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

Deliverable D6.8

Report about BEST4Hy training activities

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Executive Summary

The present document is a report on the BEST4Hy Training activities' organization and performance. BEST4Hy Training activities aim to provide technical knowledge and skills on how to dismantle hydrogen fuel cells and recover valuable materials. Main target groups have been recycling centres and manufacturers including suppliers of materials and components, but all hydrogen players along the value chain could benefit from it also.

The Training has been organized into two main activities: a Training Toolkit, with learning materials and video tutorials, and face-to-face Training days. The following chapters describe work done and results of the activities performed in the last 6 months of the project.

ENVI was responsible for the technical materials and lesson development with technical support by other partners, who delivered the Training days also. The Training activities are part of Task 6.4, WP6 dedicated to the Measure towards take up.

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1 Introduction

The BEST4Hy Training is an activity related to Task 6.4, WP6 dedicated to the Measure towards take up, mainly focused on HOW to dismantle FCH technologies and recover valuable materials from it, on the basis of results and knowledge acquired along the project. Main targets have been Recycling Centres and Manufacturers stakeholders. The Training activities been composed of Training Toolkit and Training days to engage and support the identified stakeholders in the learning process of the contents.

All the activities have been coordinated by ENVI, also in charge of creating contents and materials from information developed within the project of public domain. Other partners have given their support for the technical revision of the produced learning material and for the delivery of the technical training during the Training days. In the following chapters, each single training activity is explained.

Related deliverables are:

- Deliverable 6.1 – Training Plan
- Deliverable 6.7 – BEST4Hy Training kit

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2 Training activities and objectives

Objective of the Training activities has been the technical knowledge transfer of BEST4Hy outputs on HOW to dismantle FCH technologies and recover valuable materials from it, with some additional insights in strategic aspects such as technoeconomic and regulations. Project outcomes, lessons learnt, knowledge and skills on the recovery and recycling solutions for EoL fuel cells based on the project experience have been shared, based on the following topics: dismantling, recovery and recycling technologies, techno-economic aspects for a complete validation of the EoL strategy underpinned by the technologies, as well as replicability, market analysis and regulatory/standardization aspects.

The Training activities have been addressed to all hydrogen players along the value chain and to the following primary target groups:

- Recycling centers
- Manufacturers, including suppliers of materials and components

As defined in Deliverable D6.1 “Training plan”, the activities have included a Training Toolkit and two Training days with specific training objectives based on the type of activity (Table 1). Indeed, beside the training materials, two face-to-face training days have been delivered by POLITO (M33) and HRD (M36). The Training days have been organised to be interactive allowing stakeholders to exchange their views, identify common barriers and share best practices.

Clean Hydrogen Partnership

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Table 1 Training methodology description and main objectives

Training activities	Objectives
Training Toolkit	*By learning contents' purposes*: • Improve and transfer technical knowledge and specific skills on recovery & recycling technologies and related topics; • Disseminate and promote lessons learnt and results achieved in BEST4Hy. *By learning materials' typology*: • Offer technical materials/manuals 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 anytime and anywhere.
Training days	*By learning contents' purposes*: • Improve and transfer technical knowledge and specific skills on recovery & recycling technologies and related topics; • 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 of views; • Offer the opportunity to meet other stakeholders (even from other Countries) and share opinions, visions, barriers or best practices.

Training activities have been mainly led by ENVI with the technical support from the entire Consortium for the learning materials production and for the Training days activities and stakeholders engagement.

To summarise, main purpose of the Training activities is to provide:

- An overview of the main technical EoL strategies for FCHs technologies, with specific focus on PEMFC/SOFC;

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- Learning of the importance of 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 of the importance and the application of the Eco-design to the FCHs;
- An overview of the EU Regulation framework, plus future standardisation roadmap for development of FCHs recovery & recycling technologies;
- Understanding of the EoL technologies replicability, current market opportunities and potential for future exploitation.

2.1 Training Toolkit

The Training Toolkit has been available in the specific training section of the BEST4Hy's website since December 2023: https://best4hy-project.eu/training-toolkit/#.

The section collects all the learning materials and provides information related to the training activities developed within the project. The Training Toolkit is composed of 4 learning modules, providing technical knowledge and skills on the topics identified for the main training subject of "HOW to dismantle FCH technologies and recover valuable materials from it":

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 visualise the process, the training materials has been improved with easily understandable graphics and video tutorials, giving a visual description of the technologies explained in each module.

A full description of the Training Toolkit and learning modules can be found in the Deliverable D6.7 "Training kit".

Considering the late launch of the Training Toolkit due to delays in the completion of the information (first public news on the 11th of December, 2023), only a few website analytics data are currently available to assess the learning materials acquisition trend and users' satisfaction. However, some first interesting results have been collected in the first month, as showed in the following pictures (website analytics from the 10th of December until 26th of Dec 2023):

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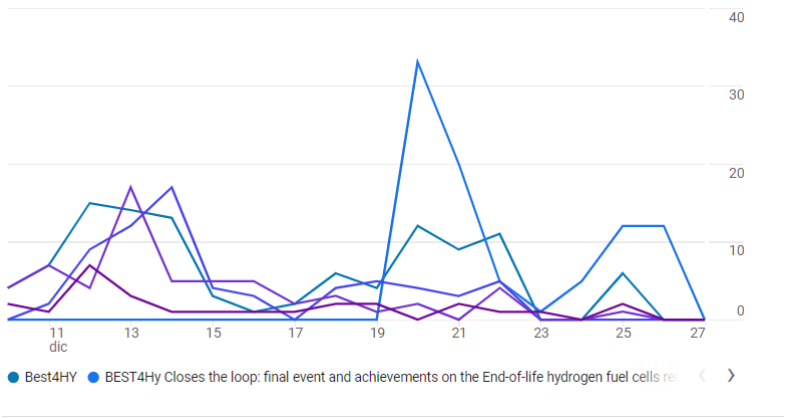

Figure 1 BEST4Hy website analytics: views by Page Title and Screen Class overtime

