

Sustainable SoluTions FOR
recycling of end-of-life Hydrogen
technologies



Deliverable D6.1

Training plan and guidelines
for training material

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Executive Summary

This document provides a training plan and guidelines to support the training materials and activities. These latter are mainly addressed to transfer to recycling centers, manufacturers, and raw materials providers the BEST4Hy's lessons learnt and achieved knowledge on how to recycle and dismantling the hydrogen fuel cells.

The training plan defines what and how to reach the stakeholders: objectives, target groups, contents of the modules and training activities. The guidelines support the development of the modules through common rules and identifies the main contents. The plan includes a Training Toolkit, that will be available in the project's website to disseminate the training materials, and two training days will be performed in the last year of the project to meet and engage the stakeholders.

The training plan and related activities are led by ENVIPARK who will be responsible for the technical materials and lesson development. The training activities are part of Task 6.4, WP6 dedicated to the Measure towards take up.



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1 Introduction

The training plan and guidelines aims to define materials and methodology to perform the training activities on how to recycle and dismantle most efficiently fuel cells stacks and valuable raw materials they contain. “HOW recycling and dismantling FCH technologies” is the main topic of this technical training, developed on the project results basis to transfer the acquired knowledge to Recycling Centres and Manufacturers stakeholders. Therefore, key objectives are the widespread of the project outcomes, lessons learnt, increasing of knowledge and skills on the recovery and recycling solutions for EoL fuel cells. Different topics will be tackled: from the dismantling, recovery and recycling technologies, to the techno-economic aspects for a complete validation, as well as the replicability and market analysis of the studied technologies.

The training activities will include a Training Toolkit and training days to engage and support the identified stakeholders in the learning process of the contents. All the activities will be coordinated by ENVIPARK, also in charge of creating contents and materials. Other partners will give their support for the technical revision of the produced learning material.

For a clear and complete understanding of “HOW recycling and dismantling FCH technologies”, the training plan identifies some primary topics on the basis of BEST4Hy’s project upon which the activities will be developed:

- How to dismantle a fuel cell - the module will give an introduction to the FCs: main parts and main valuable materials;
- Recycling technologies - adaptation and designing of existing and novel processes an overview of the processes developed within the project;
- Technical results and economical aspects - information on the technical and framework conditions for the recycling strategy;
- Measures towards take up – the main barriers but also opportunities for the take up of the recycling strategy.

The Training Toolkit will collect and provide the learning materials, divided into the above named 4 modules and containing texts, catchy and graphic materials, video tutorials. The toolkit will be available for a free consultation in a specific section of BEST4Hy’s website. Moreover, by the end of the project two face-to-face training days will be also organised by POLITO (M33) and by HRD (M36). The training days will allow a deeper involvement of the stakeholders with practical sessions and networking opportunities.

As a training plan, this document defines contents and target groups to reach within the training activities development and gives main guidelines on how to develop each single training module, materials and activities.



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2 Target groups and objectives

The main identified target group of this technical training are the Recycling Centers, as direct figure involved in the process of recovery, dismantling and recycling of the end-of-life fuel cells stacks. From a wider assessment of the entire fuel cells' life cycle, other stakeholders can be interested to the trainings to improve their knowledge and skills on the EoL FCHs technologies strategy. For instance, the design and manufacturing of the components and stacks, as well as the regulations framework analysis, are interesting aspects to take into account for a complete understanding and management of FCHs products considering a life cycle thinking approach. Thus, the training activities are mainly addressed to the following primary target groups:

- Recycling centers
- Manufacturers

The Recycling centres are interested to improve their knowledge and technical skills on how to manage the EoL fuel cells stacks, also from an economic and regulatory point of view. During the trainings, the mainly involved companies will be the one with interest on recovery process in the field of batteries, WEEE or ELVs (End of Life Vehicles). Already two recycling centres have expressed their interest into the topics during the project application, confirming the importance of the FCHs recycling technologies for the sector. From the manufacturers side, they play a key role in the EoL stage of their products, considering design and manufacturing a relevant factor influencing dismantling and recovery operations of the fuel cells stacks.

Thereby, these training will give important overview of the technical, economic and regulatory/standardisation aspects for EoL hydrogen fuel cells strategy through the transferring of knowledge and skills achieved during the project.

