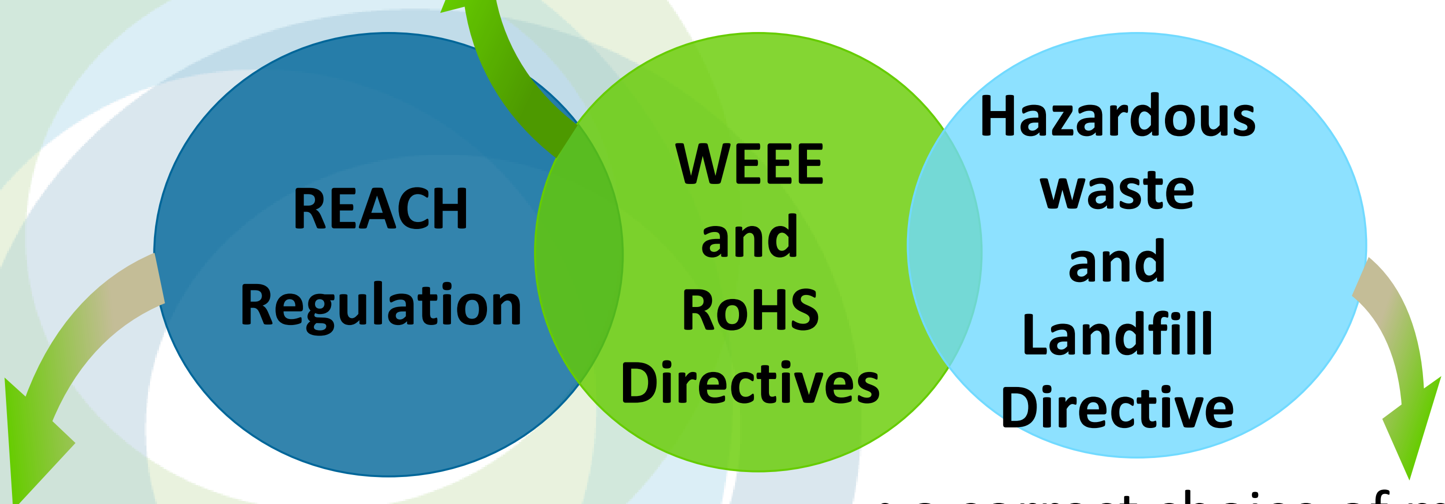
RECOMMNEDATIONS AND PERSPECTIVES ON EU REGULATIONS AND POLICIES

- collect information on large stationary
- change the scope of the Directive



- a socio-economic assessment to justify the use of Ni or other hazardous material
- consider these socio-economic aspects

- a correct choice of material in the design phase
- perform a careful LCA in the design phase
- find a pre-treatment solution

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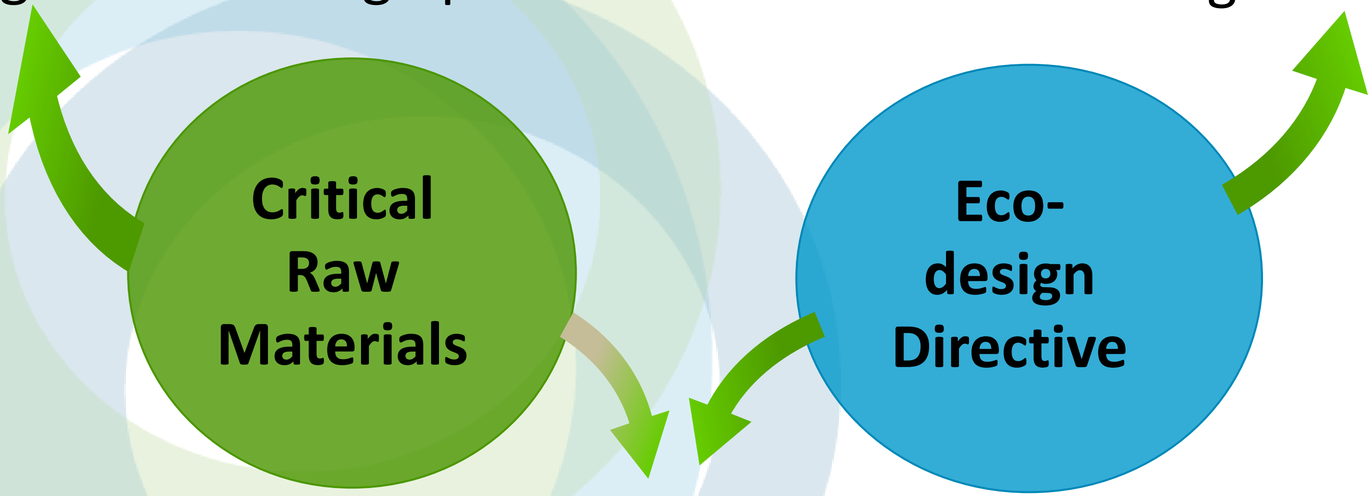
- substitution or reduction of critical raw materials to evaluate during the eco-design phase

- material selections and substitution
- FC manufacture and construction
- end of life management



- develop a more environmental friendly method of mining main metals
- promote recycling
- a more detailed research recycling methods

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RECOMMNEDATIONS AND PERSPECTIVES ON EU REGULATIONS AND POLICIES

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.

- **Innovation Deals**
- **Working groups**
- **Agreements**

work on materials during design and end of life management by the stakeholders

EU Policy makers: perceive the existing difficulties and barriers exist and to incorporate any changes of regulations.

Analysis of availability of substitution for hazardous and critical materials

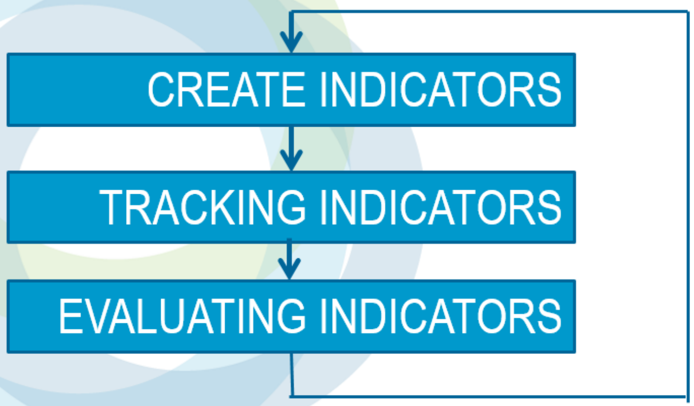
NEEDS AND CHALLENGES IN RECYCLING AND DISMANTLIG PHASE

Objective

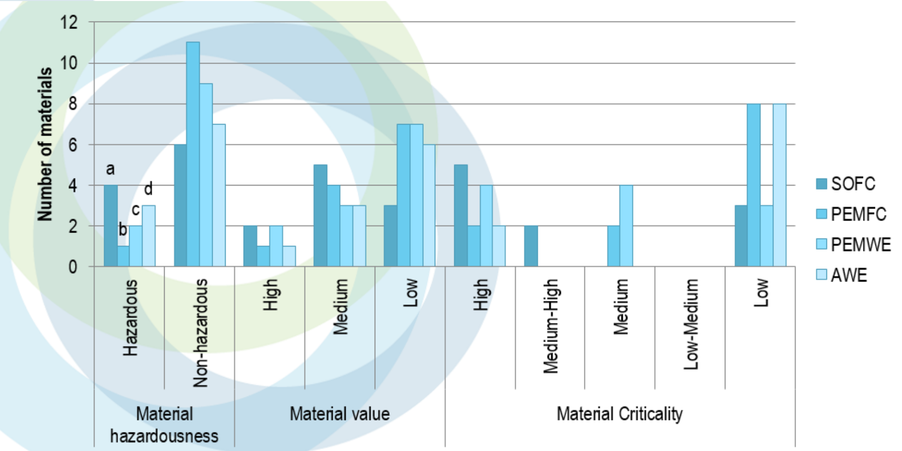
Identification of all the needs and challenges that have to face up FCH technologies, giving a clear basis where future work will be carried.

TWO MAIN ASPECTS A MANUFACTURER HAS TO TAKE IN CONSIDERATION

ECODESIGN



MATERIAL SELECTIONS



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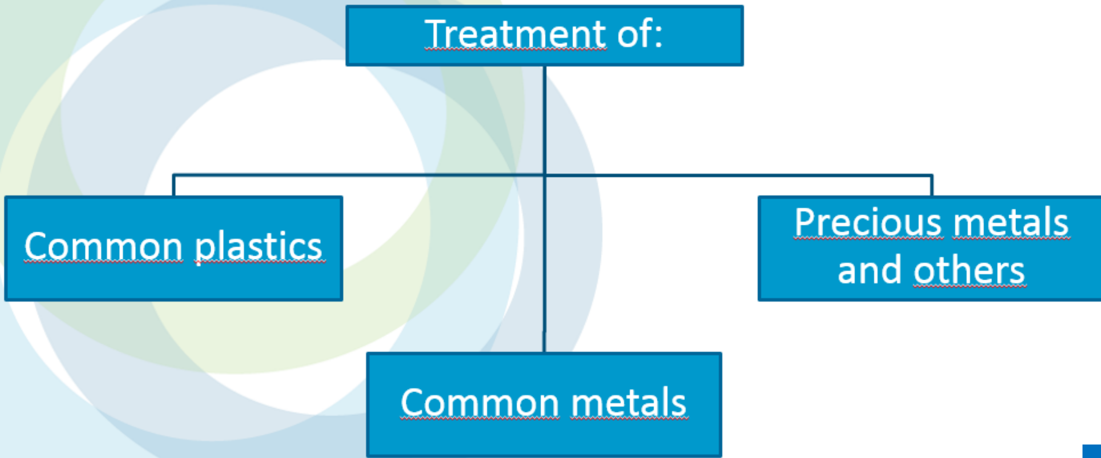
FCH Fuel Cells and Hydrogen Joint Undertaking
Foundation for the Devolopment of New Hydrogen Technologies in Aragon
imdea energy institute
Grupo López Soriano
Environment Park Parco Scientifico Tecnologico per l'Ambiente

NEEDS AND CHALLENGES IN RECYCLING AND DISMANTLIG PHASE

TWO MAIN ASPECTS THAT A RECYCLING CENTER HAS TO TAKE IN CONSIDERATION



- EXISTING TREATMENTS
- NOVEL TREATMENTS

NEEDS AND CHALLENGES IN RECYCLING AND DISMANTLIG PHASE

OTHER NEEDS AND CHALLENGES

ERP system for recyclable resources with a small-generation scale and potential environmental risk

Tax incentives

Regulation of the collection system

Extended Responsibility of Producer: Manufacturers should be an active part of the EoL processes.

- Recycling philosophy. End users and recycling companies connected.
- The customer needs clear and easy-to-understand recycling information.
- Continuously improvement of campaigns to reach more customer from the recycling center point of view
- Adapted methodology depending on the size of the FCH technology.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

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Do you have any suggestions or questions ?

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Workshop

20th March 2018, Institute IMDEA Energy, Móstoles Madrid

Results from "New recycling technologies applied to FCH products"

Antonio Valente, *Diego Iribarren, Javier Dufour - (IMDEA Energy - Systems Analysis Unit)*

Introduction

HyTechCycling's main goal:

Delivering reference documentation and studies about existing and new recycling and dismantling technologies and strategies applied to FCH technologies, paving the way for future demonstration actions and advances in roadmaps and regulations.

Mapping of existing and novel recycling technologies applicable to critical FCH materials and components

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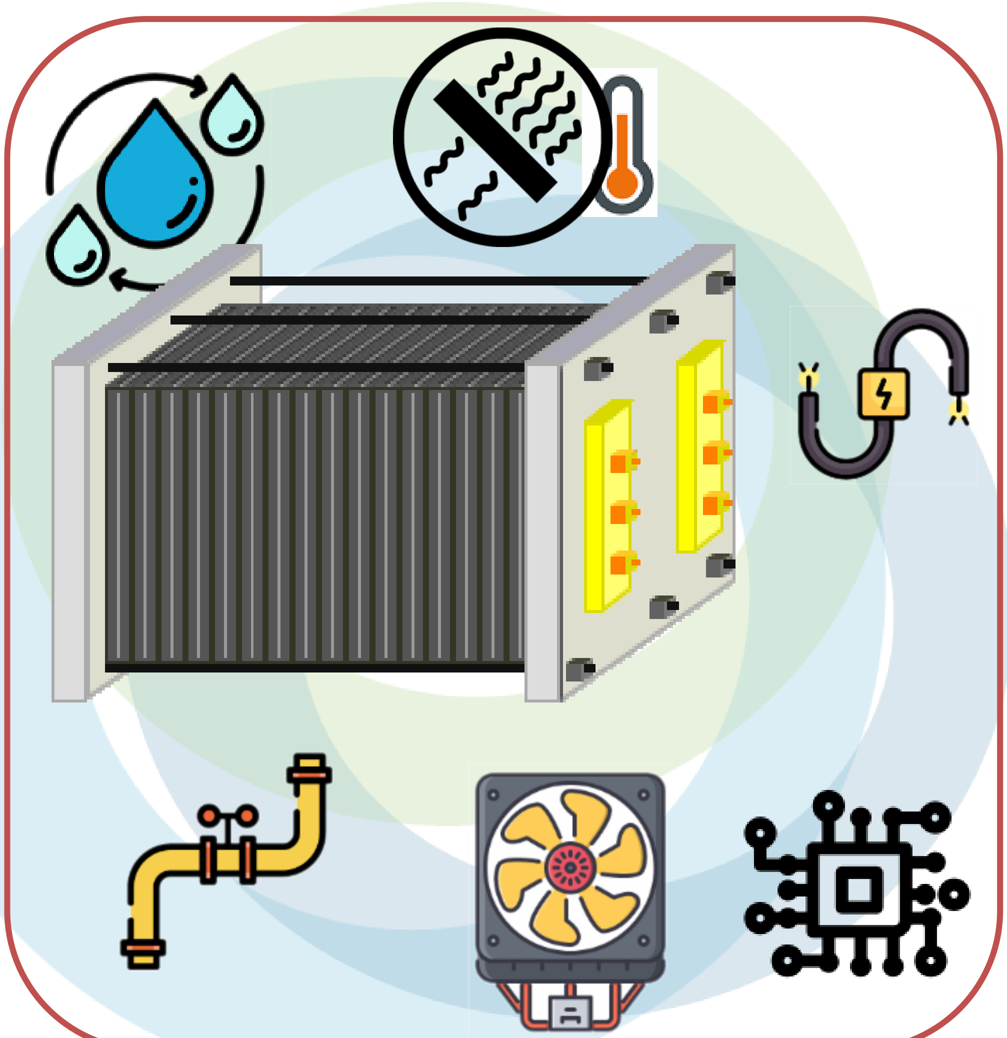
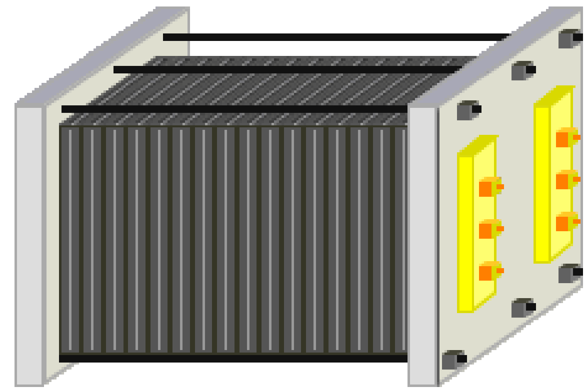
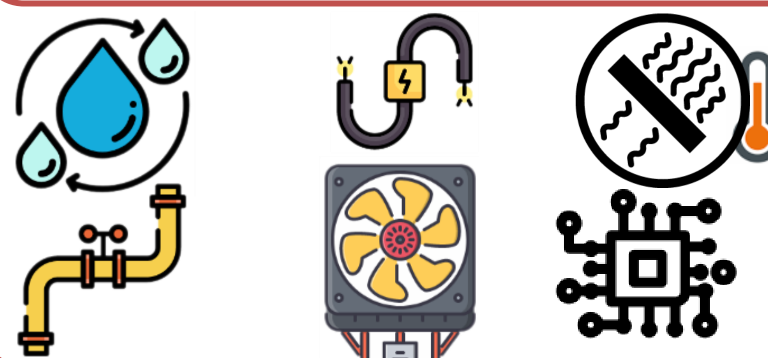
Components of the study



Stack components



BoP components

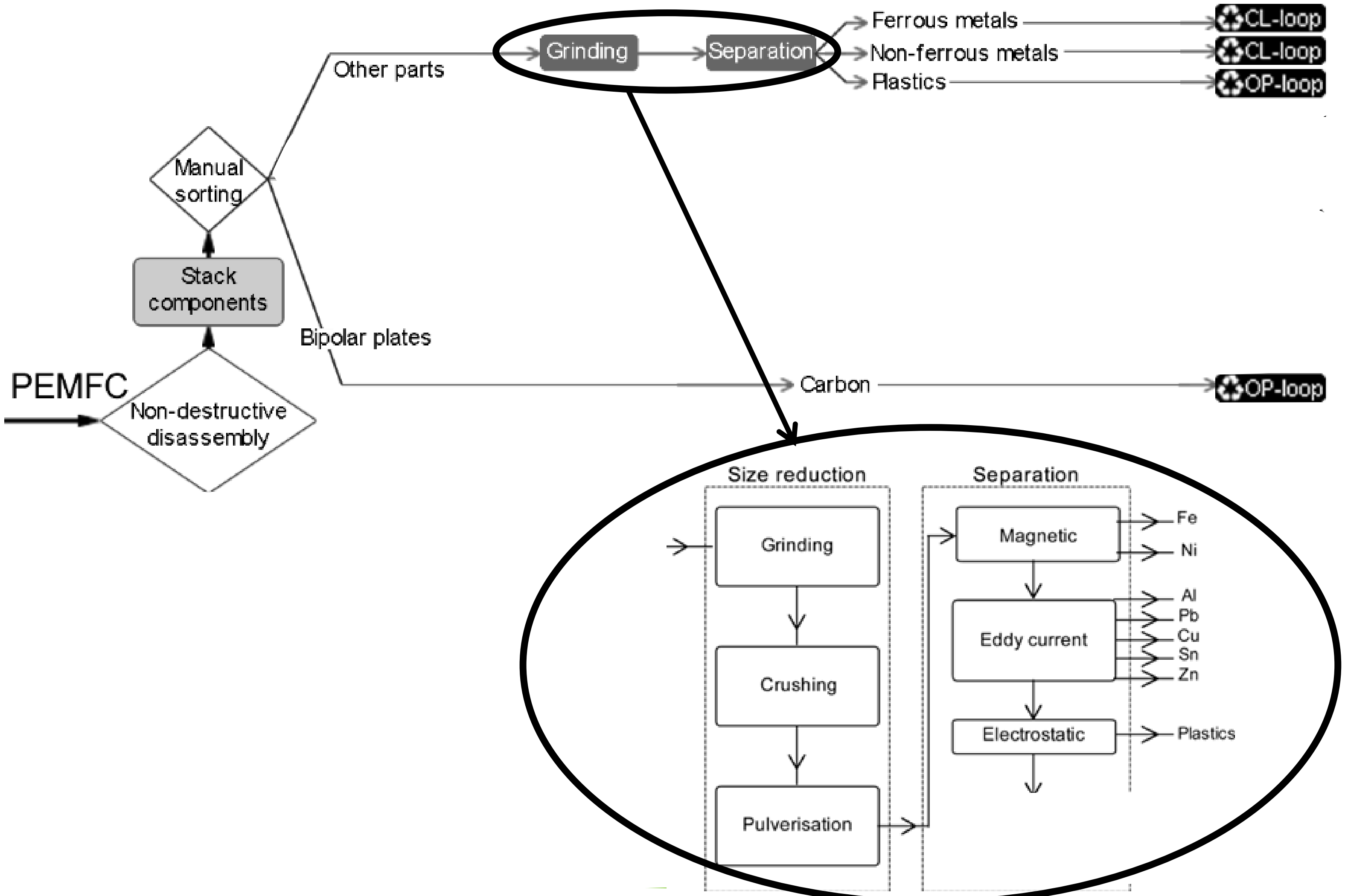


Existing and novel FCH technologies

Legend

- - -	Mutually excluding alternatives
(orange)	Existing technology (Addressed in WP2, D2.2)
(green)	Novel technology (Addressed in WP3, D3.1)
HMT	Hydrometallurgical
PMT	Pyrometallurgical
HDT	Hydrothermal
HMME	Hydrometallurgical mild extraction
SCT	Supercritical
BMT	Biometallurgical
EC	Electrochemical
AD	Alcohol dissolution
AP	Acid process
SED	Selective electrochemical dissolution
TD	Transient dissolution
CL-loop	Closed-loop recycling
OP-loop	Open-loop recycling