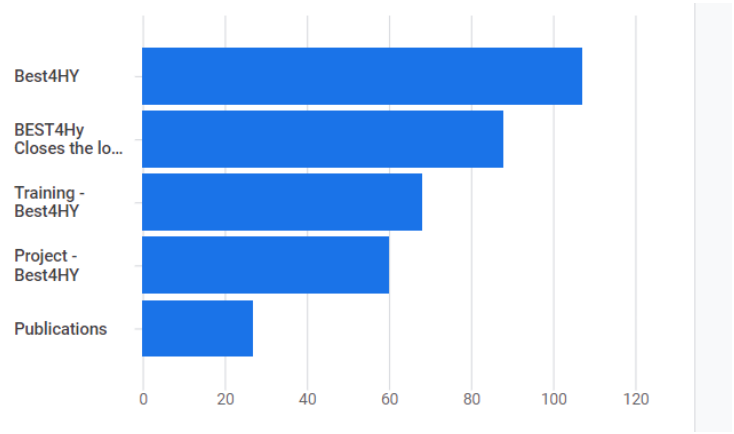

Figure 2 BEST4Hy website analytics: views by Page Title and Screen Class

	Page title and...screen axis	Views	Users	Views by user	Average duration of involvement	Event counting file_download
		471 100% of the total	177 100% of the total	2.66 Same as average	57 s Same as average	81 5.61% of the total
1	Best4HY	107	64	1.67	21 s	2
2	BEST4Hy Closes the loop: final event and achievements on the End-of-life hydrogen fuel cells recycling project - best4hy	88	70	1.26	13 s	2
3	Training - Best4HY	68	37	1.84	45 s	28
4	Project - Best4HY	60	33	1.82	1m 12s	4
5	Publications	27	15	1.80	56 s	42

Figure 3 BEST4Hy website analytics: views and users by Page Title

In the last 16 days, the Training section in BEST4Hy website results to be the third most viewed section with overall 68 views out to 471 (14,4%) and 38 visitors out to 177 (21,5%). **Errore. L'origine riferimento non è stata trovata.** also shows the "Event counting" column with focus on number of downloaded files, 28 in total from the Training page.

Data analytics for the video tutorials in the Training section and in the project's YouTube channel (https://www.youtube.com/channel/UCyBeBQS3Z7CoFs-pN8QPQmQ) are here reported:

Module 1

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- Manual dismantling process of a PEM fuel cell – 1.397 views (published in April 2022);
- Disassembling a FCH stack from automotive application – 173 views (published in October 2023).

Module 2

- Recycling End-of-Life SOFC – 186 views (published in October 2022);
- Catalyst synthesis from recycled Pt salts – 115 views (published in November 2023);
- How to remanufacture MEAs for new PEM fuel cells? – 29 views (published in November 2023);
- HYDROGEN AS SUSTAINABLE DRIVER FOR INNOVATION - Oct 26th, Turin – 36 views (published in November 2023).

These first results show stakeholders' interest in the training about BEST4Hy topics and project. A first dissemination campaign has started on social media project profiles (Figure 4) and it will further continue in the next months, reporting the final communication and dissemination activities related to the Training in the Final Report due end of February 2023.

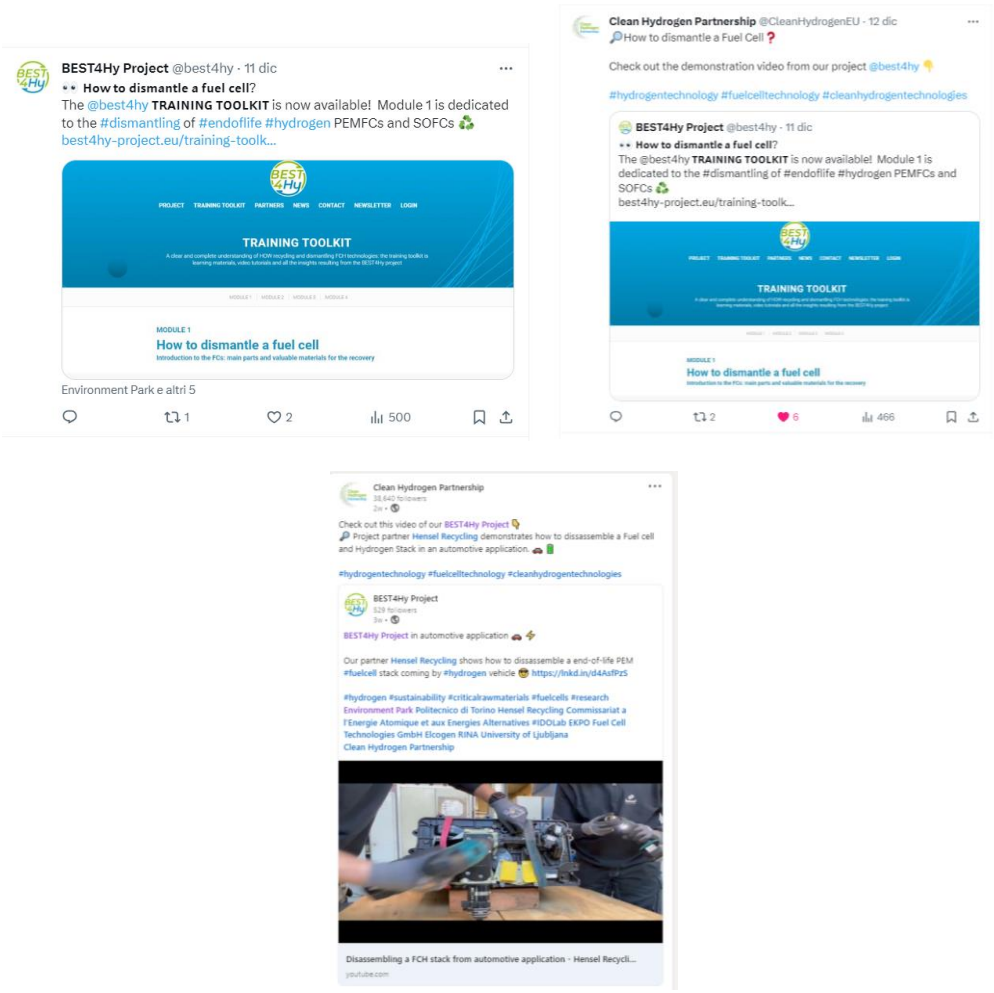

Figure 4 Example of Training Toolkit promotion by the BEST4Hy project and the Clean Hydrogen Partnership profiles