By the end of the training, the users who will have benefited of the learning materials and activities, will have acquired the following knowledges:

- Understanding and overview of the main technical EoL strategies for FCHs technologies, with specific focus on PEM/SOFC;
- Learning the importance of the critical raw materials recovery and recycling in open/closed loop scenarios and knowledge of the related technologies;
- Understanding of the techno-economic assessment and life cycle thinking approach to the FCHs (LCA/LCC);
- Learning the importance and the application of the Eco-design to the FCHs;
- Understanding and overview of the EU/Extra-EU Regulation framework, plus future standardisation roadmap for the future FCHs recovery & recycling technologies;
- Understanding of the EoL technologies replicability and its current market position and potential for future exploitation.

Meanwhile, at the end of the training, some specific technical skills will be achieved by the users and mainly focused on:



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- How to dismantle and recover fuel cells stacks' components and critical raw materials contained on them through different suitable technological solutions (existing and novel processes);
- How to recycle fuel cells stacks' components and related critical raw materials through different technological solutions (existing and novel processes), both in open and closed-loop scenarios;
- How to perform the FCHs technologies recycling considering the current regulatory and standardisation framework;
- How to understand and perform the technical and economic analysis of the recovery and recycling process for EoL fuel cells stacks and their components, considering the entire life cycle of the products (LCA/LCC);
- Understanding of the current technology replicability and its market potential for future exploitation

3 Training methodology

The training activities will be developed using both online learning materials and in-person practical sessions. By the end of M30, a Training Toolkit will be prepared and available for all the stakeholders and users in a website's section. The Training Toolkit will provide free and downloadable learning documents, catchy graphic and schemes, video tutorials. Graphics and video tutorials are thought to improve the training users' engagement and learning process through clearer visual explanation. Beside the training materials, two face-to-face training days will be also organized by POLITO (M33) and HRD (M36). The training days could also be an interactive moment during which stakeholders can exchange views, share visions, identify common barriers and share best practices.

A dedicated communication campaign and promotion of the free Training Toolkit will be performed to reach the identified target groups. The project itself, the institutional channels, as well as the direct stakeholders' contacts of each technical partner involved in the training activities, will be useful for an effective and wide campaign.

Moreover, a survey will be shared within the Training Toolkit and during the training days, allowing us to better understand and monitor the training experience, the users' background knowledge and materials contributions to the training topic learning process.

The so-developed training methodology has been planned in order to provide different types of learning materials and activities experience. The stakeholders will be able to take benefit of the training in different ways, from free and flexible materials always available on the website to practical experiences and direct exchange on specific technical issues, during the in-person training days. Table 1 summarizes the training methodology with main activities and related objectives:



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Table 1 Training methodology description and main objectives

Training activities	Objectives
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Training Toolkit

By learning contents' purposes:

- Improve knowledge on the recovery & recycling strategies and related topics, as expressed in Chapter 2;
- Improve and transfer technical knowledge and specific skills on recovery & recycling technologies and related topics (Chapter 2);
- Disseminate and promote lessons learnt and results achieved in BEST4Hy.

By learning materials' typology:

- Offer technical materials/manual with description and detailed explanation of the topics;
- Offer graphic materials and technical schemes to integrate the technical learning materials;
- Offer specific video tutorials to improve the insight and complete the learning process;
- Offer free and downloadable learning materials for every type of stakeholders, available at anytime and anywhere.

Training days

By learning contents' purposes:

- Improve knowledge on the recovery & recycling strategies and related topics, as expressed in Chapter 2;
- Improve and transfer technical knowledge and specific skills on recovery & recycling technologies and related topics (Chapter 2);
- Disseminate and promote lessons learnt and results achieved in BEST4Hy.

By learning materials' typology:

- Offer a practical session to improve the understanding and skills on the BEST4Hy technologies both at laboratory and pilot scale;
- Offer an interactive learning session with discussion and exchange views;
- Offer the opportunity to meet other stakeholders (even from other countries) and share opinions, visions, barriers or best practices.