PEMFC's EoL technologies



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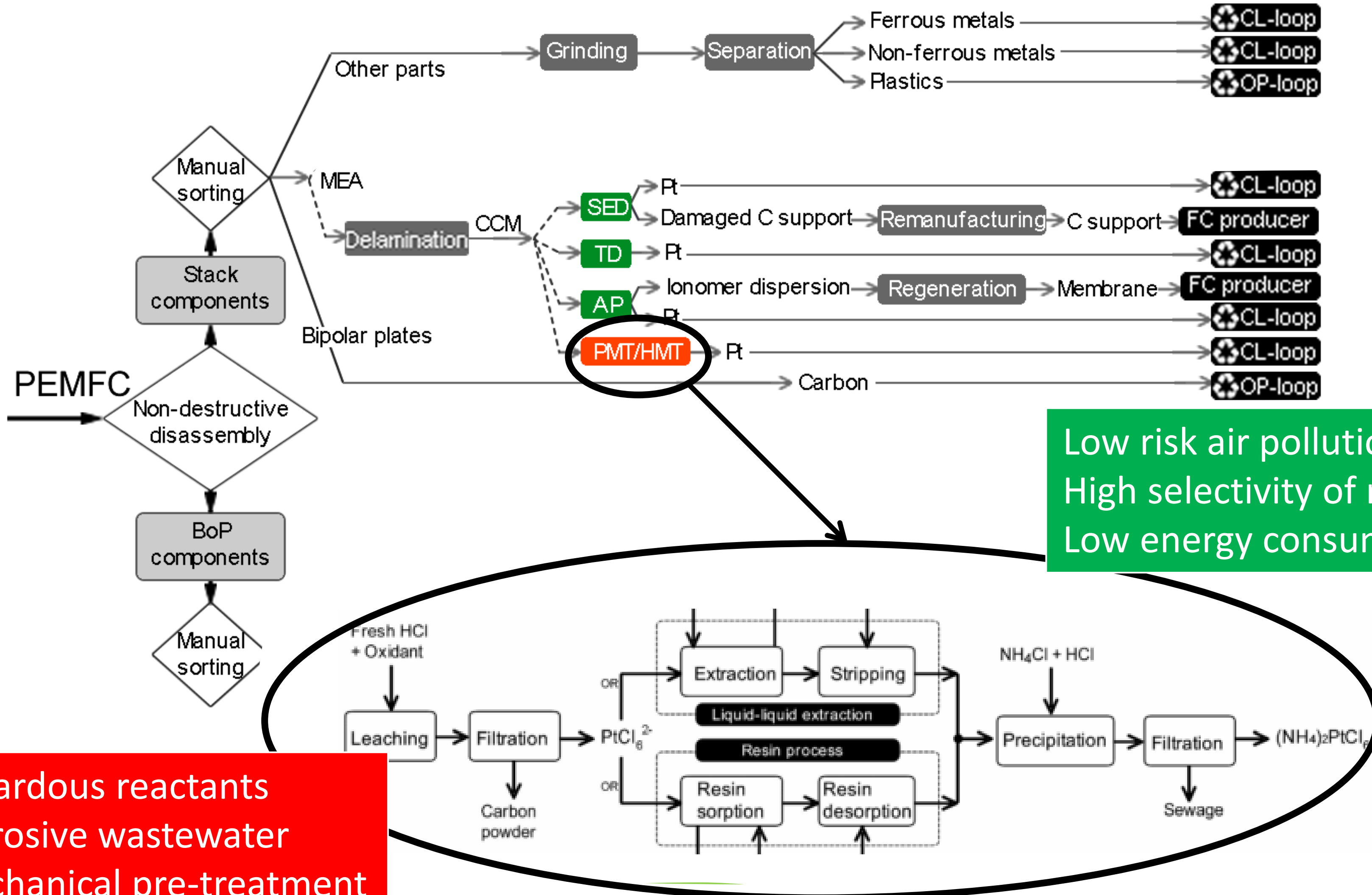
Hydrometallurgical process

(existing technology)

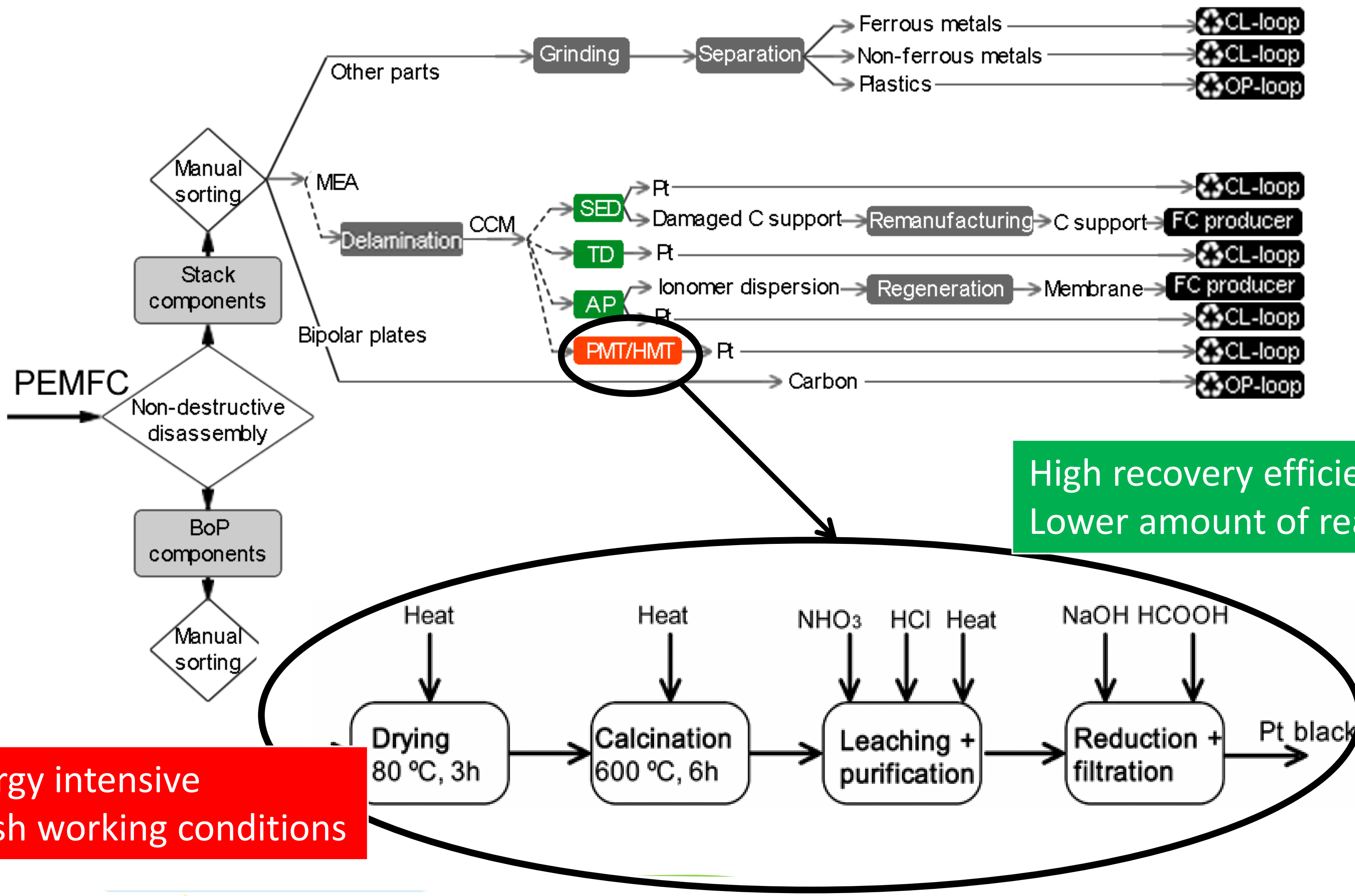


Low risk air pollution
High selectivity of materials
Low energy consumption

Hazardous reactants
Corrosive wastewater
Mechanical pre-treatment

Pyro-metallurgical process

(existing technology)



High recovery efficiency
Lower amount of reactants

Energy intensive
Harsh working conditions

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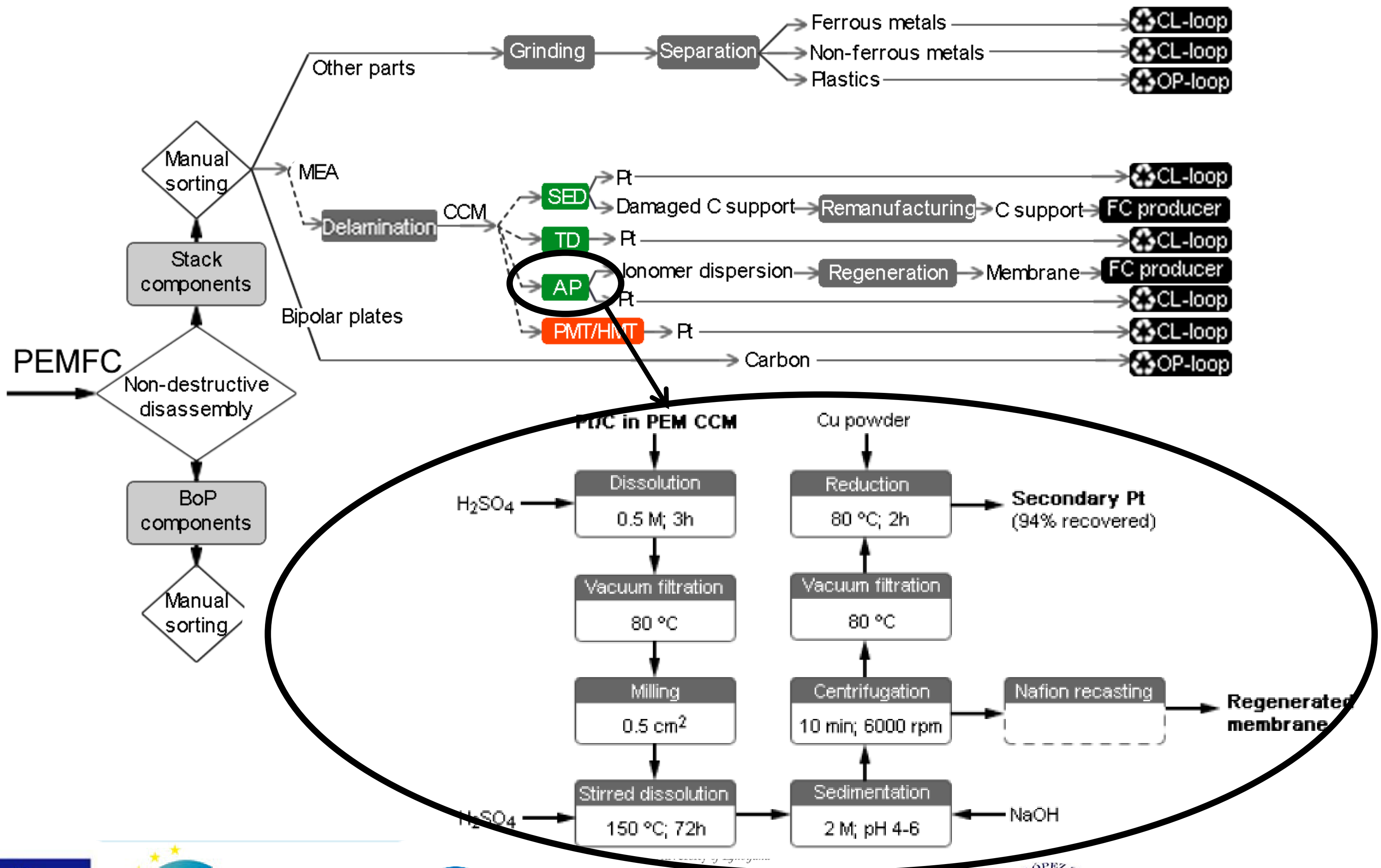
Acid process
(novel technology)



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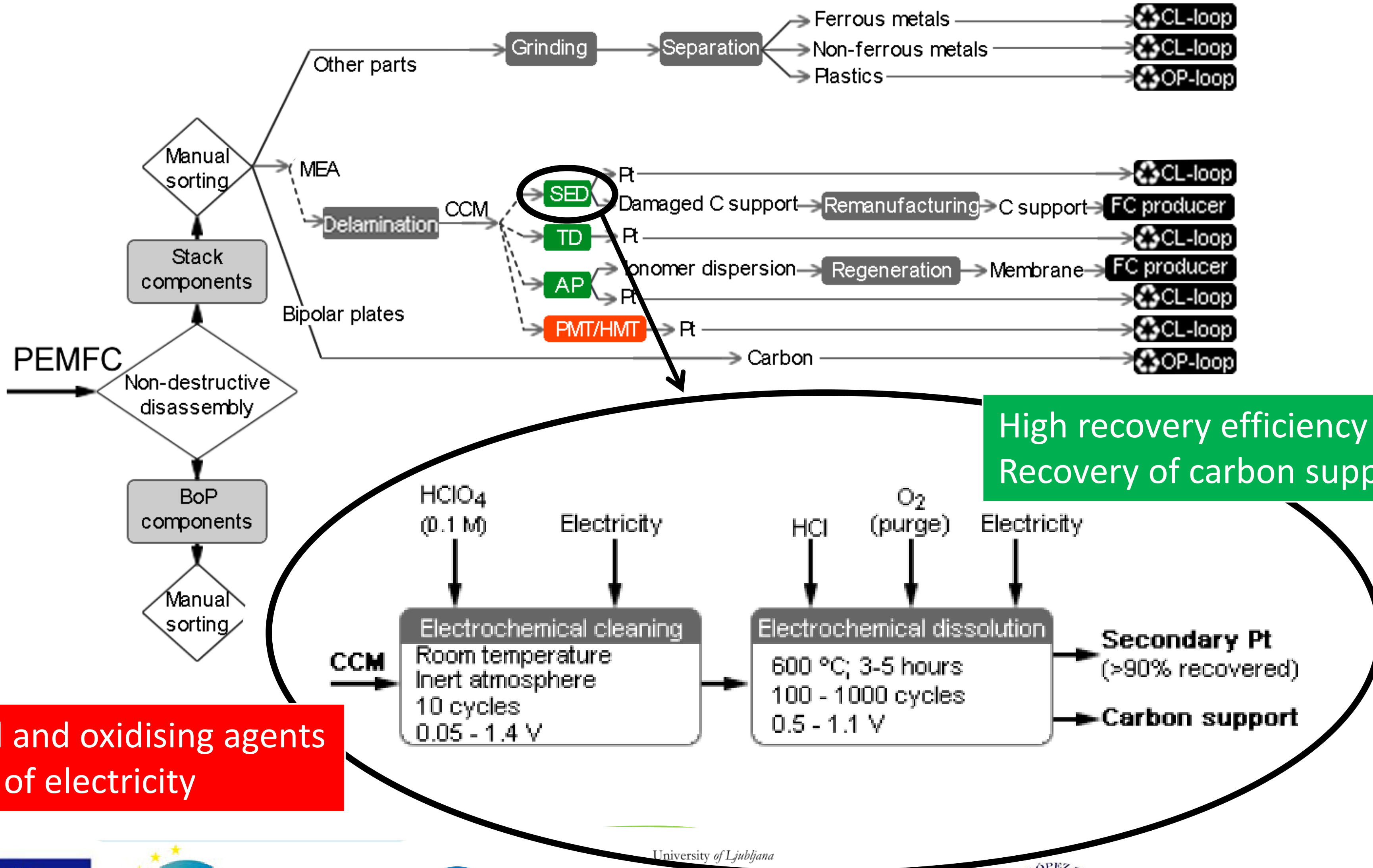
Selective electrochemical dissolution