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2.2 Training days

Complementing the Training Toolkit and other learning materials developed online, the Training days offered a practical learning experience. Two face-to-face training days were organised at POLITO (M33) and HRD (M36) premises. They were organised in correspondance with other two project workshops involving policymakers, public authorities, and AB members to show them results and final pilot plants. This supported the overall dissemination of BEST4Hy and stakeholders' networking, maximising the effect of both type of events. The two events were therefore:

- Training day nr 1 in correspondence with the "Hydrogen Day" event (October 26th, 2023)
- Training day nr 2 in correspondence with BEST4Hy Final Event (December 13th, 2023)

The two events were dedicated to explain BEST4Hy project and show its results, with some specific focus of the training on the recycling technologies for end-of-life PEM and SO fuel cells respectively. Specifically, BEST4Hy Consortium presented the research results on dismantling, recovery & recycling processes and directly showed the BEST4Hy's pilot plants.

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 industry.

2.2.1 Training day nr 1 - The "Hydrogen Day" event (Oct, 26th)

Training day nr 1 was dedicated to the Solide Oxide fuel cells research developed within BEST4Hy. The event was organised at ENVI's premises in Turin (Italy) on the 26th of October 2023. The BEST4Hy's pilot plant for the recovery of valuable materials from scrap and EoLs SOFC built by POLITO is, indeed, located in ENVI's laboratories.

The training day was organised in the framework of the annual ENVI's showcase called "Hydrogen day". The hydrogen day is generally dedicated to all companies involved into the CLEVER Cluster[1] managed by ENVI and to all hydrogen actors of the Piedmont

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[1] https://www.poloclever.it/it/polo-energy-and-clean-technologies/

territories. This year the event was organised around the topics of sustainability with a focus on BEST4Hy project and the participation of the BEST4Hy partners.

The event was titled "**HYDROGEN AS SUSTAINABLE DRIVER FOR INNOVATION**, From the production to the final uses of hydrogen devices for a sustainable and circular supply chain" (Figure 5). The general dissemination event was held in the morning, whereas the Training activities were held in the afternoon. The day involved relevant companies and academia representatives, including BEST4Hy project partners, discussing on hydrogen topics with specific focus on the sustainability aspects along the value chain.

The event was organised by ENVI and POLITO (this latter in charge of the Training Day activity) in collaboration with CLEVER Cluster – the local innovation Cluster on Clean Technology, managed by Envipark, and Sistema Poli[2], the project that joins up all the regional innovation clusters. The event concluded with a visit to the portable hydrogen genset hosted by Envipark in the context of EVERYWH2ERE[3] project, H2020/ FCH (now Clean Hydrogen Partnership) funded.

[2] https://sistemapolipiemonte.it/
[3] https://www.everywh2ere.eu/

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Figure 5 - BEST4Hy Event of "6th October 2023 - poster

The agenda of the day therefore included panel sessions in the morning, demonstrations and guided tours to the ENVI's laboratories and EVERYWHERE demosite in the afternoon. B2B and networking opportunities were also organised through the Swapcard platform. Full agenda is showed in Figure 6 and Figure 7.

The demonstration session, part of the BEST4Hy training, was conducted by partners of CEA, Hensel Recycling GmbH and Politecnico di Torino to illustrate the recovery and recycling technologies of critical/strategic raw materials and rare earth elements developed during the project. This was followed by a visit to the BEST4Hy's pilot plant for the recovery of materials from end-of-life SOFCs and to the testbench for the evaluation of the functionality of the SOFCs produced with 30% recycled material, also at Envipark's laboratories.

Morning session	
09:00 – 09:15	**Attendees' registrations**
09:15 – 09:30	**Welcome and Introduction**
09:30 – 10:30 ***Panel 1***	**Producing zero impact energy: green hydrogen and its storage technologies** Moderator *Massimo Santarelli, Full Professor Department of Energy, Politecnico di Torino* With • **Patrick Scilabra**, Project Leader, De Nora • **Paola Rizzi**, Full Professor Department of Chemistry, Università di Torino • **Carlo Luetto**, Amministratore Delegato Tecnodelta Srl
10:30 - 10:45	**Coffe break**
10:45 – 11:45 ***Panel 2***	**End uses: state of the art of the most innovative and sustainable hydrogen devices** Moderator *Alessandra Cuneo, Project Manager, RINA Consulting* With • **Sergii Pylypko**, Director of Technology, Elcogen • **Thomas Kiupel**, Research and Development Engineer, EKPO • **Diomede Malvaso**, HSE Regulatory Compliance Manager, RINA Consulting
11:45 – 12:45 *Panel 3*	**From Eco-design to End-of-life: a circular and sustainable value chain for hydrogen** Moderator *Ilaria Schiavi, BEST4Hy project coordinator, Environment Park* With • **Mitja Mori**, Assistant Professor at Faculty of Mechanical Engineering, University of Ljubljana • **Anna Marchisio**, Business Development Manager, Hensel Recycling GmbH • **Valeriy Kapelyushko**, Sustainability & Strategic Initiatives R&I Manager, Solvay Specialty Polymers • **Antonio Campanale**, Innovation for Power Generation and Hydrogen Project Manager, RINA Consulting
12:45 – 13:00	**Wrap-up**
13:00 – 14:00	**Light lunch**

Figure 6 BEST4Hy Event of 26th October 2023 – Morning agenda

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Afternoon session	
Visits to the Open Lab and demonstration on Recycling solutions for FCHs with BEST4Hy	
14:00 – 15:00 **15:00 – 15:30**	**HOW to recycle and dismantle FCH technologies?** BEST4Hy project offers a training to manufacturers and recycling centers to show solutions for the recovery and recycling of critical raw materials from fuel cells technologies with specific focus on the SO fuel cells. **Politecnico di Torino** will lead the training with **CEA Liten** (Grenoble) and **Hensel Recycling GmbH** as representatives on BEST4Hy's PEMFC research: • Demonstration on both PEM and SO fuel cells • Lab visit and show of the BEST4Hy's pilot plant for EoL SOFCs developed by Politecnico di Torino www.best4hy-project.eu
15:30 – 16:00	**Discover the demo project EVERYWH2ERE and its genset for public events** A visit to the local genset located in Environment Park and used for energy supply at local public festivals www.everywh2ere.eu

Figure 7 BEST4Hy Event of 26th October 2023 – Afternoon agenda

The event was held in English and it was made available in streaming on ENVI's YouTube Channel, collecting overall 242 views (https://www.youtube.com/watch?v=dlKaPSHiBPU&t=31s). A short promotional video was also prepared post-event to share the experience and to further disseminate the BEST4Hy' results: https://www.youtube.com/watch?v=mzmfqtfEAIE&t=9s.
The video (Figure 8 for a snapshot) reached 34 views.