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4 Training Toolkit

A Training Toolkit will be available in the specific training section of the BEST4Hy's website. The section will be the case to collect all the learning materials and provide main information related to the training activities provided by the project. The Training Toolkit will be composed by 4 learning modules (described in the next sub-chapters), providing technical knowledge and skills on the topics identified to develop the main training purpose "HOW recycling and dismantling FCH technologies":

1. **How to dismantle a fuel cell** - the module will give an introduction of the FCs: main parts and main valuable materials;
2. **Recycling technologies** - adaptation and designing of existing and novel processes an overview of the processes developed within the project;
3. **Technical results and economical aspects** - information on the technical and framework conditions for the recycling strategy;
4. **Measures towards take up** – the main barriers but also opportunities for the take up of the recycling strategy.

To help visualize the process, the training materials will be also improved with easily understandable graphics and video tutorials, giving a visual description of the technologies explained in each module.

Overall, each of the 4 modules composing the Training Toolkit will provide the following learning materials:

- Learning documents with description and technical explanation texts of the topics, equipped with graphics and schemes. They are available in pdf format and free downloadable;
- Video tutorials for a visual explanation of each single step of the described technologies (according to the topic). They are available for free visualization on both website and BEST4Hy's YouTube channels;
- Associated Deliverables related to the module's topic, which will be linked to the Publication's section of the website, where they will be available in pdf format and free downloadable. They provide an exhaustive and complete description of BEST4Hy activities and progress.

The learning materials will be easily available to all the stakeholders through BEST4Hy's website and its dedicated section, which will be specifically created to contain them. The section, perfectly integrated within the project's website and realized with an attractive graphic, will provide easy and simple browsing for a nice learning experience. The section will be completed with a short introduction to the Training to explain topics, modules, and objectives. An open survey and main training contacts will also allow us to monitor and improve the training section and activities, collecting direct feedbacks by the users.

According to the Grant Agreement, the Training Toolkit needs to be ready by M30 of the project.



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4.1 Training modules

The next chapters will detailly explain the main training topics (previously identified), which should be tackle by each module, together with main learning materials to be developed and related project WPs.

The identified chapters represent the main structure to develop in each module, but it could be directly managed and improved during the contents' development. During the learning documents production, information and project results covered by patent or other IPRs will be considering for the contents development and information sharing.

The materials preparation will also follow these main guidelines:

- ✓ Clear topic and objective of each chapter/module
- ✓ Description of the final knowledge and skills would like to achieve
- ✓ Clear and linear contents and structure
- ✓ Clear step-by-step explanation of the technology
- ✓ Use of specific but understandable technical language
- ✓ Use of catchy and easy graphs or technical schemes

4.1.1 Module 1: How to dismantle a fuel cell

Module 1 is dedicated to the dismantling technologies of fuel cell stacks. A first chapter will give an introduction to the fuel cells, main parts and valuable materials, while the others will focus on the dismantling technologies developed along the project.

Specifically, the module will provide information on how to perform, optimize the existing dismantling technologies and how to perform novel dismantling technologies. They are applied to both PEM and SOFC fuel cells.

Module 1 should be organized as follow:

- Chapter 1: Introduction to the FCs: main components and valuable materials in PEM and SOFC;
- Chapter 2&3: Description and manual to perform the existing and optimized dismantling technologies (PEM/SOFC);
- Chapter 4&5: Description and manual to perform the novel dismantling processes developed within the project (PEM/SOFC);
- 2 Video tutorials on how to perform the dismantling processes above described.

To summarize, each chapter has to include essential information such as the general description of the topic, what is needed (devices etc.) and how to perform the process.

Associated deliverables (WP1; WP2; WP3; WP4):

- D1.1: Lab scale optimization results on the 3 PEMFC recycling technologies report
- D2.3: Report on the evaluation of MEA including recycled materials in small single cell of PEMFC



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- D3.3: Pilot-scale plant (TRL5) based on two integrated existing recycling technologies for SOFCs_PU
- D4.3: Technical report on developed recovery technologies for LSC cathode materials_PU

Partners involved in module 1 are HRD and CEA for PEM fuel cells; POLITO for SOFC fuel cells. They will support the learning materials production with technical revision.

4.1.2 Module 2: Recycling technologies

Module 2 is dedicated to the recycling technologies, providing knowledge on the adaptation and designing of existing and novel processes and an overview of the processes developed within the project.

