

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



## Deliverable D6.7

BEST4Hy Training kit

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## Executive Summary

The present document refers to the Training Toolkit development in the framework of WP6 “Measure towards take up”.

The Training Toolkit provides learning materials, video tutorials and insights based on the project outputs and mainly focused on HOW to dismantle and recover valuable materials from FCH technologies, with some insights in technoeconomic aspects and measures towards take up.

The activity has been carried out by ENVIPARK with technical support by all the other partners and use D6.1 “Training Plan” as guideline.

In this report, the Training Toolkit and its learning materials are presented. Each Module has been made available on the project website at the link <https://best4hy-project.eu/training-toolkit/#>.



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# 1 Introduction

The BEST4Hy Training Toolkit is part of the Training activities planned within the project. The training is mainly focused on HOW to dismantle and recover valuable materials from FCH technologies, with some insights in technoeconomic aspects and measures towards take up, on the basis of results and knowledge acquired along the project. Main targets of the training are Recycling Centres and Manufacturers, including material and components suppliers. The training activity is composed of a Training Toolkit and Training days to engage and support the identified stakeholders in the learning process.

The Training Toolkit here described collects and provides the learning materials, divided into 4 modules and containing texts, graphic materials, video tutorials. The toolkit is available for free consultation in a specific section of the BEST4Hy's website - <https://best4hy-project.eu/training-toolkit/#>.

The Training Toolkit and the learning materials production activities have been coordinated by ENVIPARK, with the support of the other partners for the technical revision of the contents.

The Training Toolkit and the platform was expected to be published at M30, but was delayed until December (M36), when the toolkit was officially launched with all the Modules fully agreed by the partners, who needed to finalise the upscaling work.

Deliverable D6.1 "Training Plan" was used as a guideline for the Training Toolkit development.



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## 2 Training Toolkit

BEST4Hy Training Toolkit collects all the learning materials provided by the project. The Training Toolkit is composed of 4 learning modules (described in the next sub-chapters), providing technical knowledge and skills on the topics identified to develop the main training purpose of showing HOW to dismantle and recover valuable materials from FCH technologies, with some insights in technoeconomic aspects and measures towards take up:

1. **How to dismantle a fuel cell** - the module gives an introduction of the FCs: main parts and main valuable materials and how to start disassembly of a FC so to minimize material loss;
2. **Recovery technologies** - adaptation and designing of existing and novel processes for the recovery of valuable material. This gives 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 supported by the processes;
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 material is based on the project public deliverables, referenced throughout, with the addition of 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 provides the following learning materials:

- Learning documents with description and technical explanation of the topics, equipped with graphics and schemes. They are available in pdf format and freely 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 are linked to the Publication's section of the website, where they are available in pdf format and freely downloadable. They provide an exhaustive and complete description of BEST4Hy activities and progress.

The learning materials are easily available to all the stakeholders through BEST4Hy's website and its dedicated section "Training Toolkit" - <https://best4hy-project.eu/training-toolkit/#>. The section, perfectly integrated within the project's website and realized with an attractive graphic, provides easy and simple browsing for a nice learning experience.



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## 2.1 Training platform

The Training platform, so called “Training Toolkit”, has been created in the BEST4Hy website and officially launched in December 2023 (Figure 1). The Training Toolkit section is available from the top menu and it is composed by the 4 Training Modules: <https://best4hy-project.eu/training-toolkit/#>

Users have free access to each module and can easily switch from one module to another. Learning materials are downloadable as pdf format, videos are freely accessible also from BEST4Hy Youtube Channel.