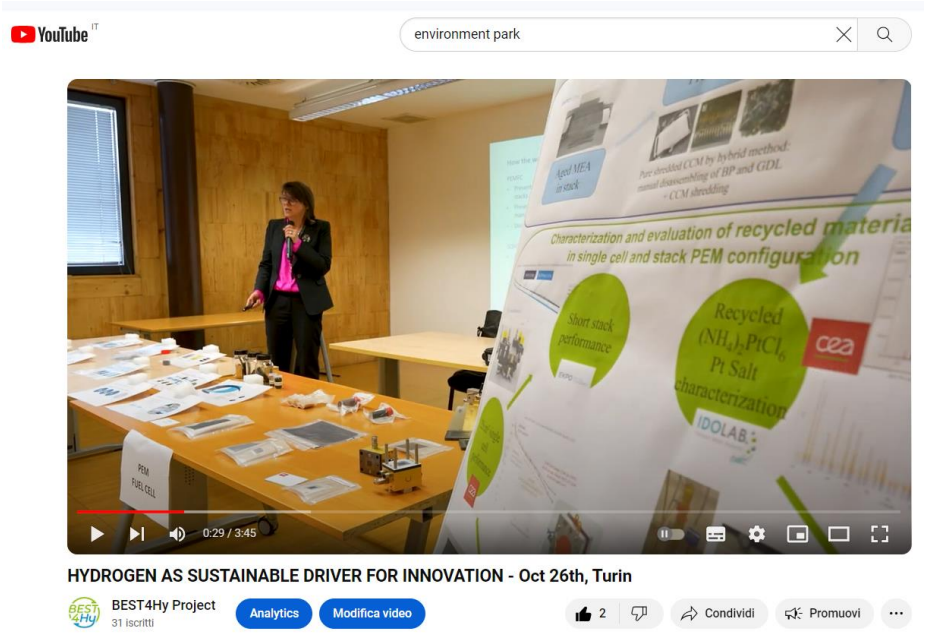

Figure 8 Oct, 26th BEST4Hy Event - post-event video on "HYDROGEN AS SUSTAINABILE DRIVER FOR INNOVATION" event

Overall, 51 people attended the entire event (both morning and afternoon), and of these, some 36 were external to the Consortium and not involved as speakers. The audience was composed of representatives from hydrogen companies, components manufacturers, research centres and local public authorities.

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During the morning session, an online Q&A session was opened and some polls were launched to involve the attendees in the discussion and to better understand audience knowledge, as well as interest in the different topics.

Questions proposed to the audience were the following:

1. Which step on the hydrogen value chain are you more interested in?
2. Which area are you working on?
3. Which is the main barrier from an end-user's point of view for the uptake of hydrogen technologies?
4. Which R&I areas for improving the sustainability of the hydrogen supply chain should be explored? 2-3 words to explain it

These polls allowed to steer some of the discussion and also to better understand the audience, providing valuable information also on the stakeholders reached.

Some 77% of the audience was directly involved into the panel session through the Q&A section and the polls.