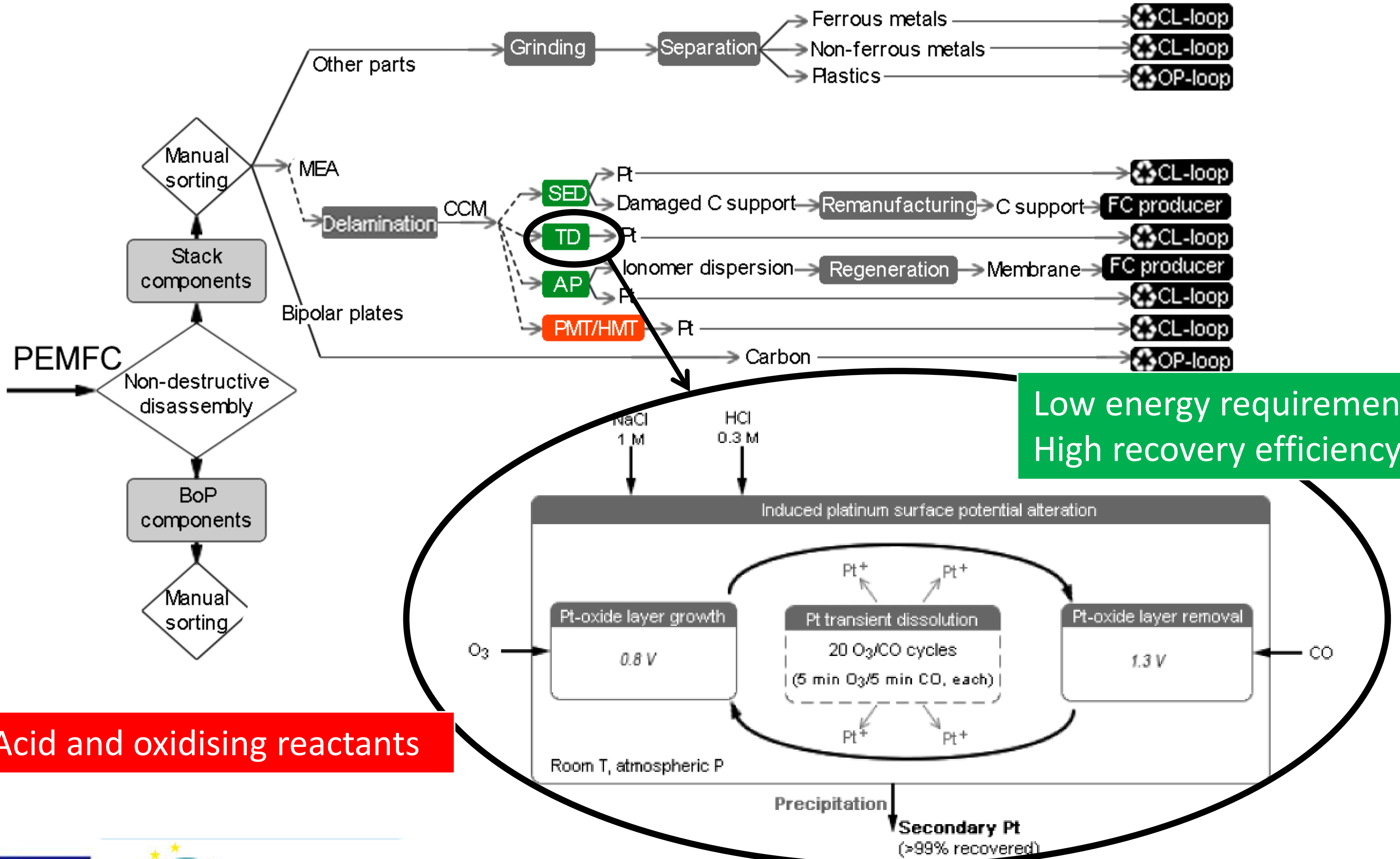
(novel technology)



High recovery efficiency
Recovery of carbon support

Acid and oxidising agents
Use of electricity

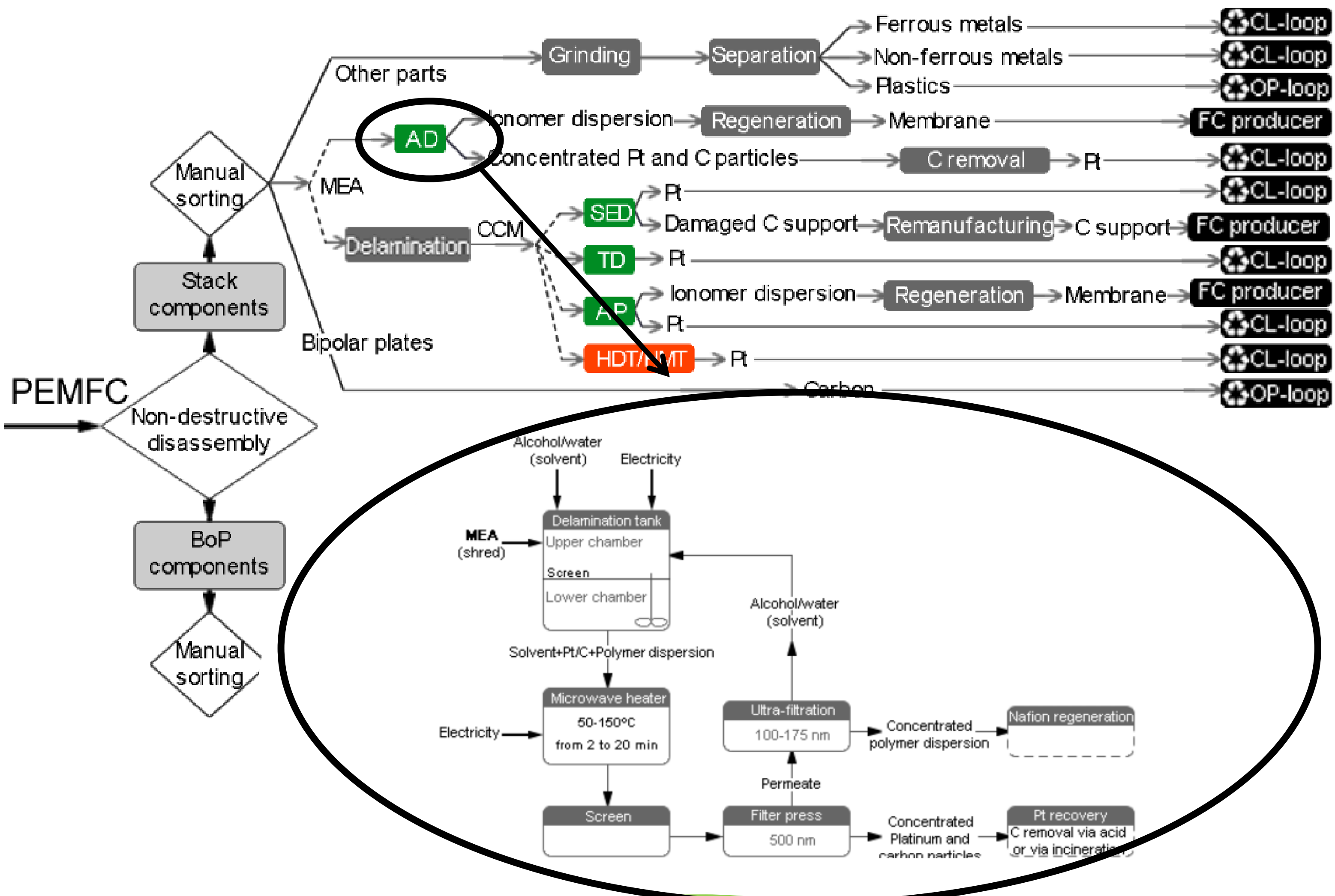
Transient dissolution process
(novel technology)



Low energy requirements
High recovery efficiency

Acid and oxidising reactants

Alcohol dissolution
(novel technology)



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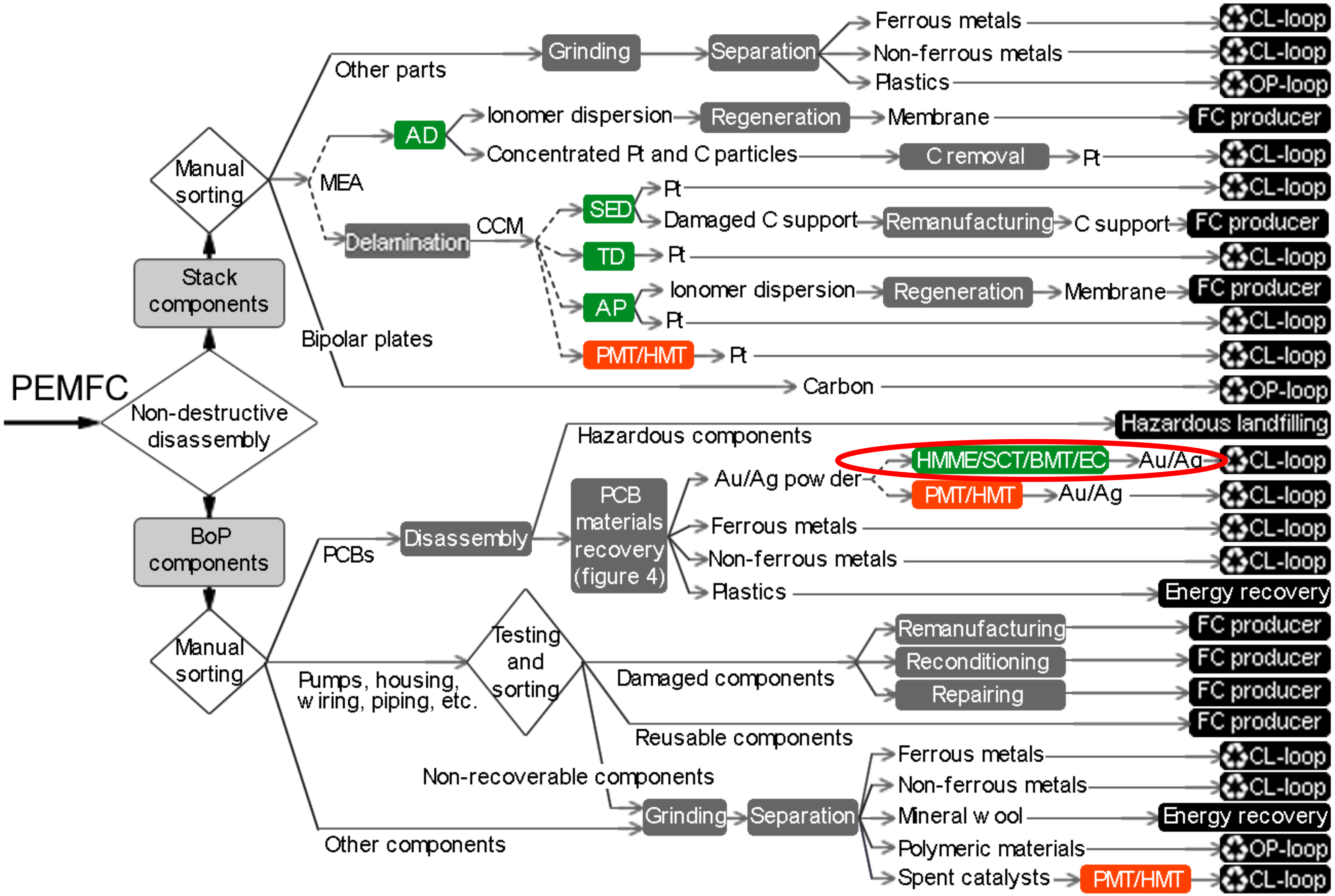
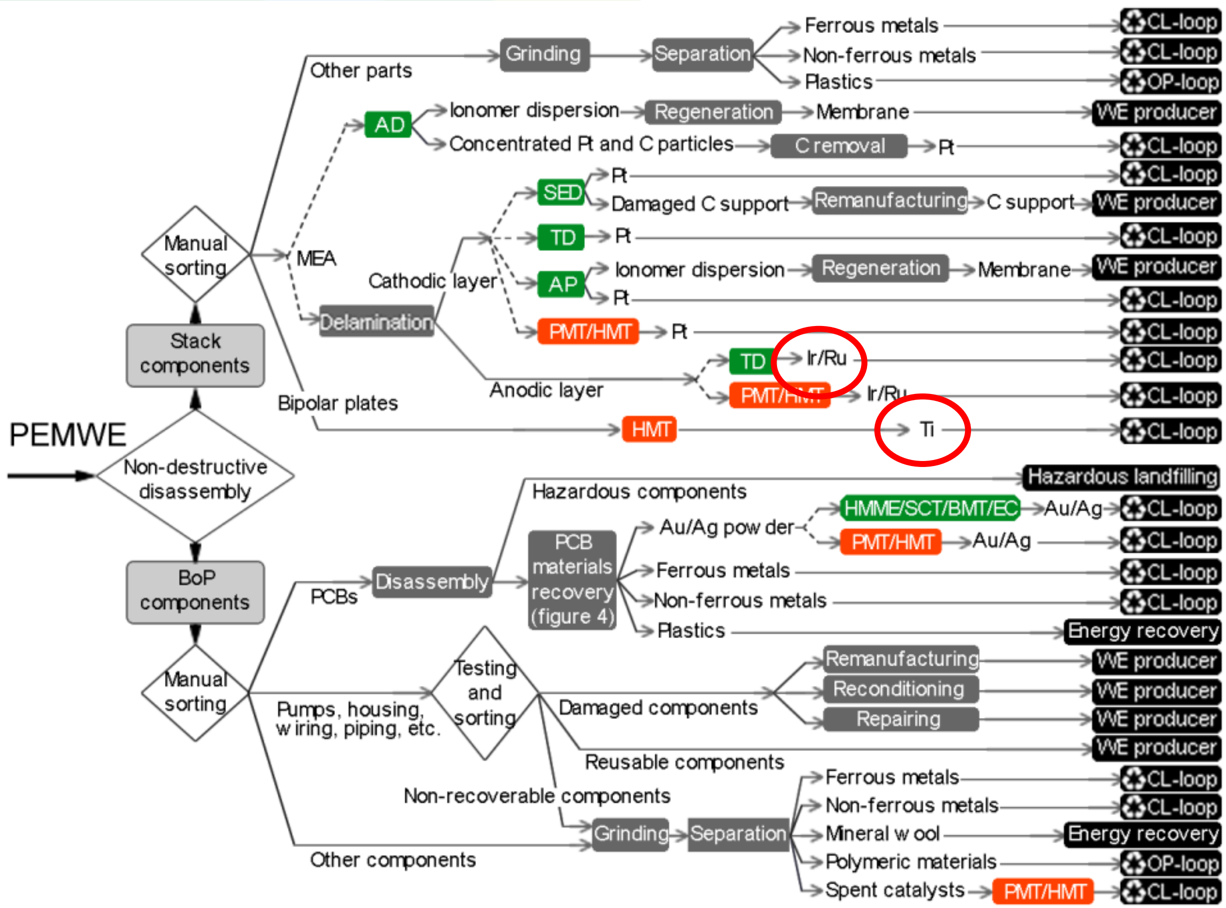
PEMFC's EoL technologies
(applicable to PEMFC's BoP components)



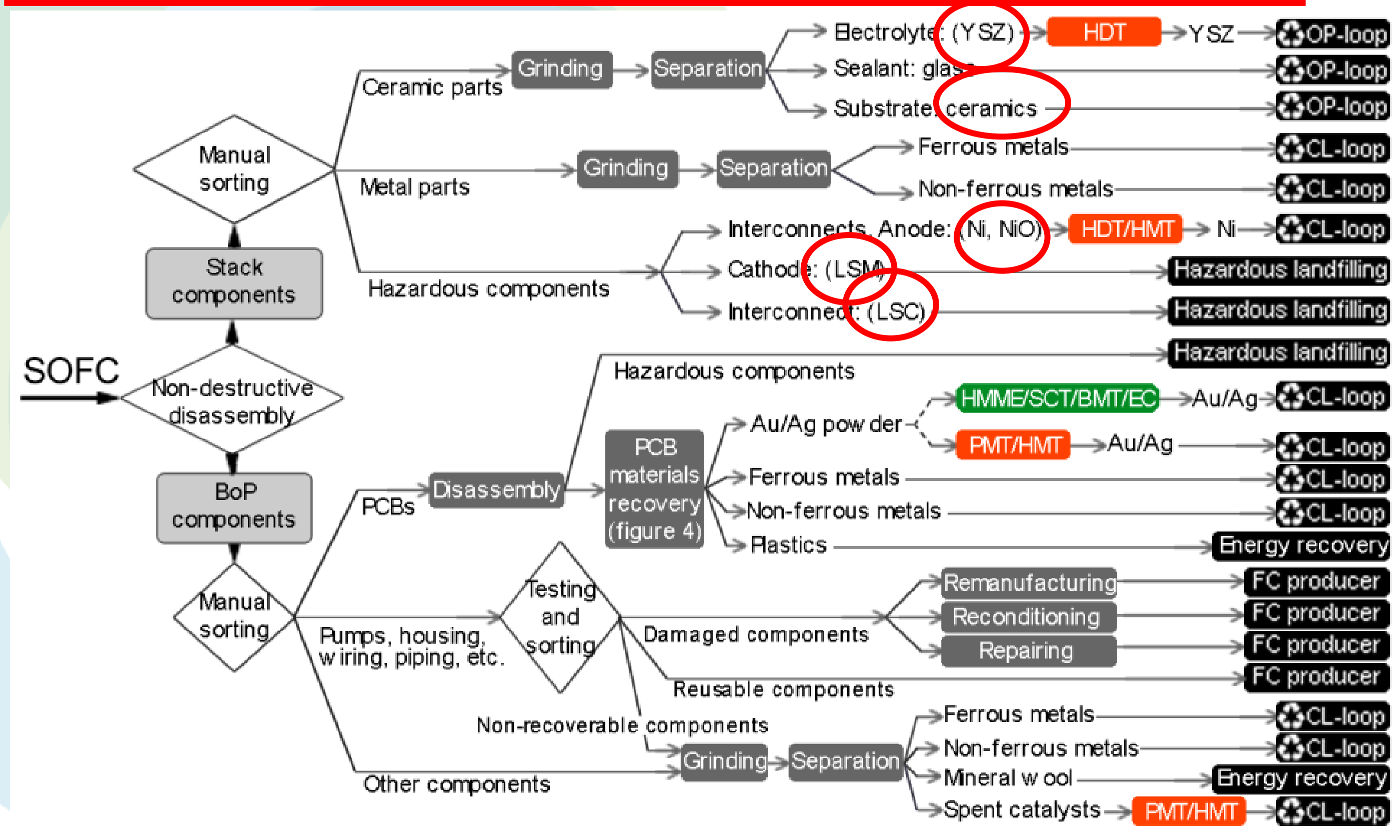
PEMWE's EoL technologies

PEMWE	Anode	Ir; Ru	Cost; hazard	HMT; PMT	TD
	Cathode	Pt	Cost	HMT; PMT	SED; TD; AP
	Electrolyte	Ionomer	Cost; hazard c	N/A	AD; AP
	Bipolar plates	Ti	Cost	HMT	N/A