Module 2 should be organized as follow:

- Chapter 1: Introduction to the current existing recovery & recycling technologies
- Chapter 2&3: Description and manual to perform the existing and optimized recovery & recycling technologies (PEM/SOFC);
- Chapter 4&5: Description and manual to perform the novel recovery & recycling processes developed within the project (PEM/SOFC);
- At least 2 Video tutorials on how to perform the recovery & recycling processes.

To summarize, each chapter has to include essential information such as the general description of the topic, what is needed (devices etc.) and how to perform the process.

Associated deliverables (WP1; WP2; WP3; WP4):

- D1.2: Technical report on the adaptation of existing technology (hydrometallurgy process) for PEMFC material recovery: results and design
- D1.5: Pilot-scale plant (TRL5) based on 3 recycling technologies for PEMFCs
- D2.3: Report on the evaluation of MEA including recycled materials in a small single cell of PEMFC
- D2.6: Report on the evaluation of MEA including recycled materials in PEMFC stack_PU
- D3.3: Pilot-scale plant (TRL5) based on two integrated existing recycling technologies for SOFCs_PU
- D3.5: Technical report on open loop analysis of different scenarios
- D4.3: Technical report on developed recovery technologies for LSC cathode materials_PU

Partners involved in module 2 are HRD and CEA for PEM fuel cells; POLITO for SOFC fuel cells. They will support the learning materials production with technical revision.



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4.1.3 Module 3: Technical results and economical aspects

This module is mainly dedicated to provide information on the technical and framework conditions for the recycling strategy. It is strictly linked with the LCA&LCC activities conducted during the project with the aim to monitor the developed recycling process from environmental and economic point of view. The module reports the project results and open the discussion on the actual dismantling and recycling processes compared to the technologies developed within BEST4Hy, considering sustainability, life cycle assessment, life cycle costs, and eco-design of fuel cell and hydrogen technologies.

Module 3 should be organized as follow:

- Chapter 1: Introduction to the LCA, LCC and Eco-design approach applied to the FCs;
- Chapter 2: Comparison between current and BEST4Hy's technologies, based on the LCA results;
- Chapter 3: Comparison between current and BEST4Hy's technologies, based on the LCC results: advantages and barriers;
- Chapter 4: Eco-design and lessons learnt: the experience of the sister projects eGHOST/SH2E on the Eco-design for fuel cells;
- Optional videos to explain main contents developed in the module.

Associated deliverables (WP5):

- D5.1: Environmental profile of existing EoL technologies and effects in the scope of circular economy in the manufacturing phase;
- D5.2: LCA and LCC impacts of novel EoL technologies and ecolabeling of FCH products;
- D5.3: Guidelines for the setup Ecolabelling qualification.

Partner involved in Module 3 is the University of Ljubljana. It will support the learning materials production with technical revision.

4.1.4 Module 4: Measures towards take up

Module 4 is finally dedicated to the measure towards to take up, explaining main barriers but also opportunities for the take up of the recycling strategy. The module aims to provide an overview of the regulatory framework on the end-of-life treatment of rare/not-rare materials contained in FCH technologies, the current level of standardization and the further steps. The potential replicability and marketability of the BEST4Hy recycling processes are also explored.

Module 4 should be organized as follow:

- Chapter 1: EU/Extra-EU Regulatory framework analysis: how to treat rare/not-rare materials contained in FCH technologies;
- Chapter 2: A standardization roadmap for future Eco-design of FCH technologies;



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- Chapter 3: Measure towards to take up: replicability and market position for BEST4Hy recycling technologies;
- Optional videos to explain main contents developed in the module.

Associated deliverables (WP6):

- D6.2: BEST4HY Regulatory and Standardisation Assessment
- D6.3: Regulatory and Standards stakeholders activities outcomes and guidelines for policies
- D6.4: Analysis of replicability: Permitting aspects and authorisation assessment

Partners involved in Module 4 are ENVIPARK, RINA, HRD. They will support the learning materials production with technical revision.