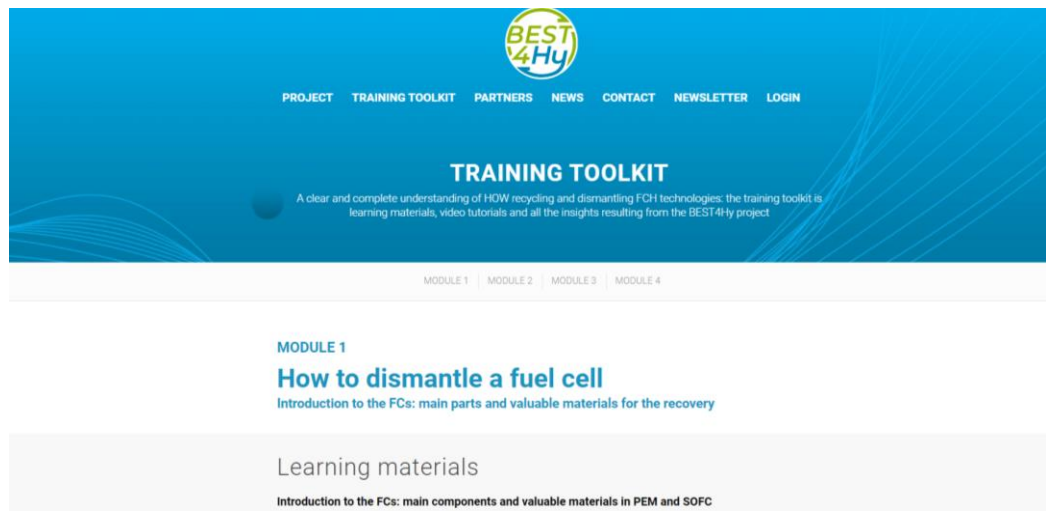


Figure 1 Training Toolkit on BEST4Hy website

## 2.2 Training modules

The next chapters will explain in detail the main training topics, tackled by each module, together with main learning materials developed and related project WPs.

The materials preparation has followed some main guidelines as explained in the Training Plan (D6.1):

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

Single chapters slightly differ from what planned in D6.1 “Training Plan”. The content development followed the project, considering that some topics are linked to confidential information.



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## 2.2.1 Module 1: How to dismantle a fuel cell

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

Specifically, the module provides information on how to perform and optimize the existing disassembling technologies and how to perform novel dismantling technologies. They are applied to both PEM and SO fuel cells.

Considering the overall recovery process of material from SO fuel cells developed by POLITO, the dismantling phase has been included in Module 2 of the training. However, the contents are only partially shared due to confidential information restricted to the Consortium.

Module 1 is organised as follow:

- Chapter 1: Introduction to the FCs: main components and valuable materials in PEM and SOFC;
- Chapter 2: Description and manual to perform the existing disassembling technologies (PEMFC);
- Chapter 3: Description and manual to perform the novel dismantling processes developed within the project (PEMFC).

The following figures show the uploaded material:

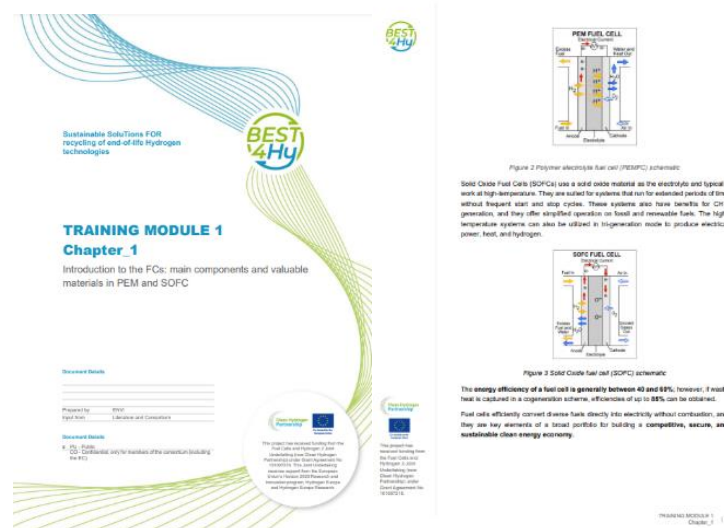


Figure 2 Example of Module 1 Chapter 1: Introduction to the FCs: main components and valuable materials in PEM and SOFC



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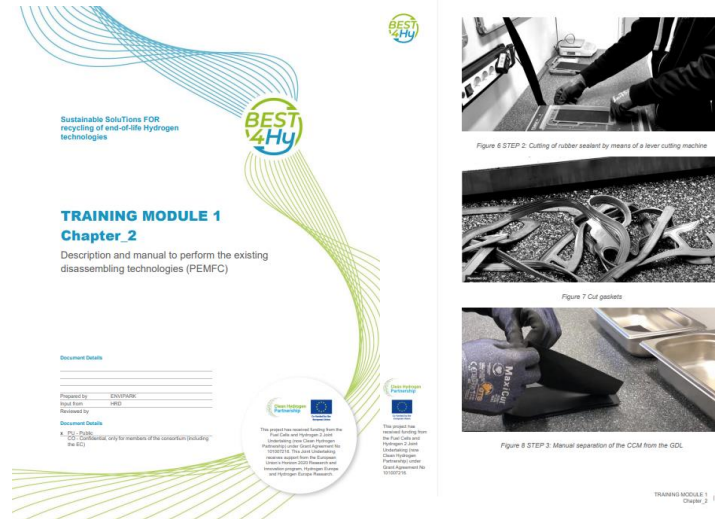