SOFC's EoL technologies

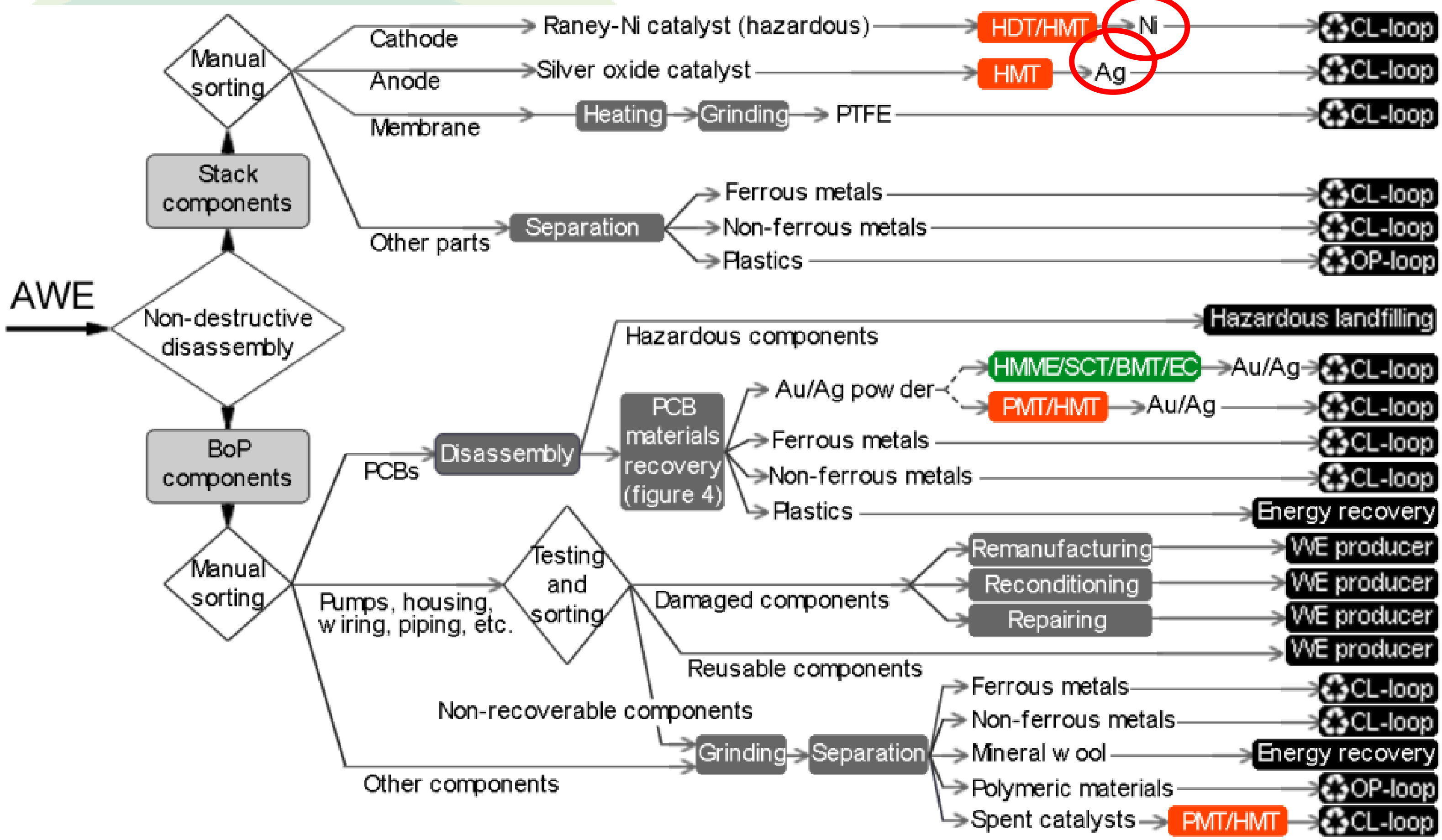
SOFC	Anode	YZS	Cost; supply risk	HDT	N/A
		Ni; NiO	Hazard	HDT; HMT	N/A
	Cathode	LSM	Hazard; supply risk	N/A	N/A
	Electrolyte	YZS	Cost; supply risk	HDT	N/A
	Interconnects	Ni; NiO	Hazard	HDT; HMT	N/A
		LSC	Hazard; supply risk	N/A	N/A



No plastics

AWE's EoL technologies

AWE	Anode	Ag	Cost	HMT	N/A
	Cathode	Ni; NiO	Hazard	HDT; HMT	N/A



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Existing and novel EoL technologies overview

Process [a]	Working conditions	Reactants	Energy requirements		Catalyst recycling yield	Further recovered materials	Duration
			Heat	Electricity			
SED	Harsh (T)	$HClO_4$, O_2, HCl	-	Moderate	~90%	C support	3-5 h
TD	Mild	NaCl, HCl, CO, O_3	-	-	~90%	-	~3 h
AP	Harsh (pH)	H_2SO_4, NaOH, Cu	Moderate	High	> 94%	Ionomer	>80 h
AD	Mild	Alcohol and water	-	Moderate	~90%	Ionomer	< 1 h
PMT	Harsh (pH,T)	Acids, HCl, NaOH, HNO_3	High	-	~90%	-	~10 h
HMT	Harsh (pH)	Oxidants, HCl, NH_4Cl, NaOH	-	-	< 80%	-	>24 h

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SWOT analysis

STRENGTHS	WEAKNESSES
PMT: S4, S10, S11, S12, S14	PMT: W1, W2, W3, W5, W7, W9, W10
HMT: S1, S2, S7, S10, S11, S14	HMT: W3, W4, W6, W9
AP: S4, S5, S9, S10, S14	AP: W1, W2, W3, W6, W7, W9, W10
SED: S1, S4, S5, S6, S8, S14	SED: W7, W9
AD: S2, S3, S4, S5, S6, S9, S13	AD: W1, W7, W8
TD: S1, S3, S4, S6, S10, S13, S14	TD: W9

OPPORTUNITIES	THREATS
PMT: O4, O5	PMT: T1, T2
HMT: O4, O5	HMT: T1
AP: O2, O4, O5	AP: T1, T2, T4
SED: O2, O3, O4, O5	SED: T1, T3, T4
AD: O1, O2, O3, O4, O5	AD: T3, T4
TD: O1, O2, O4, O5	TD: T1

Strengths
S1: Low investment cost
S2: Low operational costs
S3: Mild operating conditions
S4: High recovery efficiency
S5: Recovery of more than one material
S6: Fast process
S7: Low energy requirements
S8: Low complexity
S9: Toxic compound removal
S10: Versatile technology for other sectors
S11: Mature technology
S12: Co-processing of material from different sources
S13: Low environmental concerns
S14: High potential for reuse in high-value application

Weaknesses
W1: High investment costs
W2: High operational costs
W3: Harsh operating conditions
W4: Low recovery efficiency
W5: Applicable to only one type of material
W6: Lengthy process
W7: High energy requirements
W8: Low-value product
W9: Use of hazardous reactants
W10 Significant environmental concerns

Opportunities
O1: Potential economic incentives for eco-friendly techniques
O2: Potential breakthrough in technology
O3: Anticipated fulfilment of future circular economy targets
O4: High deployment of FCH technologies
O5: High social demand of green market

Threats
T1: More severe regulations on hazardous materials
T2: More severe restrictions on emission levels
T3: FCH deployment ruled out by policy-makers
T4: Increased electricity prices

Conclusions

www.hytechcycling.eu/downloads/

(Deliverable 2.2)

Existing end-of-life technologies applicable to FCH products.

A. Valente, M. Martín-Gamboa, D. Iribarren, J. Dufour, 2018

(Deliverable 3.1)

New end-of-life technologies applicable to FCH products.

A. Valente, D. Iribarren, J. Dufour, 2018

✔ Delivery of information at the EoL technology level

Next step:
Definition of EoL strategies beyond the technology level

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

HyTechCycling

HyTechCycling

Workshop

20th March 2018, Institute IMDEA Energy, Móstoles Madrid

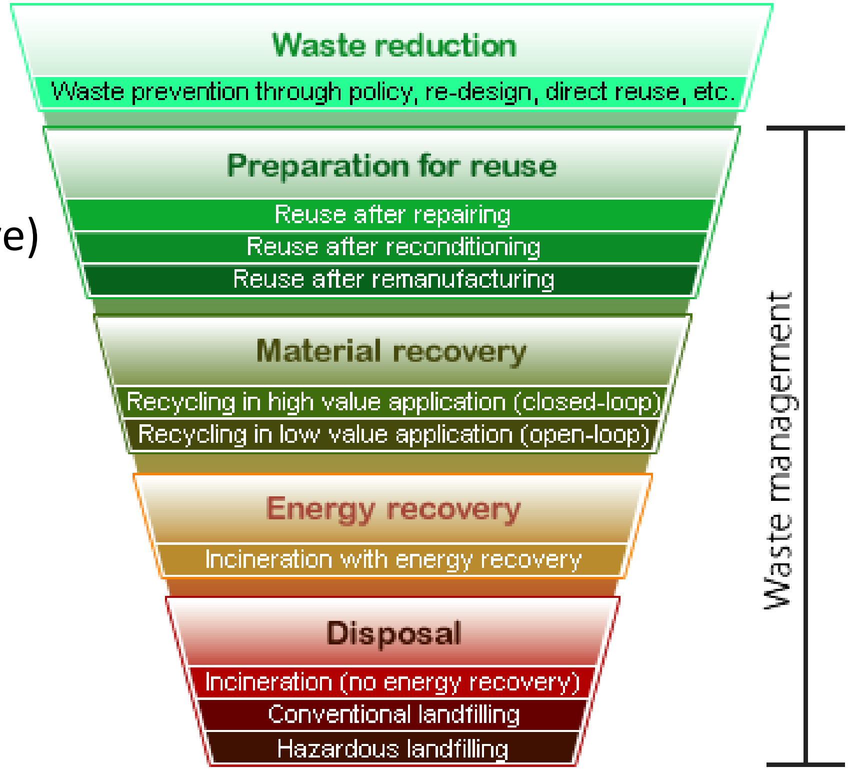
Results from "New strategies for FCH technologies in the phase of recycling and dismantling"

Antonio Valente, *Diego Iribarren, Javier Dufour - (IMDEA Energy - Systems Analysis Unit)*

Introduction

Alignment with the relevant European directives

(Eco-design Directive)
(Waste Electrical and Electronic Equipment Directive)
(Waste Framework Directive)



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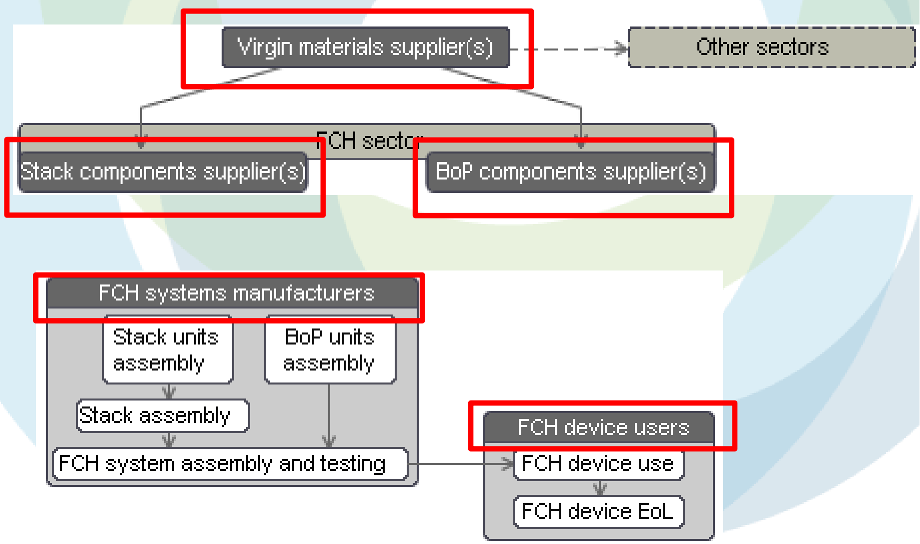
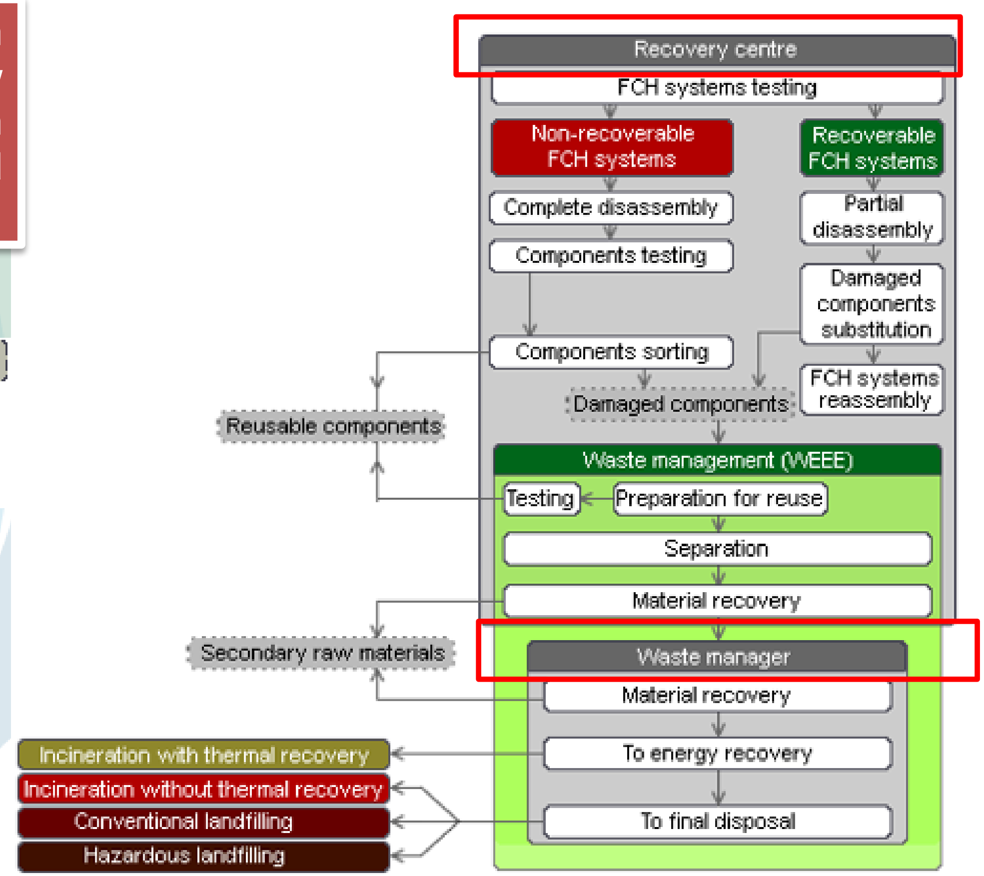
Main actors

- ✓ The main actors involved in the supply chain were identified in order to propose new strategies to optimise the FCH supply chain addressing aspects of logistic, eco-design and manufacturing practices.





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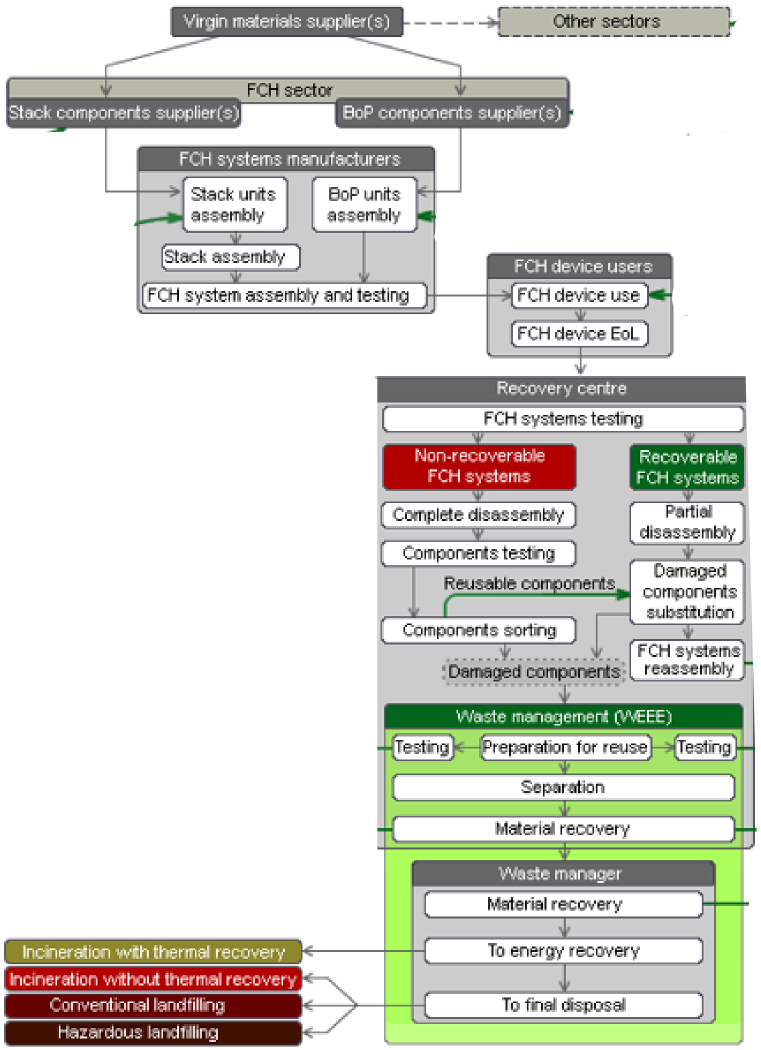
Global picture

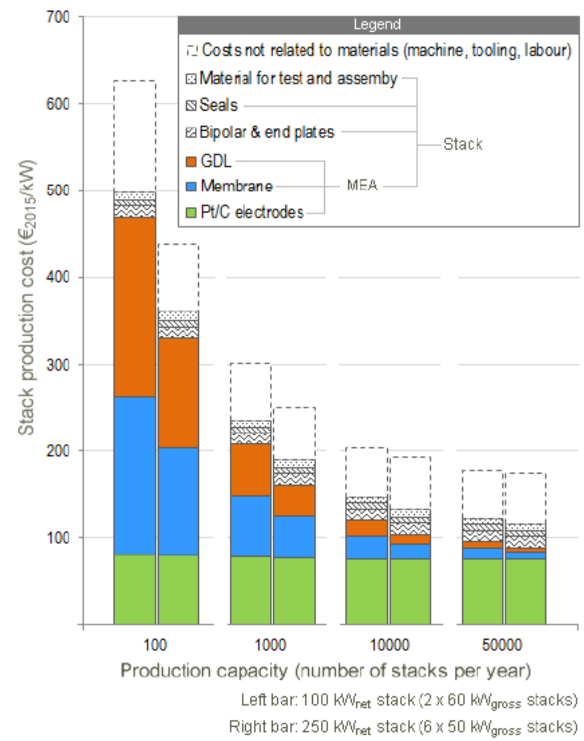


- Definition of **strategies**

Based on the role of the identified actors

Based on ecodesign

- **Material substitution / reduction**
- **Regulatory recommendations**
- **…**



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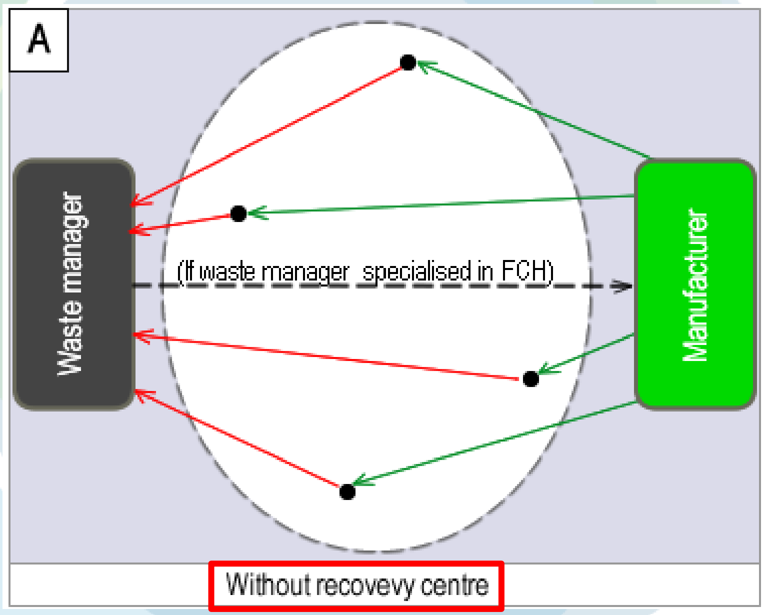
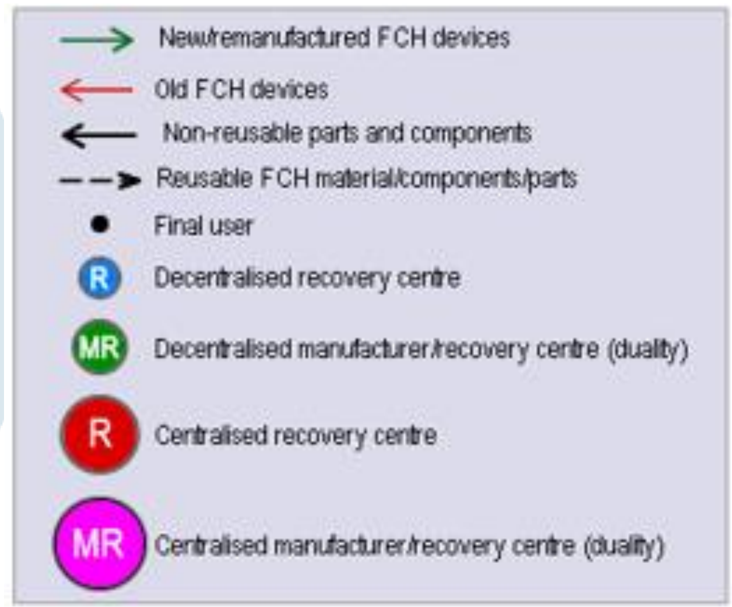
Scenarios

- ✓ The roles and the operations performed by **raw material suppliers**, FCH **component suppliers**, FCH **manufacturers**, FCH **users**, **waste managers** were defined. In particular, the role of a specialised **recovery centre** is emphasised in different scenarios of FCH market deployment.