4.2 Training days

At the completion of the Training Toolkit and developed online learning materials, the training days represent a practical learning experience. The dismantling, recovery & recycling processes will be explained and directly showed to the stakeholders at the recycling BEST4Hy's pilot plants, enhancing their knowledge and skills. These days will be likewise an opportunity to meet stakeholders from different countries so that the training could also be a moment during which stakeholder can exchange views, share visions, identify common barriers and share best practices.

The face-to-face training days will be organized at the end of the project at the POLITO (M33) and HRD (M36) premises.

As responsible partners of the overall PEM/SOFC activities, HRD and POLITO will host the training days with the main objectives to involve Recycling Centers and Manufacturers interested to discover the project and to be updated with the last recycling technologies for FCHs. The partners will show the achieved results and specifically, the pilot plant at TRL5, designed and built during the project to perform an automatic and cost-effective process for the recycling of PEM (HRD) and SOFC (POLITO) fuel cells, and the main results of BEST4Hy project.

These training days will be also an important moment for the research results transferring to the companies and BEST4Hy stakeholders' network, beyond the scientific community. Besides the main learning and training purpose, the training days and activities can also be counted as one of the first dissemination and exploitation activities of the project results with a specific focus on the industries. During the same months of the planned training (M33; M36), other two workshops are even organized to involve policymakers, public authorities, and AB members to show them results and final pilot plants, enhancing the overall dissemination and exploitation process of BEST4Hy. Indeed, a worth considering opportunity to increase and meet the stakeholders' community behind the project.

The training days will be scheduled including the same topics as the one developed in the 4 modules above described, with specific focus on the technical skills of module 1 and 2.



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Certainly, main objective of these face-to-face training is the knowledge and skills transferring to the Recycling Centers on how to perform the recovery & recycling process on FCHs at their end-of-life.

The training days could be independently organized by each partner, in terms of contents, agenda and number of days. A general and suggested overview of the topics, considering both frontal and practical session learning sessions, could be the following:

- Introduction to the current existing recycling technologies for EoL fuel cells;
- Existing and novel technologies for the dismantling and recycling of EoL FCHs: BEST4Hy methodology and approach;
- Optimization process and results achieved at laboratory scale;
- Demonstration of the developed BEST4Hy technology at pilot plant;
- Techno-economic assessment and technologies' validation: LCA/LCC analysis' results;
- Regulatory and standardization roadmap for FCHs;
- Replicability and market potential.

The involvement of POLITO as a training days organizer, could be also an opportunity for the involvement of students and researchers of the university. Future recycling experts could take advantage of the BEST4Hy training to be updated on the last recycling FCHs technologies results and future developments. This activity could further represent a first step for the creation of an eventual course of study specifically dedicated to critical raw materials, FCHs devices, WEEE and all other related relevant topics.

Considering the main target groups, the expectation from these activities is to reach overall at least 20 stakeholders, between Recycling Centers and Manufacturers with interest in the FCHs recycling process. At the end of each day, a training survey will be also used to assess satisfaction of the learning materials and session provided, as well as the project's topics.

Equally important, the training days will be o trying to create an interactive learning experience among both trainers/users and users/users, creating the right conditions to exchange views, challenges and opportunities of each of the participants.



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5 Conclusions

The present document has identified main methodologies and guidelines to run the training activities along the project. Main objectives and target groups to reach have been defined, together with the following aspects: topics, module and type of learning materials contained in the Training Toolkit; platform where the learning materials is available for consultation; training days activities and suggested schedule.

The Training Toolkit is planned to be ready at the M30. Considering the learning materials topics, all the WPs are involved in the toolkit preparation led by ENVIPARK. Therefore, the collaboration of each of them is required, since the beginning of the third year of the project in order to comply with the deadline. Materials will be developed following the main project progresses and deliverables. In case of missing content due to project delays results, they will be prepared as soon as the project progresses and by the end its end.

The Training Toolkit will be accompanied by an active dissemination to promote the learning materials and the BEST4Hy training activities in order to involve a wide number of stakeholders.

Definitely an important role in the stakeholder's engagement will be played by the Training days at M33 and M36. POLITO and HRD will be responsible for the face-to-face training activities organisation and the pilot plant process demonstration.

To conclude, a final survey will be useful to have feedbacks from the stakeholders and assess the quality of the learning materials, training experience and other general feedbacks about the project and its results.



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