Figure 3 Example of Module 1 Chapter 2: Description and manual to perform the existing disassembling technologies (PEMFC)

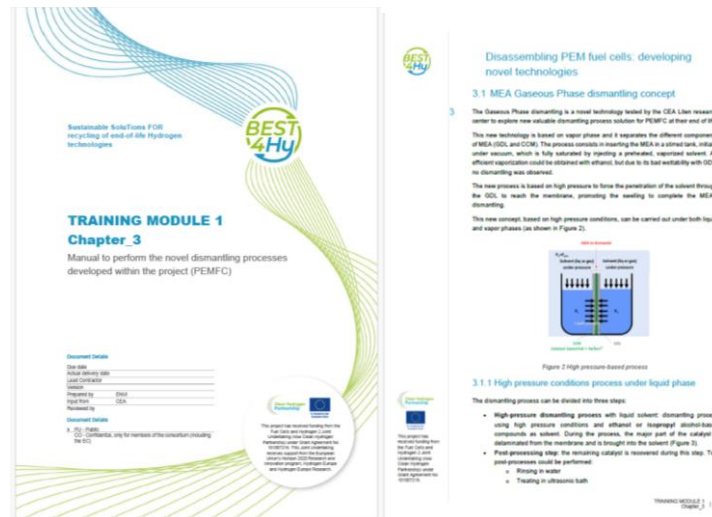


Figure 4 Example of Module 1 Chapter 3: Description and manual to perform the novel dismantling processes developed within the project (PEMFC).

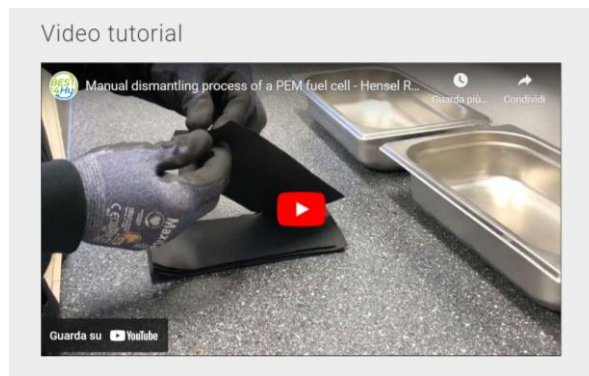


Figure 5 Video Tutorial on Manual dismantling process of a PEM fuel cell



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Two videos on dismantling process have been created for Module 1. In the website, a direct link is also available to explore the dedicated playlist on the BEST4Hy YouTube Channel (<https://www.youtube.com/watch?v=RvNtTs3VTFQ>):

- Manual dismantling process of a PEM fuel cell;
- Disassembling a FCH stack from automotive application.

At the bottom of the page, an Insights section is created with a list of associated deliverables provided for deeper information on the module topics:

- 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
- 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 have been HRD and CEA for PEM fuel cells; POLITO for SO fuel cells. They have supported the learning materials production with technical revision.

## 2.2.2 Module 2: Recovery technologies

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

Contents reported in the learning material are coming only from public deliverable available at the time of composing the Training Material. All public deliverables, including those produced at the end of the project, are in any case linked from/referred to from within the Training Modules as the recovery process for end-of-life SO fuel cell, are not currently available in the training toolkit.

Module 2 is organised as follow:

- Chapter 1: Introduction to the current existing recovery & recycling technologies;
- Chapter 2: Description and manual to perform the existing and optimized recovery & recycling technologies (PEMFC);
- Chapter 3&4: Description and manual to perform the novel recovery & recycling processes developed within the project (PEMFC/SOFC).

The following figures show the uploaded material:



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Figure 6 Example of Module 2 Chapter 1: Introduction to the current existing recovery & recycling technologies



Figure 7 Example of Module 2 Chapter 2: Description and manual to perform the existing and optimized recovery & recycling technologies (PEMFC)



Figure 8 Example of Module 2 Chapter 3 Description and manual to perform the novel recovery & recycling processes developed within the project (PEMFC).