Short-term scenario





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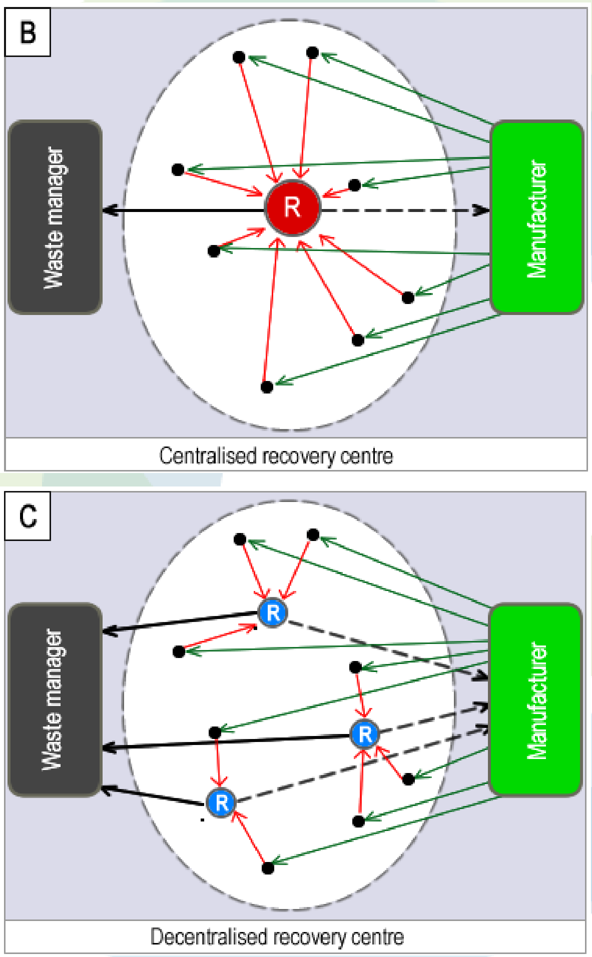
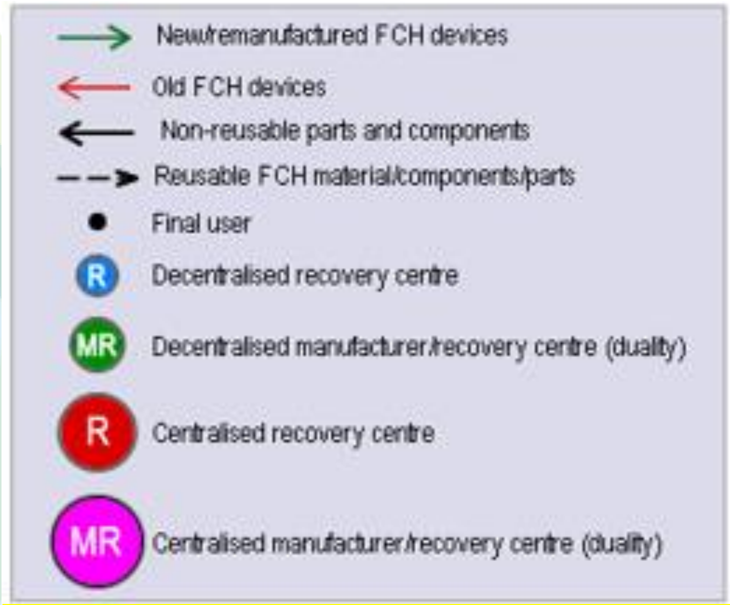
Scenarios

Mid-term scenario





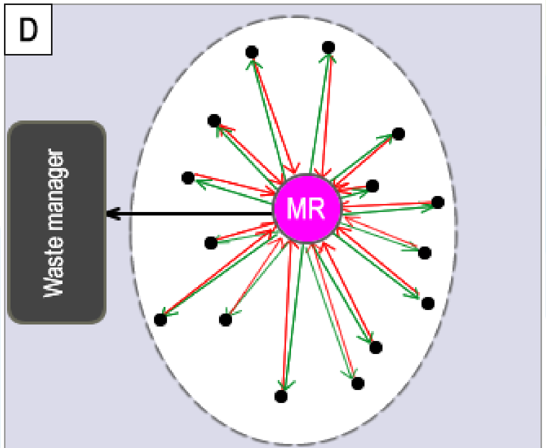
-RCs reduce the need for regular waste management

-Promote the reuse of components and materials → reducing costs of FCH products

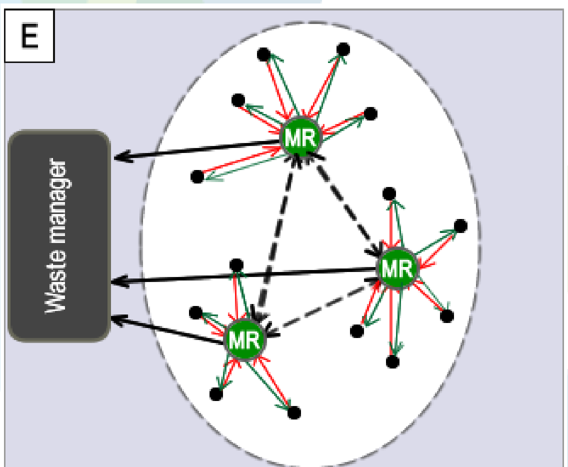
-Novel EoL technologies may start to be used together with existing ones

Scenarios

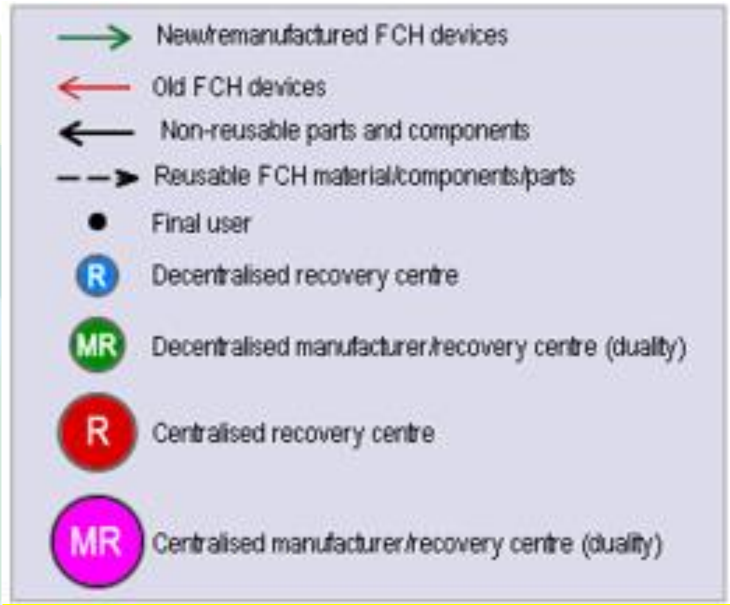
Long-term scenario



Centralised manufacturer/recovery centre (dual role actor)



Decentralised manufacturer/recovery centre (dual role actor)



Dual role ->higher control on the life-cycle-> optimisation of the supply chain

Need for logistic optimisation

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Conclusions

www.hytechcycling.eu/downloads/

(Deliverable 3.2)

New end-of-life strategies for FCH products.

A. Valente, D. Iribarren, J. Dufour, 2018

✔ Delivery of information at the strategy level

Next step:
Further research
business model *etc.*

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

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FCH JU Workshop, 20. March 2018, Madrid, Spain

HyTechCycling

LCA approach and LCA of materials represented in FCH technologies

Mitja Mori [a], Andrej Lotrič [a], Rok Stropnik [a], Boštjan Drobnič [a], Mihael Sekavčnik [a]

[a] University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, SI-1000, Ljubljana , Slovenia

HyTechCycling

Put the task into prospective

- Components identification
- Material classification
- LCI lists

Identify materials

Identify processes

- Currently used
- Legislation
- Newly proposed
- LCI lists

- **4.1 Methodoloy-done**
- **4.2 Materials-done**
- 4.3 Case studies with processes

LCA modelling

WP2

Materials, Processes

WP2+WP3

Current+New strategies

WP4

LCA modelling

FCH Fuel Cells and Hydrogen Joint Undertaking

Foundation for the Devolopment of New Hydrogen Technologies in Aragon

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HyTechCycling

Main objectives

Previous work

- **Criticality assessment of materials** used in core components of the FCH technologies under consideration: AWE, PEMWE, PEMFC, SOFC: D2.1
- **List of relevant materials & processes:** LCA study input (LCI table in LCA). D2.1 & D2.2
- **LCA study:** methodology, impact criteria and indicators, boundary conditions, etc.): D4.1

Objectives of this and future tasks

- **Link materials and processes** lists to LCA modelling stage D4.2;
- LCA of all available materials D4.2;

Next steps

- Define **reference model system** (power output/consumption, size/mass) D4.3
- Obtain data for **masses of materials** in each considered technology D4.3
- **Case studies** (stepwise approach)**:** D4.3

  Basic single LCA models: manufacturing, operation, EoL

  Combination of considered basic models

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LCA approach & methodology

Basic LCA approach

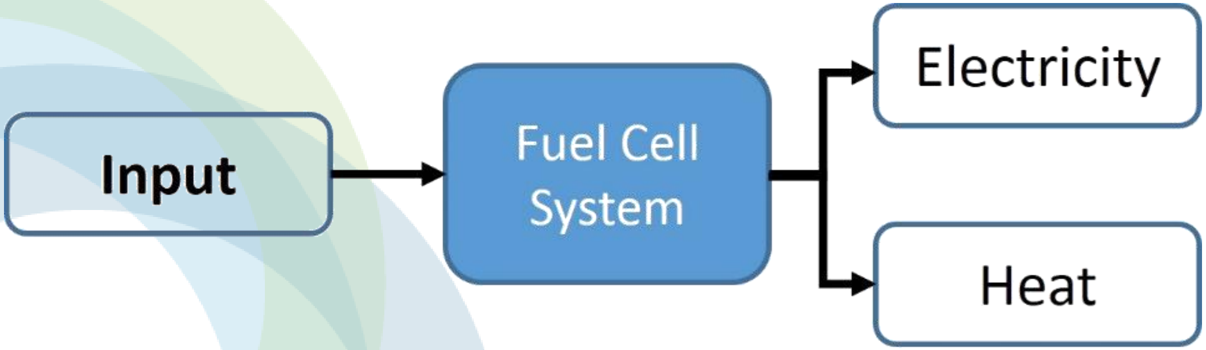
- Functional unit
- The scope
- Boundaries of the study
- Software & databases
- Cut-off criteria
- Life cycle impact assessment methodology

Life Cycle Inventory – from WP2 (Regulatory analysis, critical materials and components identification and mapping of recycling technologies) **and WP3** (New strategies and technologies)

LCA results from LCA of used materials in considered technologies

Basic LCA approach - FU

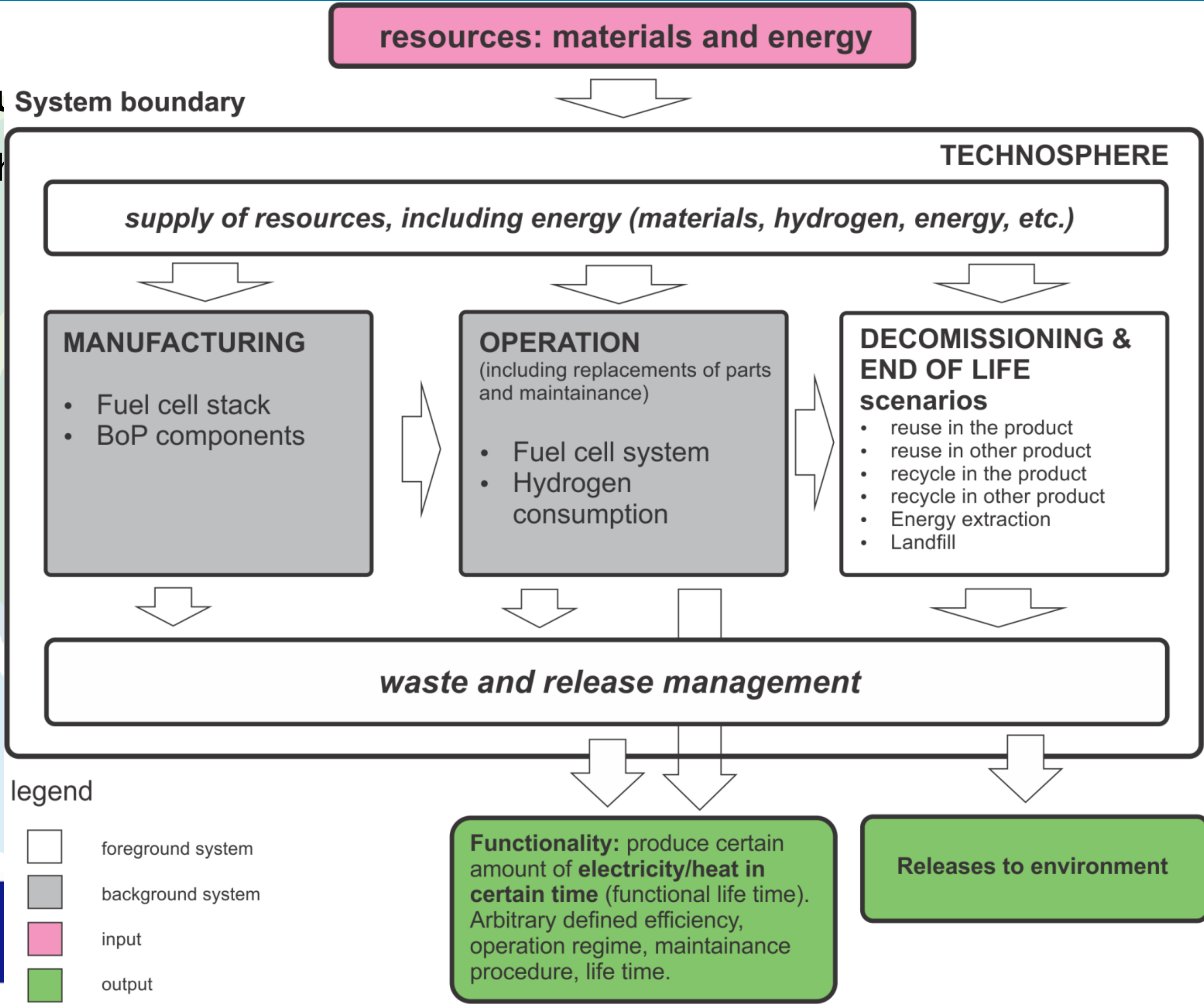
- **Functional unit**: 1kWh of exergy



Sketch of a FC unit as a multi-functional process

Basic LCA approach – The scope

- Fu
- Th



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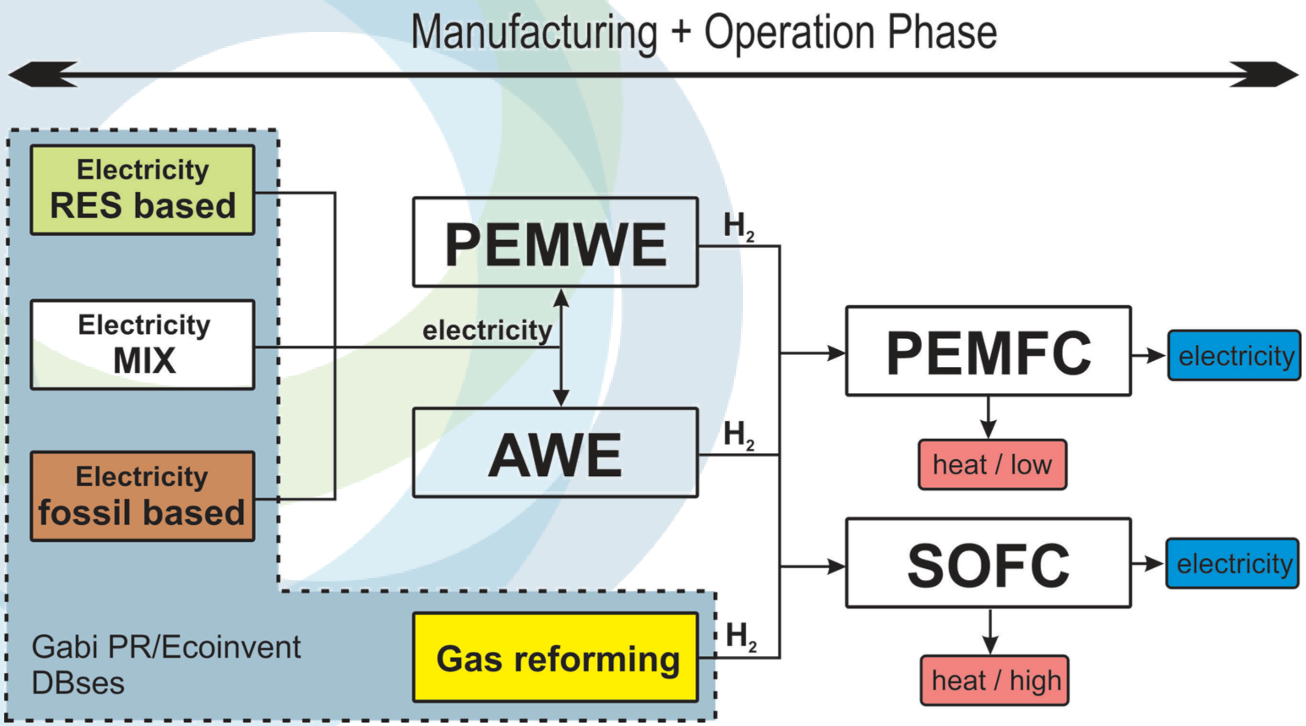
Basic LCA approach - technologies

- **Functional unit**: 1kWh of exergy
- **The Scope**: cradle to grave LCA approach (modelled step wise)
- **Boundaries:** considered technologies + gas reforming + electricity distribution



HyTechCycling Basic LCA approach: Software + DBses

- **Functional unit**: 1kWh of exergy
- **The Scope**: cradle to grave LCA approach (modelled step wise)
- **Boundaries:** considered technologies + gas reforming as reference case
- **Software:** Thinkstep Gabi
- **Databases**: Gabi PR + Ecoinvent 3.3 + purchasable DBses

Local content (25) Available datasets (0) Purchasable datasets (66)

Nation	Name	Type	Source	Parent Folder	QA	Last change
Processes						
DE	Hydrogen steam reforming, from natural gas | single route, at plant | 0.0899 kg/m3, 2 g/mol, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017
NL	Hydrogen steam reforming, from natural gas | single route, at plant | 0.0899 kg/m3, 2 g/mol, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017
NL	Hydrogen steam reforming, from heavy fuel oil | single route, at plant | 0.0899 kg/m3, 2 g/mol, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017
DE	Hydrogen steam reforming, from heavy fuel oil | single route, at plant | 0.0899 kg/m3, 2 g/mol, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017
RER	Hydrogen via steam cracker | production mix, at producer	agg	PlasticsEurop	PlasticsEurope	✓	1. 01. 2017
RER	Hydrogen via electrolysis | production mix, at producer	agg	PlasticsEurop	PlasticsEurope	✓	1. 01. 2017
RER	Hydrogen technology mix | production mix, at producer	agg	PlasticsEurop	PlasticsEurope	✓	1. 01. 2017
DE	Hydrogen (cracker) steam cracker, from naphtha | single route, at plant | 0.0899 kg/m3, 2 g/mol, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017
EU-28	Hydrogen (Europipeline) via Europipeline | single route, at plant | 0.0899 kg/m3, 2 g/cm3, 120 MJ/kg net calorific v...	agg	ts	Inorganic intermediate p	✓	1. 01. 2017

Life Cycle Impact Assessment – CML2001

Midpoint assessment method

Global indicators

- Abiotic Depletion (ADP elements) [kg Sb-Equiv.] & Abiotic Depletion (ADP fossil) [MJ]
- Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]
- Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2-Equiv.]
- Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]

Regional indicators

- Acidification Potential (AP) [kg SO2-Equiv.]
- Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]
- Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.