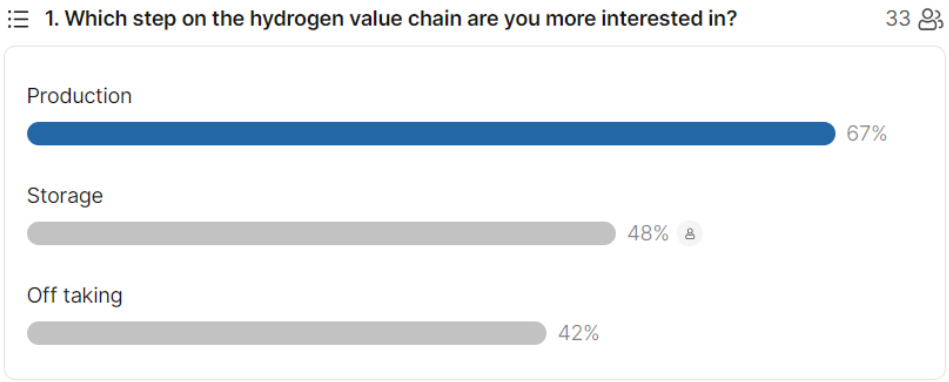

Figure 9 Question nr 1

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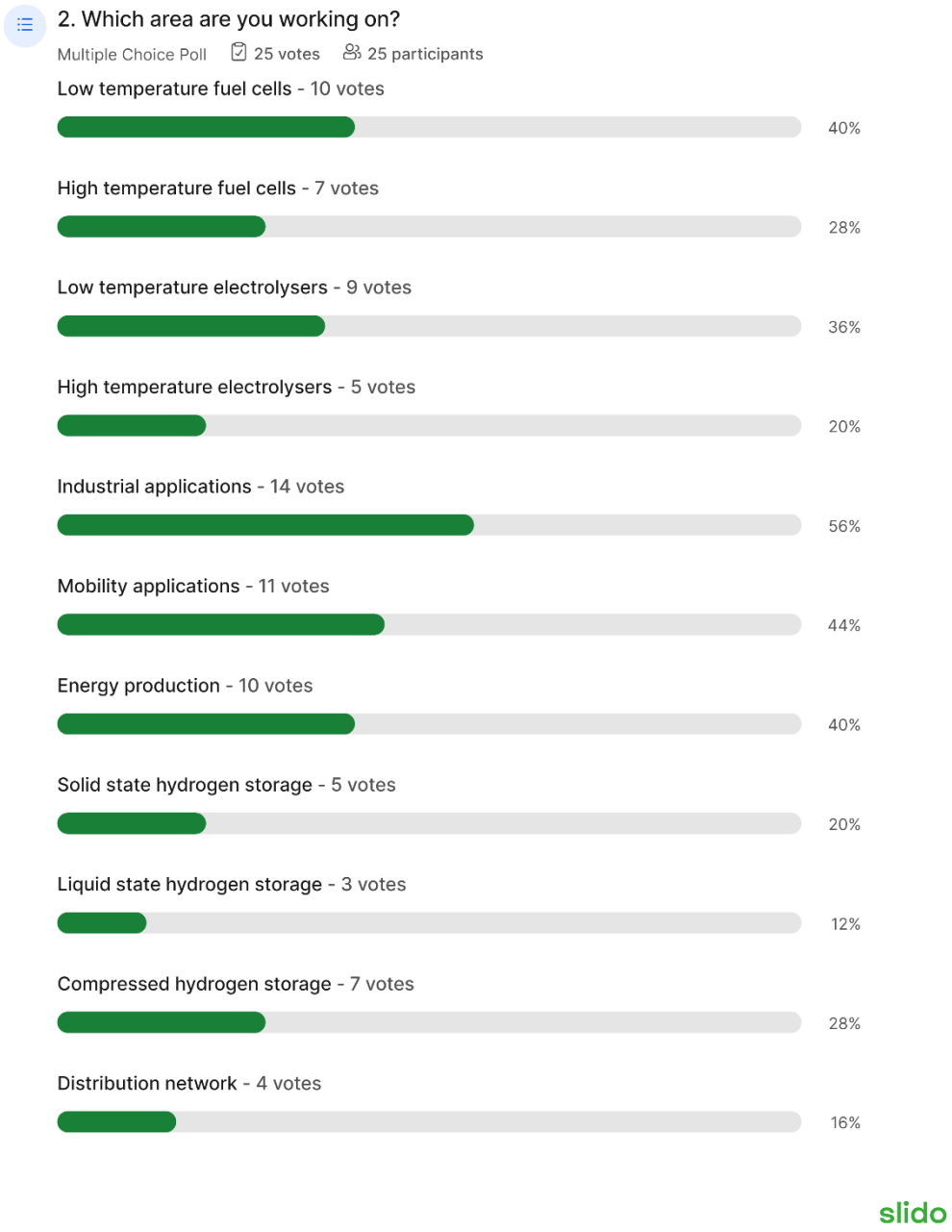

Figure 10 Question nr 2

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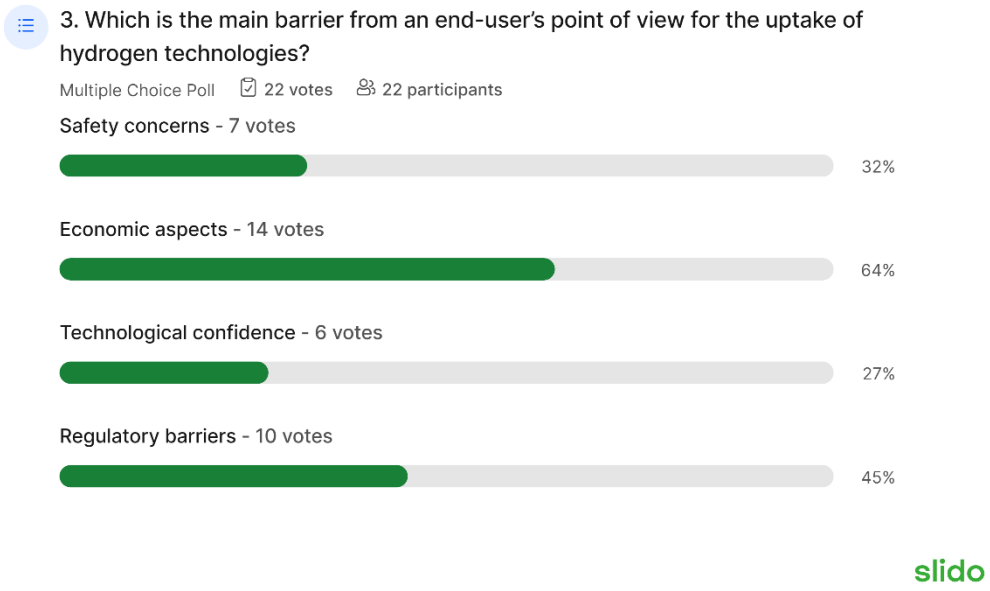