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Figure 9 Example of Module 2 Chapter 4: Description and manual to perform the novel recovery & recycling processes developed within the project (SOFC).

Three videos on the recovery and recycling processes have been created for Module 2. In the website, a direct link is also available to explore the dedicated playlist on the BEST4Hy YouTube Channel (<https://www.youtube.com/watch?v=e1JARiw1myE&t=8s>):

- Recycling End-of-Life SOFC;
- Catalyst synthesis from recycled Pt salts;
- How to remanufacture MEAs for new PEM fuel cells?

At the bottom of the page, an Insights section is created with a list of associated deliverables provided for deeper information on the module topics:

- 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 have been HRD and CEA for PEM fuel cells; POLITO for SOFC fuel cells. They have supported the learning materials production with technical revision.



## 2.2.3 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 an environmental and economic point of view. The module reports the project results and opens the discussion on the actual dismantling and recycling processes compared to the technologies developed within BEST4Hy, with first considerations on sustainability, life cycle assessment, life cycle costs, and eco-design of fuel cell and hydrogen technologies.

In this case, the main training contents are project outputs on the following topics:

- LCA and LCC models for BEST4Hy recycling technologies
- Eco-labelling for FCH technologies

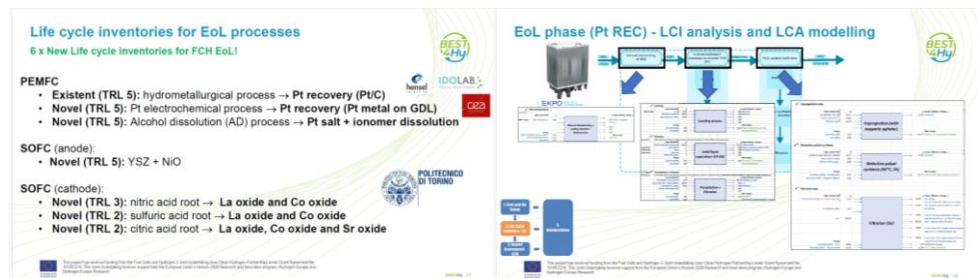


Figure 10 Example of Module 3: LCA and LCC model for BEST4Hy recycling technologies



Figure 11 Example of Module 3: Eco-label for FCH technologies

At the bottom of the page, an Insights section is created with a list of associated deliverables provided for deeper information on the module topics:

- 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 ecolabelling of FCH products;
- D5.3: Guidelines for the setup Ecolabelling qualification.

Partners involved in Module 3 have been the University of Ljubljana and RINA. They have supported the learning materials production with technical revision.



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## 2.2.4 Module 4: Measures towards take up

Module 4 aims to provide an overview of the regulatory framework on the end-of-life treatment of rare/critical/strategic materials contained in FCH technologies, the current level of standardization and the further steps.

In this case, the main training contents are project outputs on the regulation and standards analysis performed along the project (Figure 12, Figure 13):

- Overview of the current regulatory and standardization assessment for management of end-of-life FCH technologies
- Proposed standardization and regulatory-roadmap for future management of end-of-life FCH technologies
- Measure towards take up: replicability and market position for BEST4Hy recycling technologies



Figure 12 Example of Module 4: Regulatory Framework analysis for FCH technologies



Figure 13 Example of Module 4: Standardisation analysis for FCH technologies



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At the bottom of the page, an Insights section is created with a list of associated deliverables provided for deeper information on the module topics:

- 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 have been ENVIPARK, RINA, HRD. They have supported the learning materials production with technical revision.

### 3 Conclusions

BEST4Hy Training Toolkit provides 4 training modules on how to recycle and dismantle most efficiently fuel cells stacks and how to recover the valuable raw materials they contain. This technical training has been developed on the basis of project results to transfer the acquired knowledge to the stakeholders, including Recycling Centres, suppliers of materials and Manufacturers of components and systems.

The toolkit is composed of text materials, graphic materials and, video tutorials and it is available in the specific “Training Toolkit” section embedded in the BEST4Hy website.

The Training Toolkit section has been published in December 2023 and each module content has been adapted considering publicly available BEST4Hy results.



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