Local indicators

- Eutrophication Potential (EP) [kg Phosphate-Equiv.]
- Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
- Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
- Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]

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LCI of materials – Inventory table

Material	Technology	Availability in databases	EoL technologies according to D3.1 [3]
Aluminium	BoP	available[1]	conventional
Asbestos	AWE	available[1]	n.r.
Carbon	PEMFC	available[1]	SED
Cerium gadolinium oxide	SOFC	unavailable[2]	n.r.
Copper	BoP	available[1]	conventional
Glass-ceramic	SOFC	unavailable[2]	conventional; HDT
Graphite	PEMFC	available[1]	n.r.
Gold	BoP	available[1]	HMT; PMT; novel
Iridium	PEMWE	unavailable[2]	HMT; PMT
Lanthanum chromate	SOFC	purchasable[1]	N/A
Lanthanum Strontium Cobalt Ferrite	SOFC	unavailable[2]	N/A
Lead	BoP	available[1]	conventional
Lithium-ion ($LiFePO_4$)	BoP	available[1]	n.r.
Nickel	SOFC, AWE, BoP	available[1]	HDT; HMT
Nickel-based oxide doped with YSZ	SOFC	unavailable[2]	n.r.
Palladium	SOFC, PEMFC, BoP	available[1]	HMT; PMT; SED; TD; AP
PEEK	AWE, PEMWE, PEMFC	purchasable[1]	AP; AD
PFSC (Nafion)	AWE, PEMWE, PEMFC	purchasable[1]	AP; AD
Phyllosilicates (Vermiculite, Mica, …)	SOFC	available[1]	n.r.
Plastics	AWE, BoP	available[1]	conventional
Platinum	SOFC, PEMFC	available[1]	HMT; PMT; SED; TD; AP
Potassium Hydroxide	AWE	available[1]	n.r.
Rubber (Viton, Kalrez, Silicone, …)	AWE, PEMWE, PEMFC, BoP	available[1]	n.r.
Ruthenium	PEMWE, PEMFC	purchasable[1]	HMT; PMT
Silver	SOFC, AWE, BoP	available[1]	HMT
Steel product	SOFC, PEMWE, PEMFC, BoP	available[1]	conventional
Strontium-doped lanthanum manganite	SOFC	unavailable[2]	N/A
PTFE (Teflon)	AWE, PEMWE, PEMFC, BoP	purchasable[1]	AP; AD
Tin	BoP	available[1]	conventional
Titanium	PEMWE	available[1]	HMT
Yttria-stabilised zirconia (YSZ)	SOFC	unavailable[2]	HDT

[1] available or purchasable in Ecoinvent 3.3
[2] unavailable in GaBi or Ecoinvent 3.3 databases
[3] HDT: hydrothermal treatment; HMT: hydrometallurgical treatment; PMT: pyrometallurgical treatment; TD: transient dissolution; AP: acid process; SED: selective electrochemical dissolution; AD: alcohol dissolution; N/A: not available; n.r.: not reported

LCI of materials – numerical model

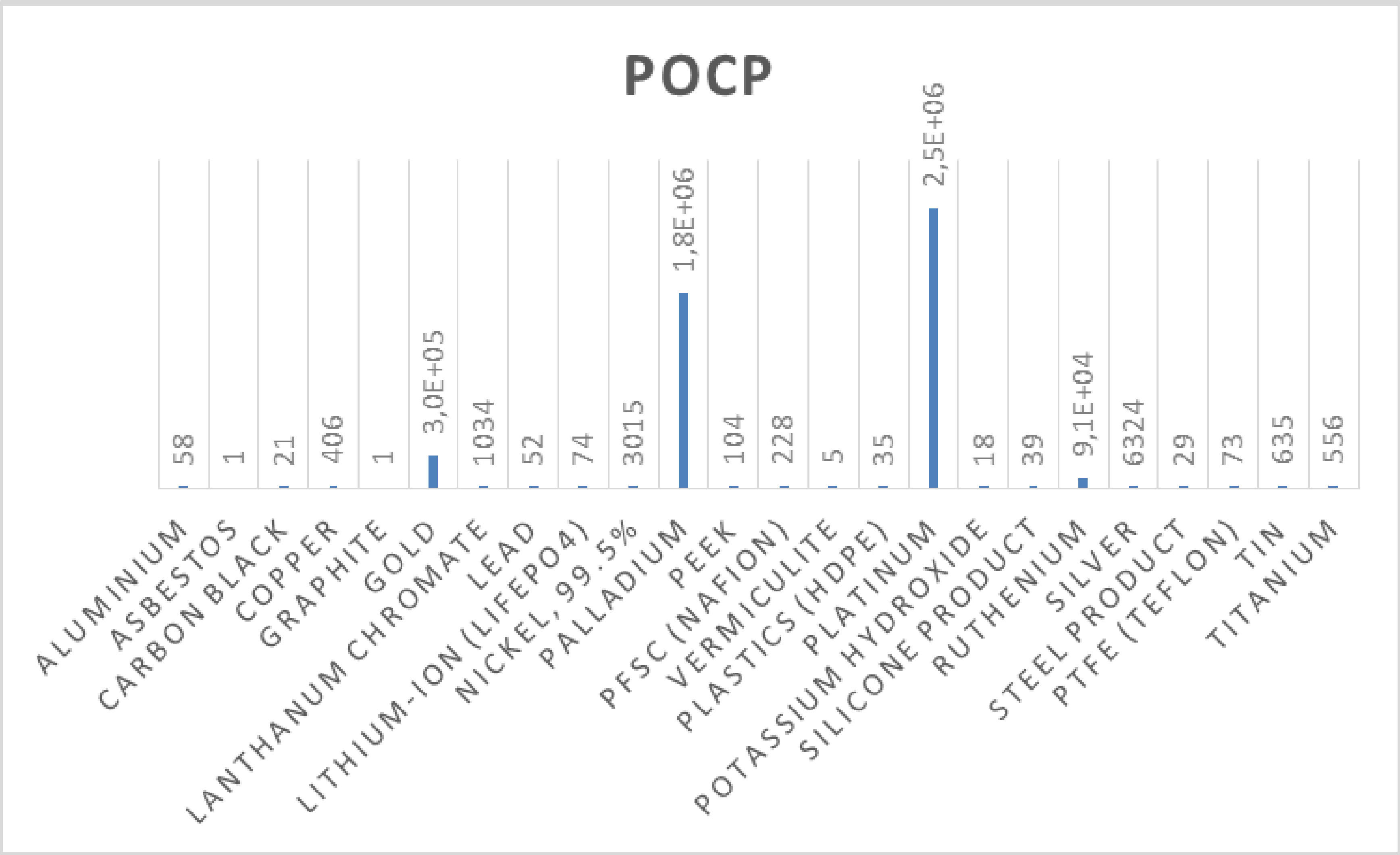
Hytechcycling - materials in production phase_v2

Process plan: Mass [kg]
The names of the basic processes are shown.

EU-28: Aluminium ingot mix ts	CA: Nafion - for use in fuel cell ts
GLO: market for asbestos, crysotile type ecoinvent 3.3	GLO: market for vermiculite ecoinvent 3.3
GLO: market for carbon black ecoinvent 3.3	GLO: market for polyethylene, high density, granulate
GLO: market for copper ecoinvent 3.3	GLO: market for platinum ecoinvent 3.3
GLO: market for graphite ecoinvent 3.3	GLO: market for potassium hydroxide ecoinvent 3.3
GLO: market for gold ecoinvent 3.3	GLO: market for silicone product ecoinvent 3.3
EU-28: Lanthanum Chromate production (estimation) ts	ZA: Ruthenium ts
GLO: market for lead ecoinvent 3.3	GLO: market for silver ecoinvent 3.3
DE: Lithium Iron Phosphate/ Carbon Composition (cathode active material) ts	GLO: market for metal working, average for steel product manufacturing ecoinvent 3.3
GLO: market for nickel, 99.5% ecoinvent 3.3	DE: Polytetrafluoroethylene granulate (PTFE) Mix ts
GLO: market for palladium ecoinvent 3.3	RoW: tin production ecoinvent 3.3
DE: Polyetherether ketone granulate (PEEK) ts	GLO: market for titanium, primary ecoinvent 3.3

Results are discussed with **12 environmental indicators** and for 1g of all invelved materials in their production stage → **Functional unit**: 1g of identified material

Results: 12 indicators / all materials



Normalized to minimal value for each specific impact indicator

Results: 12 indicators / all materials

- **Gold** has the biggest impact of all materials – present mainly in BoP components
- **Platinum group** (platinum, palladium, ruthenium, irridium) and **silver** have very big impact
- If PGM metals, silver and gold are excluded, the biggest impact come from: **Nickel and Titanium**
- **Cobalt** has also relatively big impact but comes mainly in alloys that are present in SOFC

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Results: technologies - PEMFC

	ADP elements	ADP fossil	AP	EP	FAETP	GWP	GWP, ex. biogenic carbon	HTP	MAETP	ODP	POCP	TETP
Carbon black	4,3E+01	9,3E+01	2,2E+01	2,2E+01	3,4E+01	3,4E+01	3,4E+01	2,4E+01	3,1E+01	6,0E+05	2,1E+01	2,3E+01
Graphite	1,0E+00	1,0E+00	1,0E+00	1,0E+00	3,1E+00	1,0E+00	1,0E+00	1,0E+00	3,1E+00	4,6E+03	1,0E+00	1,0E+00
Palladium	4,6E+06	6,3E+04	3,4E+06	2,8E+05	2,7E+06	6,8E+04	6,8E+04	3,9E+05	1,5E+06	1,3E+08	1,8E+06	7,8E+04
PEEK	1,8E+02	3,7E+02	9,8E+01	3,1E+01	1,3E+01	2,3E+02	2,3E+02	1,8E+01	4,2E+01	2,4E+01	1,0E+02	3,4E+01
PFSC (Nafion)	1,1E+03	2,3E+03	7,7E+02	6,7E+02	1,0E+00	1,1E+04	1,1E+04	1,0E+00	1,0E+00	1,0E+00	2,3E+02	1,2E+00
Platinum	1,9E+07	3,4E+05	4,8E+06	2,0E+06	1,4E+07	3,8E+05	3,8E+05	2,5E+06	9,8E+06	4,7E+08	2,5E+06	3,8E+05
Silicone product	1,1E+02	4,9E+01	3,2E+01	3,5E+01	2,1E+02	4,3E+01	4,2E+01	4,3E+01	3,3E+02	1,1E+06	3,9E+01	3,0E+01
Ruthenium	3,2E+06	6,9E+04	1,5E+05	2,5E+04	8,7E+02	8,5E+04	8,5E+04	1,2E+04	2,8E+04	1,3E+05	9,1E+04	2,2E+04
Steel product	8,0E+01	2,3E+01	2,1E+01	3,8E+01	5,6E+02	2,9E+01	2,8E+01	7,7E+01	6,6E+02	6,1E+04	2,9E+01	1,6E+02
PTFE (Teflon)	1,4E+04	2,2E+02	7,6E+01	2,1E+01	5,3E+00	1,6E+02	1,6E+02	1,2E+01	3,6E+01	3,3E+05	7,3E+01	2,7E+01

In the table the most environmentally influential materials are marked with red bracket

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Results: technologies - PEMWE

PEEK	2,3E+00	1,6E+01	4,6E+00	1,5E+00	1,3E+01	7,9E+00	8,1E+00	1,7E+01	4,2E+01	2,4E+01	3,6E+00	2,9E+01
PFSC (Nafion)	1,4E+01	1,0E+02	3,6E+01	3,2E+01	1,0E+00	3,8E+02	3,9E+02	1,0E+00	1,0E+00	1,0E+00	7,9E+00	1,0E+00
Silicone product	1,4E+00	2,1E+00	1,5E+00	1,7E+00	2,1E+02	1,5E+00	1,5E+00	4,2E+01	3,3E+02	1,1E+06	1,3E+00	2,6E+01
Ruthenium	4,0E+04	3,0E+03	7,0E+03	1,2E+03	8,7E+02	2,9E+03	3,0E+03	1,2E+04	2,8E+04	1,3E+05	3,1E+03	1,9E+04
Steel product	1,0E+00	1,0E+00	1,0E+00	1,8E+00	5,6E+02	1,0E+00	1,0E+00	7,5E+01	6,6E+02	6,1E+04	1,0E+00	1,4E+02
PTFE (Teflon)	1,7E+02	9,8E+00	3,6E+00	1,0E+00	5,3E+00	5,5E+00	5,7E+00	1,2E+01	3,6E+01	3,3E+05	2,5E+00	2,3E+01
Titanium	7,2E+00	1,5E+01	1,5E+01	3,2E+01	2,6E+03	1,4E+01	1,5E+01	4,3E+02	2,1E+03	2,0E+06	1,9E+01	2,6E+02

In the table the most environmentally influential materials are marked with red bracket

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Results: technologies - AWE

	ADP elements	ADP fossil	AP	EP	FAETP	GWP	GWP, ex. biogenic carbon	HTP	MAETP	ODP	POCP	TETP
Asbestos	1,0E+00	1,0E+00	1,0E+00	1,0E+00	3,2E+00	1,0E+00	1,0E+00	1,0E+00	3,3E+00	4,5E+03	1,0E+00	1,0E+00
Nickel, 99.5%	7,8E+03	1,1E+02	5,4E+03	7,9E+02	8,0E+03	1,4E+02	1,4E+02	1,6E+03	4,5E+03	3,7E+05	2,9E+03	4,3E+02
PEEK	1,8E+02	3,6E+02	9,4E+01	3,0E+01	1,3E+01	2,2E+02	2,2E+02	1,7E+01	4,2E+01	2,4E+01	1,0E+02	3,3E+01
PFSC (Nafion)	1,1E+03	2,3E+03	7,4E+02	6,5E+02	1,0E+00	1,1E+04	1,1E+04	1,0E+00	1,0E+00	1,0E+00	2,2E+02	1,2E+00
Plastics (HDPE)	2,2E+00	7,2E+01	1,3E+01	5,2E+00	1,4E+01	2,6E+01	2,6E+01	3,3E+00	1,9E+01	8,0E+03	3,3E+01	1,4E+00
Potassium hydroxide	1,0E+02	2,5E+01	2,1E+01	3,0E+01	1,4E+02	2,7E+01	2,7E+01	3,8E+01	1,4E+02	7,6E+04	1,7E+01	4,0E+01
Silicone product	1,1E+02	4,8E+01	3,0E+01	3,4E+01	2,1E+02	4,1E+01	4,0E+01	4,2E+01	3,3E+02	1,1E+06	3,7E+01	2,9E+01
Silver	4,3E+06	3,9E+03	5,8E+03	4,0E+04	2,1E+05	4,2E+03	4,3E+03	5,0E+04	1,8E+05	1,5E+07	6,1E+03	5,2E+03
PTFE (Teflon)	1,4E+04	2,2E+02	7,3E+01	2,0E+01	5,3E+00	1,5E+02	1,5E+02	1,2E+01	3,6E+01	3,3E+05	7,0E+01	2,6E+01

In the table the most environmentally influential materials are marked with red bracket

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Results: technologies - SOFC

Material	Technology	Availability in databases	EoL technologies according to D3.1 [3]
Cerium gadolinium oxide	SOFC	unavailable[2]	n.r.
Glass-ceramic	SOFC	unavailable[2]	conventional; HDT
Lanthanum chromate	SOFC	purchasable[1]	N/A
Lanthanum Strontium Cobalt Ferrite	SOFC	unavailable[2]	N/A
Nickel	SOFC, AWE, BoP	available[1]	HDT; HMT
Nickel-based oxide doped with YSZ	SOFC	unavailable[2]	n.r.
Palladium	SOFC, PEMFC, BoP	available[1]	HMT; PMT; SED; TD; AP
Phyllosilicates (Vermiculite, Mica, …)	SOFC	available[1]	n.r.
Platinum	SOFC, PEMFC	available[1]	HMT; PMT; SED; TD; AP
Silver	SOFC, AWE, BoP	available[1]	HMT
Steel product	SOFC, PEMWE, PEMFC, BoP	available[1]	conventional
Strontium-doped lanthanum manganite	SOFC	unavailable[2]	N/A
Yttria-stabilised zirconia (YSZ)	SOFC	unavailable[2]	HDT

[1] available or purchasable in Ecoinvent 3.3

[2] unavailable in GaBi or Ecoinvent 3.3 databases

[3] HDT: hydrothermal treatment; HMT: hydrometallurgical treatment; PMT: pyrometallurgical treatment; TD: transient dissolution; AP: acid process; SED: selective electrochemical dissolution; AD: alcohol dissolution; N/A: not available; n.r.: not reported

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Final remarks

- LCA of materials is done.
- Materials with biggest environmental impact are identified and quantified through indicators – done without SOFC materials?!
- The contribution to overall environmental impact of single material will be different in case studies of considered technologies – data needed from industry stakeholders.