Figure 11 Question nr 3

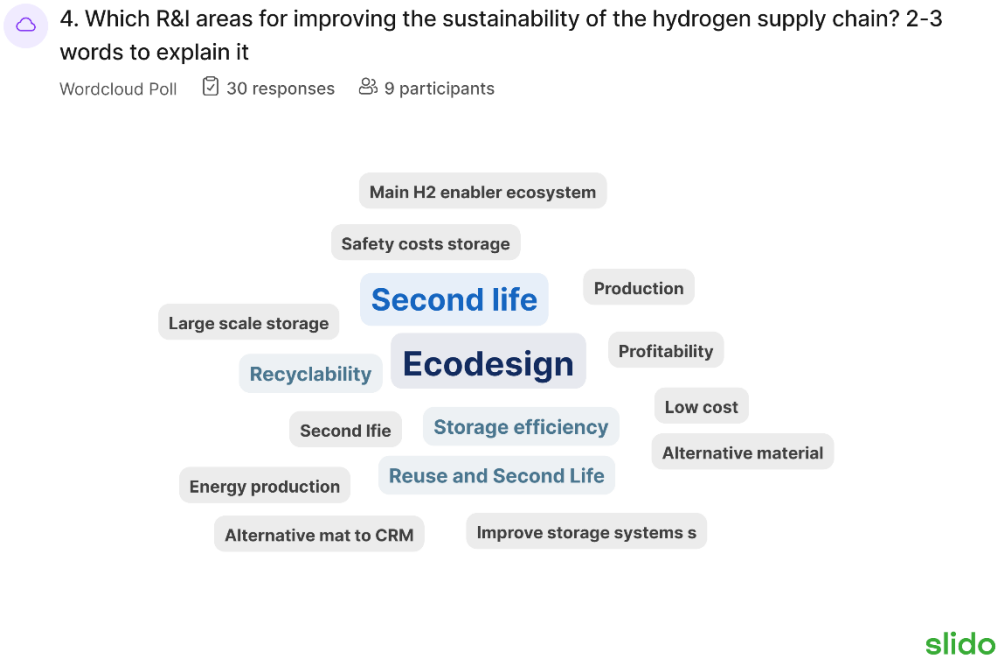

Figure 12 Question nr 4

During the afternoon session, partners CEA, HRD and POLITO, together with EKPO and Elcogen, provided the audience with a deeper explanation of the overall recovery and recycling processes developed within BEST4Hy through posters, samples and prototypes to explain each single process step as planned in the Training plan (specifically Module 1 and 2).

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The following pictures refer to the LinkedIn posts showing some moments of both morning and afternoon session of the day:

Figure 13 BEST4Hy Event of 26th October 2023- LinkedIn posts showing moments of the morning and afternoon session

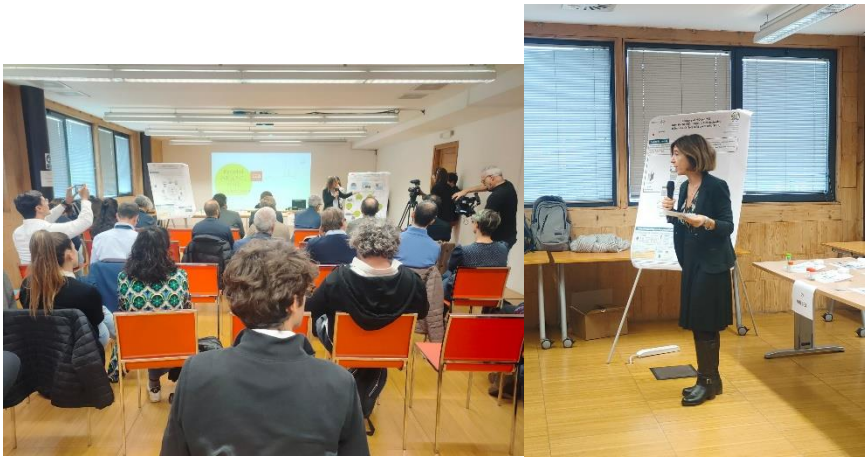

Figure 14 BEST4Hy Event of 26th October 2023– demonstration/training session

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2.2.2 Training day nr 2 and BEST4Hy Final Event (December the 12th and the 13th, 2023)

Training day nr 2 was dedicated to the research on materials recovery from Proton Exchange Membrane fuel cells developed within BEST4Hy. The event was organized by Hensel Recycling and IDO-Lab at their premises in Achaffenburg and Karlstein am Main (Germany) with the support of project coordinator ENVI.

The training event was integrated into a morning workshop (see agenda below) with demonstrations sessions and training on fuel cell's disassembly at Hensel Recycling headquarter (December the 12th, 2023, PM), and on materials recovery technology at IDO-Lab laboratories (December the 13th, 2023, PM).

During the workshop, BEST4Hy's project results were presented according to the following agenda:

Timing (CET)	Activity
9:00 – 9:15	**Attendees' registrations**
9:15 – 9:30 (5 minutes discussion)	**BEST4Hy: Introduction and project concept** Environment Park BEST4Hy project coordinator
9:30 – 10:15 (including up to 15 minutes discussion)	**PEMFC: recovery and recycling processes** Results and demonstrations by Hensel Recycling, IDO Lab, CEA, EKPO
10:15 – 11:00 (including up to 15 min discussion)	**SOFC: recovery and recycling processes** Results and demonstrations by Politecnico di Torino, Elcogen
11:00 – 11:05	**Clemens Hensel – considerations on involvement in BEST4Hy**
11:00 - 11:15	**Coffee break**
11:15 – 12:00 (including up to 15 min discussion)	**Technoeconomic and environmental aspects for EoL FCs recycling** University of Ljubljana and RINA
12:00 – 12:45	**Towards the Take up** Environment Park and RINA
12:45- 13:00	**Final remarks**

Figure 15 BEST4Hy Final Event agenda (morning of December the 13th, 2023)

The event was a private workshop, organised to disseminate the project results to the Advisory Board members and to other invited stakeholders, such as recycling and metal industries representatives, materials and components suppliers and research centres. A hybrid format was chosen to enlarge participation. Overall, 12 stakeholders participated showing high interest on the topics. Among them: Toyota Europe Motor, Solvay/Syensqo, Hensel Recycling North America, JRC, Hellas CERTH, Enabled Future Limited, Kuchta Group, Heraeus, Aschaffenburger Liefer GmbH (AVG), Metalor/Tanaka, metal association (FVEM), Chemorus and a journalist from Recycling Magazine.

The event was animated by questions from and to the audience to share opinions and feedbacks on the project results.

The following pictures show some moments of the workshop, where also samples and posters were used to show each process step as expected by the training plan. Due to confidential content, no pictures are available for the afternoon visits at the laboratories,

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which were however very well attended by the stakeholders who had the opportunity to see, at HRD, a dismantled EoL fuel cell plus other interesting material from other EoL FCH technologies and, at IDO-Lab, the pilot plants developed for the hydrometallurgical and alcohol dissolution processes.