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Future work and data needed

- Materials were assessed according to LCA methodology → **done!**
- Obtain **masses of materials** in FCH reference systems → **request to AB sent!**
- Obtain **LCI data for SOFC** materials and their recycling/dismantling processes → **othr. software techniques (budget)!**
- Set up **reference models** for each considered FCH technology → **under construction!**
- Mass in energy balance in EoLa to assess recycling and dismantling technologies → **not started yet!**
- Define different **scenarios after analysis of basic LCA models!**

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

HyTechCycling

http://hytechcycling.eu/

Mitja Mori: mitja.mori@fs.uni-lj.si

Thank you for your attention!

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Results analysis of the questionnaires to FCH manufacturers, recycling centers, distributors and end users

Speaker: Sabina Fiorot
Environment Park

Location:
Institute IMDEA Energy
Parque Tecnológico de Móstoles Avda. Ramón de la Sagra, 3. 28935, Móstoles Madrid

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Objectives

Involve all FCH lifetime actors

new strategies for recycling and dismantling phases

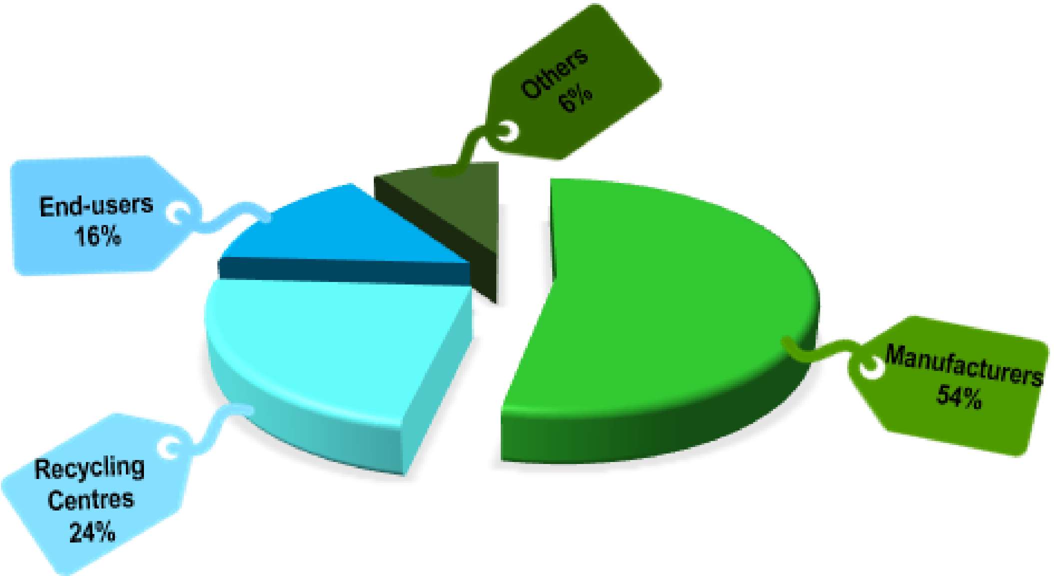
Collect FCH actors needs and worries as regards FCH's end-of-life

Analyze those needs and concerns

Help establishing a business model

FCHs ACTORS

75 companies contacted, 54% of them were manufacturers, 24% were recycling centers, 16% end-users and 6% companies considered as other. The latter are mainly associations or organizations, directly or indirectly involved in Hydrogen Technologies and recycling -such as EFCF the European Fuel Cell Forum- through which it was possible to access to a broader network of manufacturers, recycling centers, end-users and distributors.



End-of-life issues/Manufacturer point of view

- **End users**: 33% Energy Utilities; 25% automotive companies; 17% chemical industries; 8% telecommunication companies
- **End users**: System integrators; Stack producers; installation companies; OeM, integrators
- **60%**: Use logistics companies to truck devices to end users → Mainly standard logistic companies
- **80%**: Sell directly the product without distributors. The distributors are mainly installation companies → 1 in no-EU countries use distributors

End-of-life issues/Manufacturer point of view

- **100%** interested in buying FCH recycled materials → 1 have an agreement with recycling centers
- **60%** Have yet collected EoL devices from end users → 80% more than 10 old devices
- **30%** Internally have a specific area that work on EoL devices
- **90%** think it is profitable (having internally a EoL dedicated sector)

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End-of-life issues/RCs point of view

HTM-hydrometallurgical
PMT-pyrometallurgical

50% Have the technology required for FCHs recovery

60% Think about investing in technology for recycling FCH

For the other 40%, investment depends on the market and methods employed

84% have no reluctance in treating FCH technology

40% agree components distributed between specialized centers

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End-of-life issues/end users point of view

- 67% think about end-of-life products
- 20% Have already FCHs at end of life stage and return it to manufacturers
- With specific agreements with manufacturers
- 80% think it is the best and more profitable way

ERP system can be the best practical means for improving these problematic recycling Systems. Producers must take responsibility for recycling their goods after the life cycle, either by direct recycling of their own waste or by subsidizing the resource recycling system.

New strategies in EoL/role of the actors

In the short term scenario we have identified the role of FCHs manufacturers, waste manager and end users as crucial.

In the mid-term scenario we have identified the role of FCHs manufacturers, end users and recycling centers as crucial.

60% of FCHs manufacturers have already signed with the actors mentioned, in order to have profit for the Company:

- refund system for old systems is already in planning, contracts to PGM recycler
- platinum recycling agreement
- specifics agreement depending on the wastes
- they are include in the selling contract
- providing a discount on new materials if the older are returned.

New strategies in EoL/role of the actors

RCs are interested in specific agreements with manufacturers:
The agreements between manufacturers and recyclers favor the correct management of the waste, enabling the amortization of investments to implement new treatments in a longer term. In addition, they stabilize cash flows by improving the economic returns of these businesses.

- Frame Agreement for end-of-life FCH

End users are interested in specific agreements with RCs and manufacturers.

- 40% evaluate the transport of old devices payd by manufacturer or recycling center economically advantages
- 60% evaluate economically advantages to pay directly the transport of old devices but with economic incentives: example a reduced price for a new or remanufactured device → agreements

New strategies in EoL/novel technologies for recovery

The Hytechcycling project has detected some novel technologies for recovering PEMFC and PEMWE stack's critical materials. These novel technologies are mainly related to the possibility of recovery more than one valuable product of stacks and the precious metals

60% interested in investing on them

- For new recycling processes implementation you have to obtain a new authorization
- Long time to receive authorization
- Main re-adaptations: For the recycling of this waste investment in new equipment are needed: facilities and machinery / staff training

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New strategies in EoL/role of the actors

In the long term scenario we have detected the manufacturer with a dual role: manufacturer and FCH recovery center (MR).

"yes it could be a business in the future. not before two years"

In the long run it will not only be profitable, but also necessary to recycle the expensive materials such as titanium, platinum and iridium. With the limited availability and high cost, FCH recovery will either become part of the manufacturer's business or the gap will be filled by dedicated companies.

Nowadays the material recovery plays an important role and they expect the same also in future

At EoL they refund old stacks/systems and recycle them. Old MEAs will be sent to an PGM recycler. Other metals will be separated internally and recycled.

New strategies/Eco-design

The Eco-design Directive is a framework directive that helps EU to achieve the 20-20-20 targets. The Eco-design Directive applies to energy-related products with a sales volume above 200,000 units per year through the internal European market.
The eco-design is an important field in the study of end-of-life. Indeed, eco-design aspects must be taken into account for FCH technologies to be optimally recycled and disassembled. It must be taken into account in the total FCH technologies lifecycle.
Among the manufacturers interviewed only 33% take into account the aspects of the directive, mainly because the volume is much less than 200,000 units/year.

Critical and hazardous materials

First, the material choice is a burning issue. FCH technologies require some critical and hazardous material.
According to the manufacturers questioned:

- □ 83% of them have reduced the quantity of hazardous materials.
- □ 30% of them have reduced the quantity by 30%.
- □ the remaining part has inserted it as an objective for the next years

New strategies/Eco-design

Reduction in weight and volume of the product

The achievement of the adequate properties by using better construction techniques (at the material supplier level) should be prioritised over oversizing the component (at the component manufacturing level).

- □ 34% of FCHs manufacturers can reduce of 30% of the total FCHs weight (and more)
- □ 66% of FCHs manufacturers can reduce it between 10-20%

Reduction achieved:

- by applying new technologies and concepts
- Improving system integration
- developing and producing product with less materials.
- system upscaling
- increasing of performances
- Improving engineering and design (lightweight engineering, thinner cell-plated etc)
- Optimizing portable and containerized system
- increasing the current density (a smaller system can be utilized for the same production capacity).

New strategies/Eco-design

Incorporation of used components

Another aspect linked with eco-design is the incorporation of used components in the FCHs, this imply a new design of the products in order to optimized the recycling and disassembling phases:

□ all agree it can be sustainable as far as the reliability of the FCSs are guaranteed if compared with FCHs mounting new components
□ all think it is easier for the BoP componets
□ 80% of FCHs manufacturers already implement used materials in the design
□ some of them are developing but mainly with the bipolar plates, but not yet developed it in the stacks
□ 40% of them think as many components as possible are recycled or refurbished
□ all agree the most important step is to find a suitable procedure to recycle the different components.

New strategies/Eco-design

Design harmonization and standardization

The design harmonization and standardization provides multiple benefits. It simplifies the dismantling and recycling process, consequently it reduces the costs. In addition, it helps improve the products' quality and durability.

□ 83% of FCHs manufacturers are interested in rethinking the design of their product in order to optimize the recycling and dismantling phases.

□ 100% agree to standardize their fabrication process.

Limitations for the business model of the recycling of FCH technologies

01 Need of Cooperation between manufacturers and waste separation companies

02 Complexity in reuse some materials: mainly due to the FCHs classification

03 Technology and specific materials needed for the stack and other BoP components

04 The lack of logistics.

05 Need to find another second application able to deal with whole or parts of the FCH equipment's

06 The critical mass of material to be recycled not reached in order justify adequate capacity of the recycling plant and guarantee profitability for the recycling business.

Concerns related to regulations

01 Transboundary waste movements.

02 Harmonisation of waste regulation in EU countries. Clarification of the “waste” and “end of waste” status and its harmonisation within different countries it is necessary to develop the market. Once a material, device, etc is classified as waste, before being use as “raw material” again, it has to be declassified as a waste. Depending on the country, this step could be not possible.

03 A clarification on the treatment of residues.

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Proposal to address barriers and develop the recycling potential

Actors role

- WORKING GROUPS WITH THE MAIN ACTORS
- Engagement of the end users:a small bonus for end users should be double-checked in order to incentivize theactive participation of some of the stakeholders, as end users
- “AGREEMENTS” between manufacturers and recycling centres to assure manufacturers to

  buy the recycling materials and reuse it.

Design&recovery

- New investments to implement novel technologies
- A harmonization in FCH fabrication process.
- Rethink the design of the product to optimize the recycling and dismantling phases

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700190. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

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Do you have any suggestions or questions ?

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First assumptions of the business model

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Directives definition

Directive 2006/66/EC applies to Fuel Cells

'**Battery**' or '**accumulator**' means any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more primary battery cells (non-rechargeable) or consisting of one or more secondary battery cells (rechargeable).

Directive 2012/19/EU applies to Water Electrolysers

'**Electrical and electronic equipment**' or '**EEE**' means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current.

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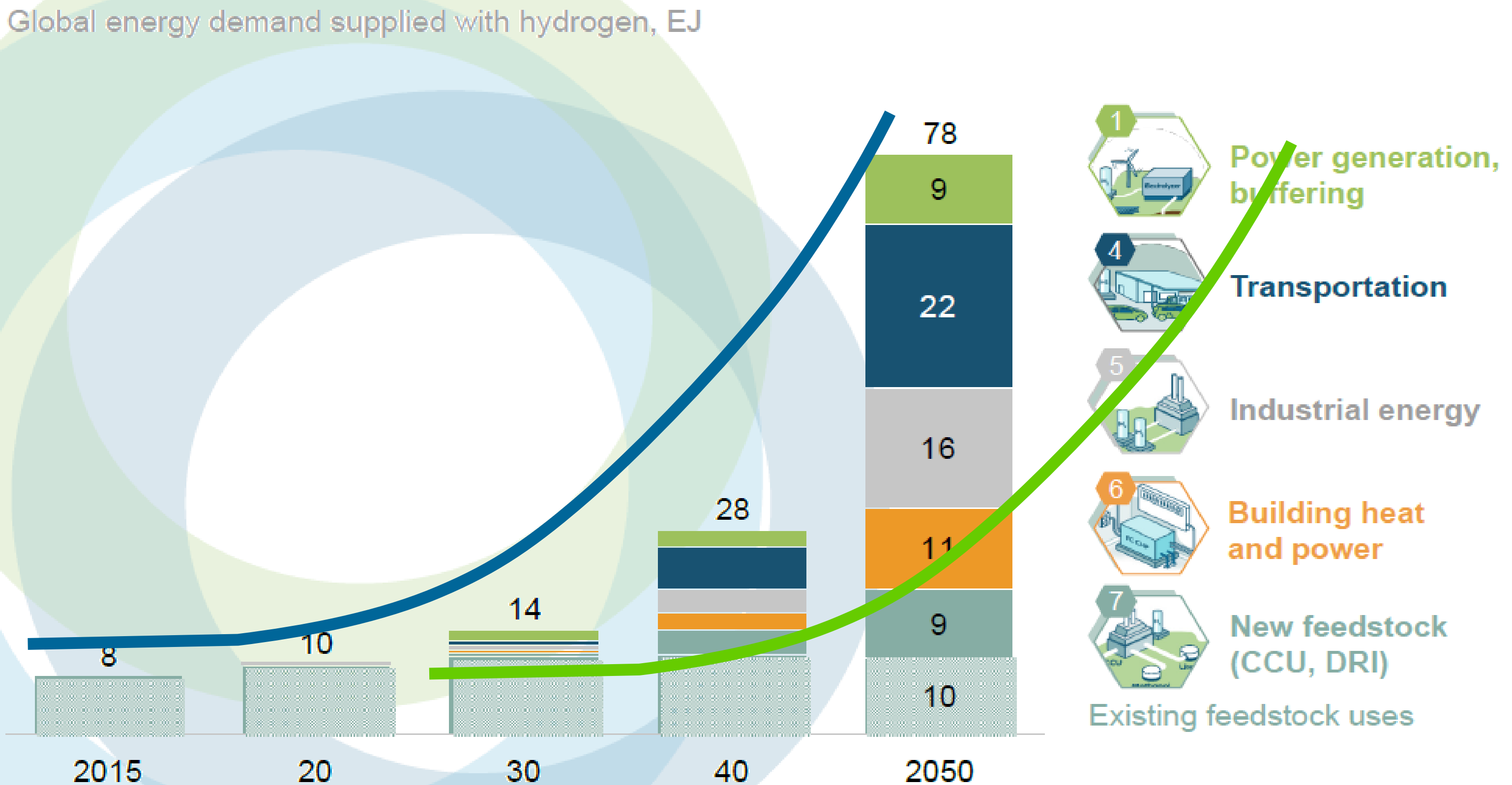
Time scale evolution



SOURCE: Hydrogen Council

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Extended Responsibility of the Producer

Third step

Creation of specialised ERP associations of the FCH manufacturers and distributors.

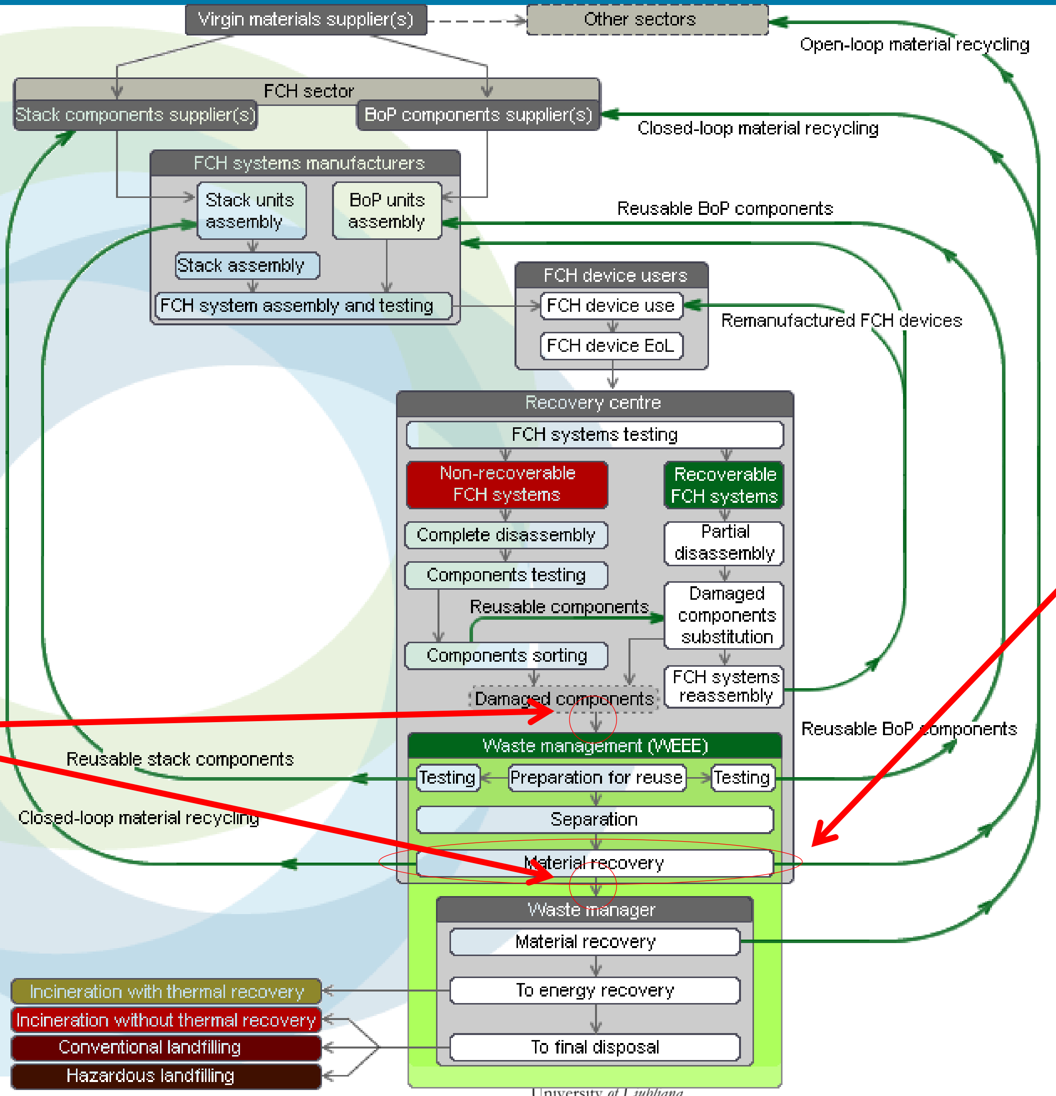
Second step

Introduction of the manufacturers in the Existing ERP associations.

First step

Agreements between manufacturers and recycling centres.

Basic scheme for FCH life cycle



Our focus with the new technologies.

Transport of waste.

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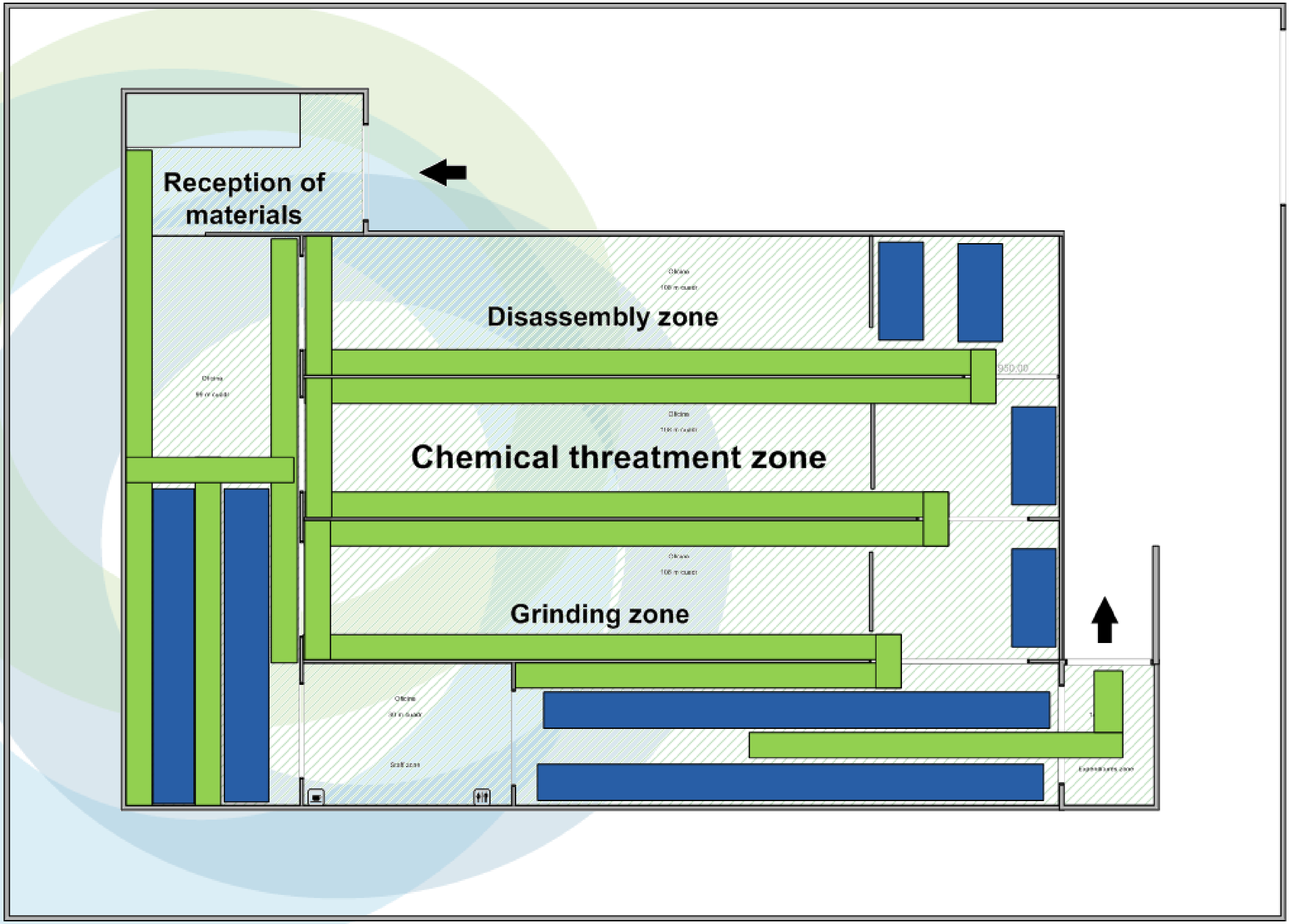
Layout for a RC



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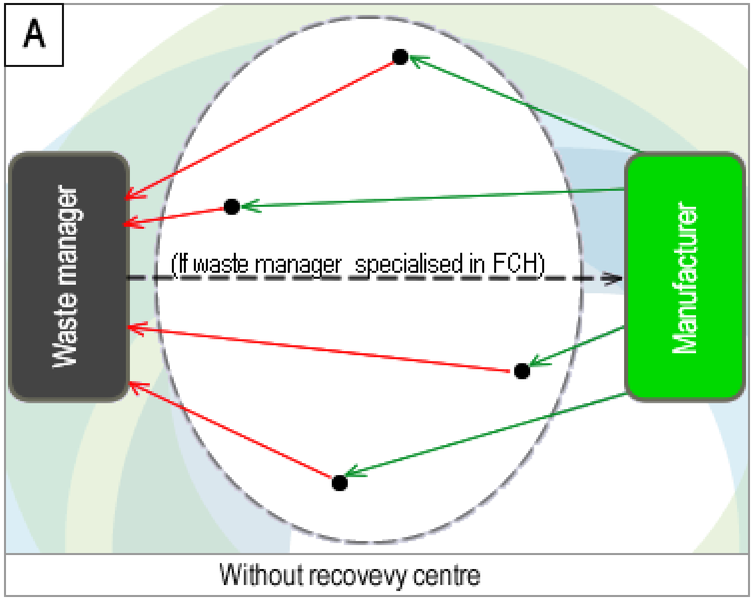
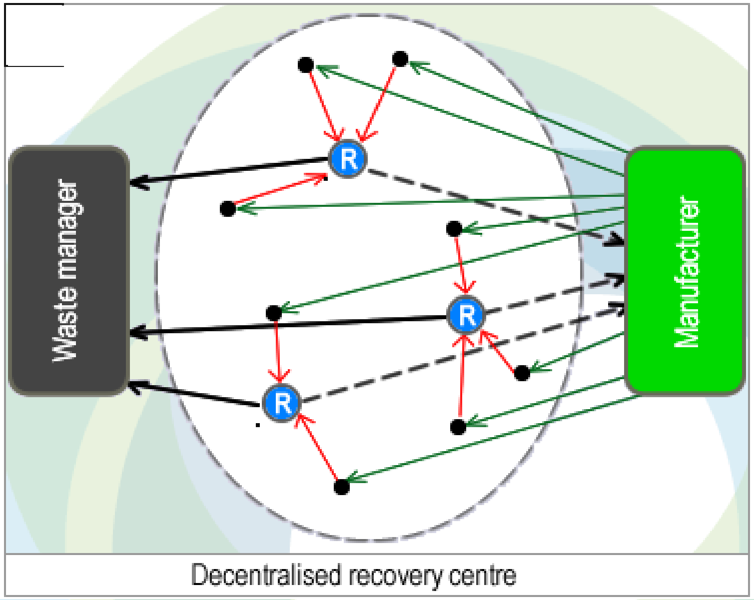
Short-term Horizon



As it has been presented, in the first stage, there are not recovery centres, and the fuel cells will goes to the waste managers, which will be in charge of the whole process.

This is the worst scenario and it can face only a small amount of FCH equipments.

Mid-term Horizon

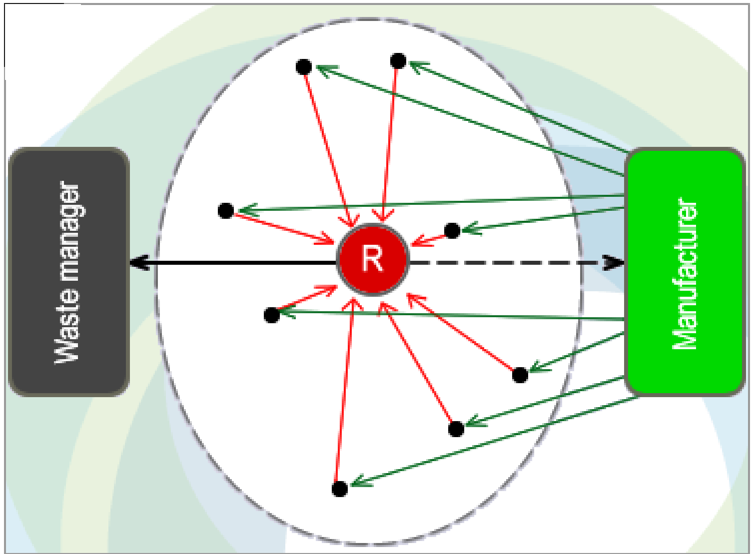


Current recycling centres are able to work in the recycling and dismantling of the technology and implement new technologies.

New recycling centres can be created and can implement new technologies for the FCH technologies in a more specialised way.

Not a big market is a problem

Mid-term Horizon



Centralised recovery centre

A big recycling centre that is current developed can increase its work with the FCH while maintain its normal activities.

A centralised one is not a proper option for all the technologies due to its recycling technologies variety.

Four centralised (one per technology) just in a widely developed scenario.

Costs Structure

	Existing recycling centre	New recycling centre
Infrastructures	✗	✓
CAPEX new technology	✓	✓
OPEX new technology	✓	✓
Energy consumption	✓	✓
Environmental taxes*	✗	✓
New training for operators	✓	✓
New licenses **	✓	✓
Building licenses	✗	✓
Place in the market***	✗	✓

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Revenue incomes

Reutilization as spare parts in other fields for components of the FCH technologies

- Humidifier and filters for the air.
- Power Electronics: Universities, technician trainings, lower requirements of power electronics.
- Refrigeration

There are also some materials that may be charged with specific taxes.

•<u>Fragile point. Some recycled materials are nowadays profitable without them.</u>

Finally, all this materials could be scrap which after treated can be sold obtaining profits, and following the structure that the recycling centres follows today.

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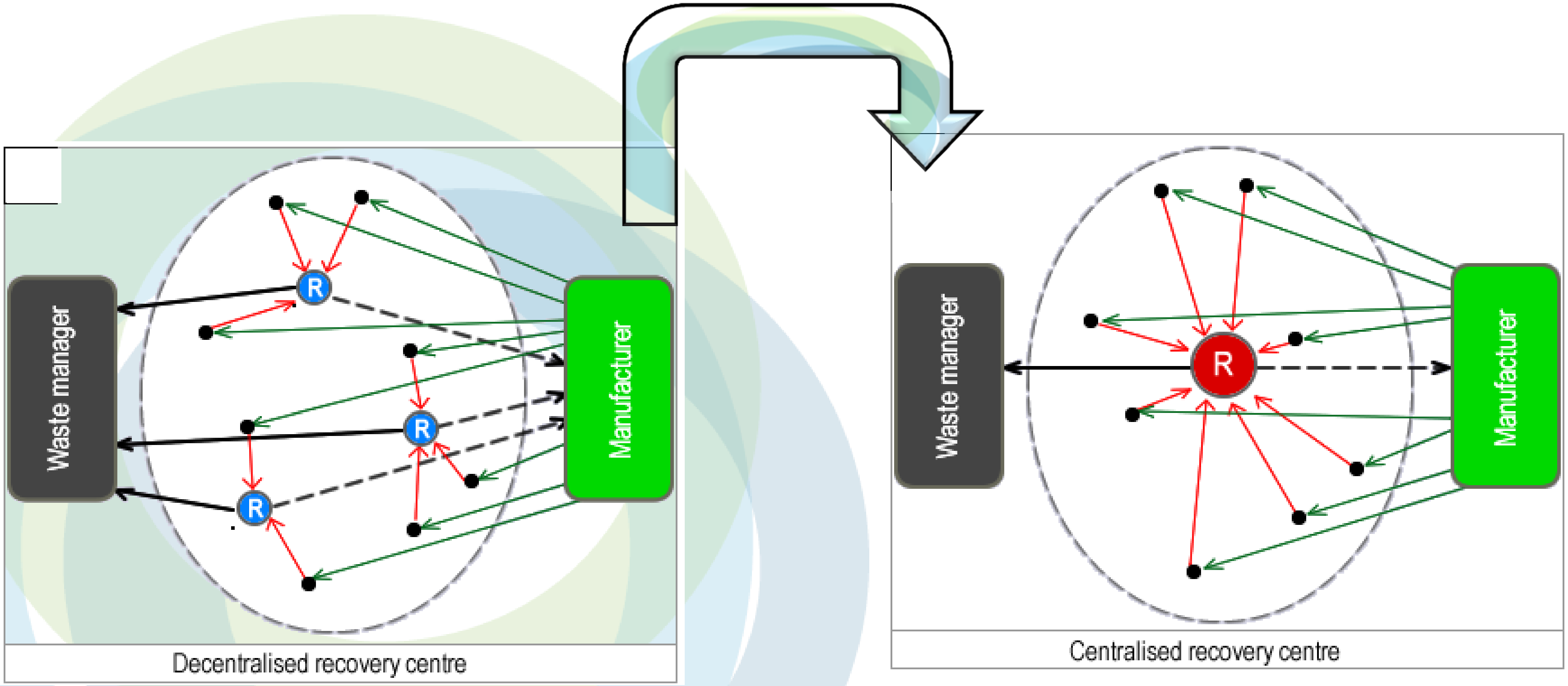
Infrastructure developments



Cooperation between centres.
Each of them for one technology
Needs for transportation between specialized centres.

Possible simplification:
Avoiding intermediate logistics.
Mixing different technologies based on the new technology available in the centre.

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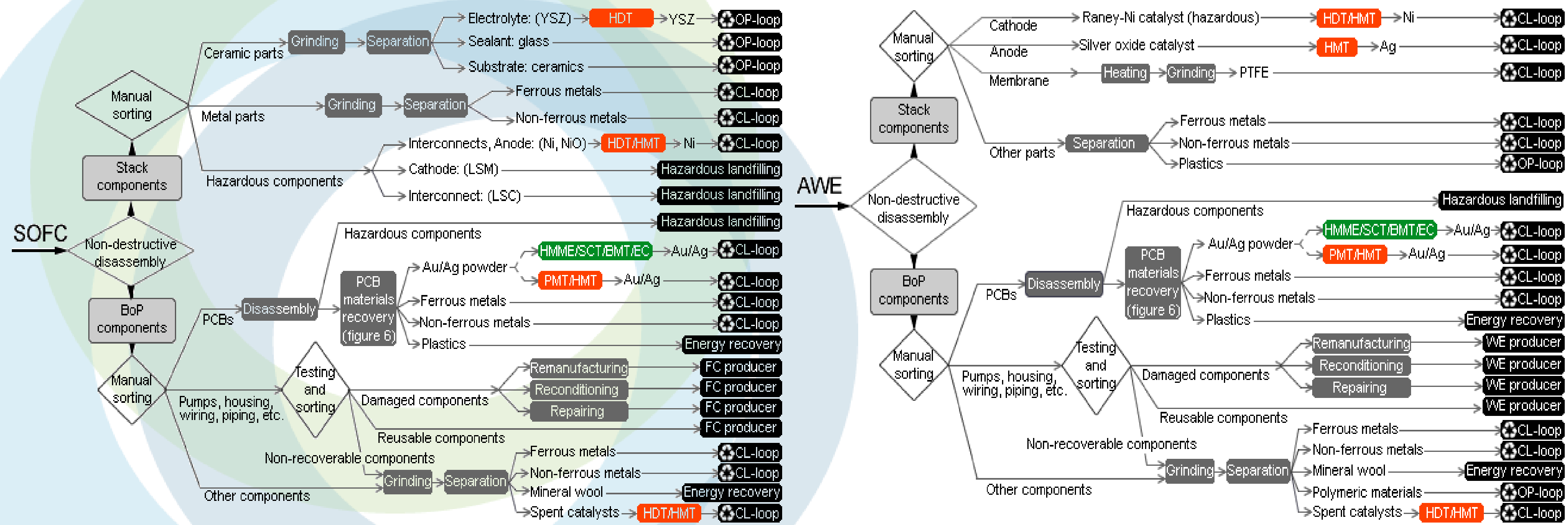
Strategic alliances

Assuming that a mixed recycling centre of WEEE and batteries is created SOFC and AWE has the same new treatments.



Possible problems of scale of the machinery.
Take into account the Open Loops of SOFC.
Some materials do not have any recycling strategy.

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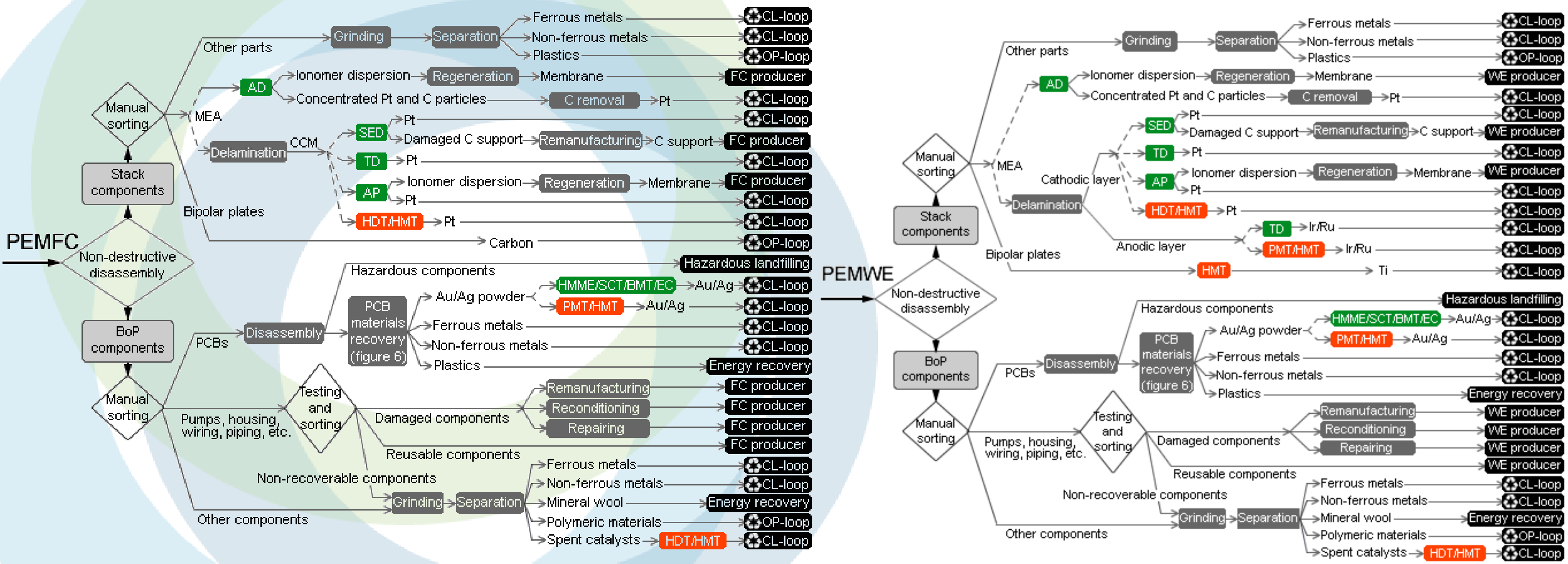
Strategic alliances

Same situation in PEM technology.



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Please,
feel free to suggest, add or correct me!

Thanks for your attention

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