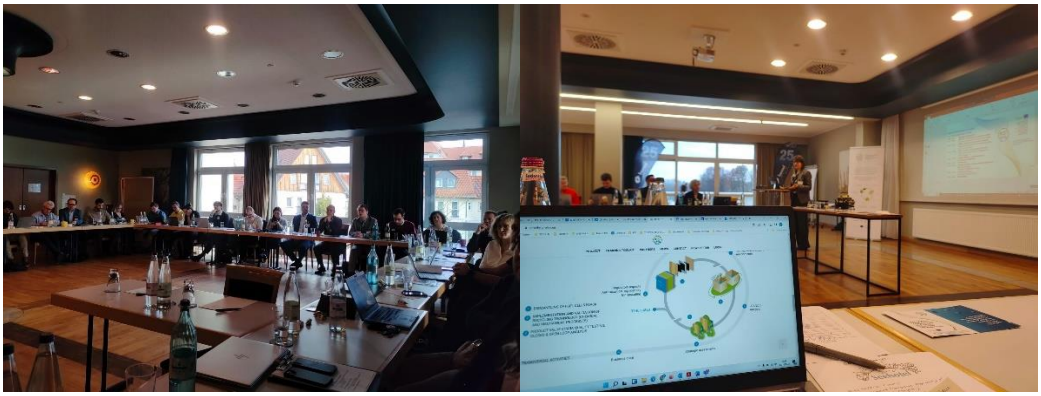

Figure 16 BEST4Hy Final event – morning workshop and demonstration

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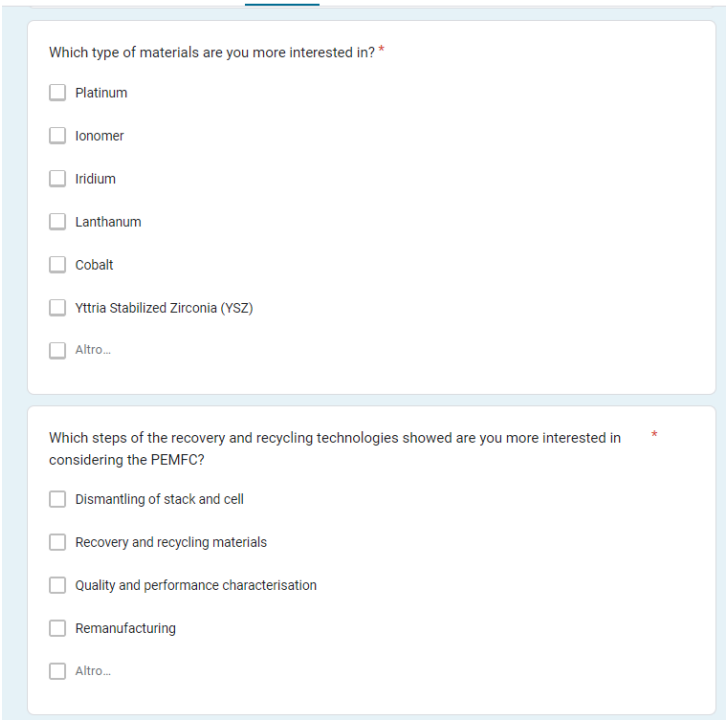
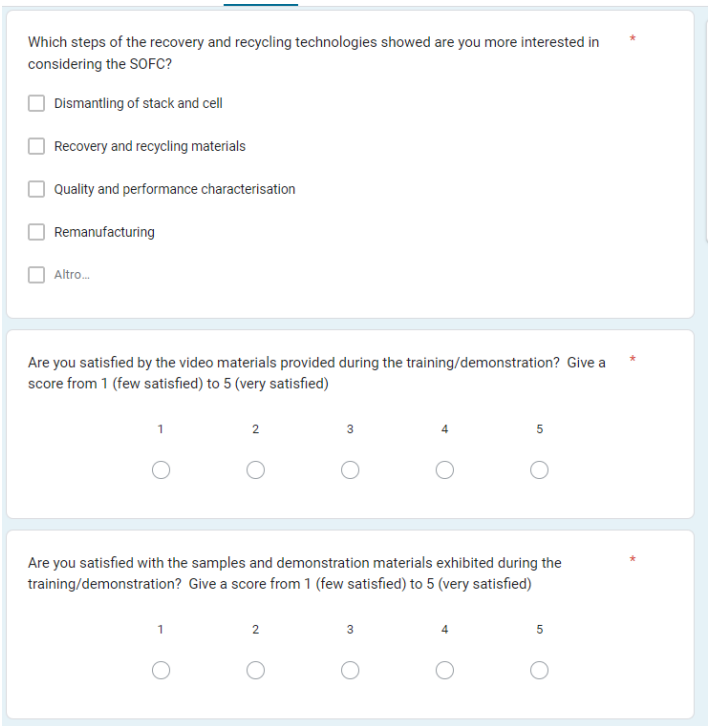
2.2.3 Training Survey

Aside from the statistics on the learning material uploaded o the website, a training survey was used to assess the face-to-face Training days: https://docs.google.com/forms/d/e/1FAIpQLSdIunKz7lUXcBH1zxgkYMlAE3rA6Fievnc_8BRjG3DuvcAXlg/viewform?usp=sf_link

Main questions are here reported:





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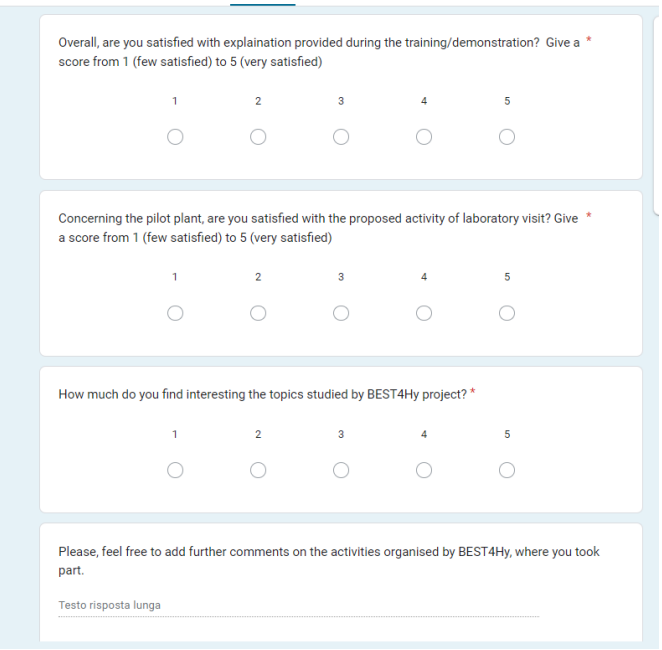

Figure 17 BEST4Hy Survey – Training satisfaction

The BEST4Hy Survey will be embedded into the Training Toolkit website section in order to collect further inputs, which will be reported in the Final Report, if available.

The 5 answers received so far have been analysed, showing the field of activity of the companies attending the training events:

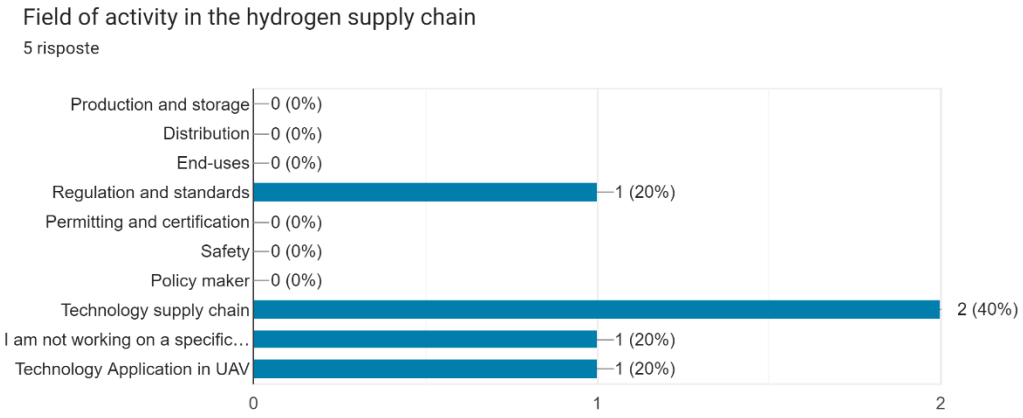

Figure 18 BEST4Hy Survey - field of activity in the hydrogen supply chain

In terms of interest in the training topics, the replies showed a preference for the recycling of EoL PEM fuel cells, especially for the recovery of ionomer.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007216.

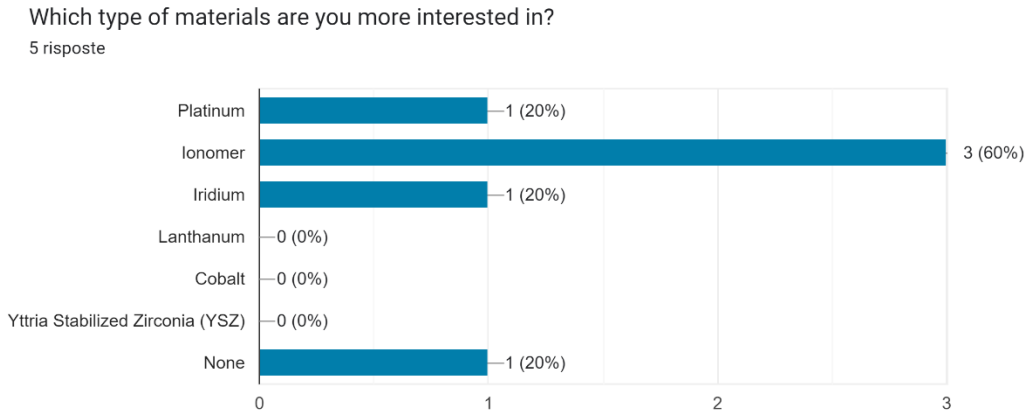

Figure 19 BEST4Hy Survey – Type of materials of interest

Regarding the learning materials, videos and event provided, the satisfaction survey provides 4 and 5 scores in a 1-5 ranking for the Lab visits.

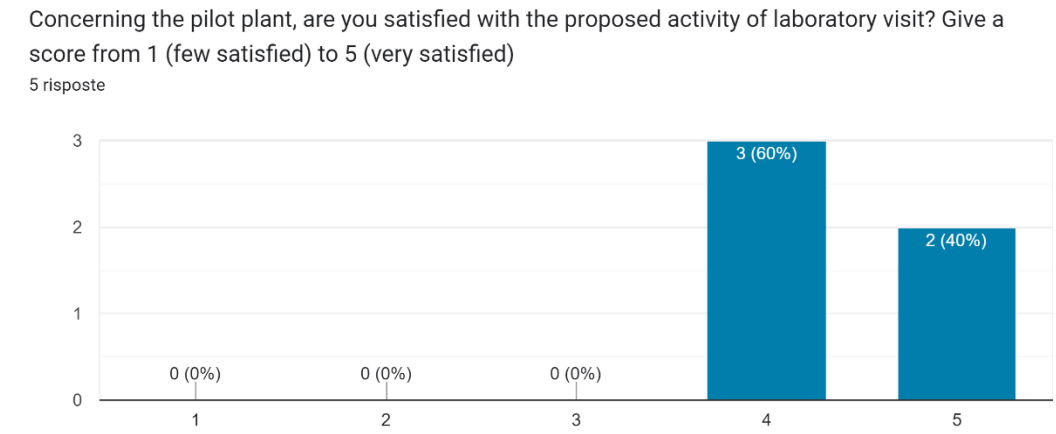

Figure 20 BEST4Hy Survey - Laboratory visit satisfaction

3 Conclusions

The present document has reported the Training activities performed during the BEST4Hy project. The activities were mainly led by ENVI with the involvement of the entire Consortium for both learning materials production and face-to-face training.

The Training activities followed the guidelines provided by the D6.1 “Training Plan” for what concern the training methodology and objectives. D6.7 “Training Kit” also explained the learning materials and kit produced within the project and available in the dedicated platform on the BEST4Hy’s website (https://best4hy-project.eu/training-toolkit/#). The Training Toolkit and platform was launched in December 2023, while the face-to-face

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Training days were organised in October and December 2023 respectively in correspondence with two major dissemination events. Both events have seen the involvement of the entire Consortium in the presentation of the project results and specific recovery and recycling processes explanation with related laboratories visits at the pilot plants. A survey was also shared among the attendees to assess the appeal of the activities. The training days have been overall an interactive learning experience among both trainers/users and users/users, creating also networking conditions to exchange views and discuss challenges and opportunities.

Both the Training Toolkit and the Training days received positive feedbacks by the attendees, even if disseminated in a short time. In the next months, the dissemination campaign for the BEST4Hy's project results and training will continue and further results up to February 2024 will be reported in the Final Report.

Clean Hydrogen Partnership

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