Clean Hydrogen Partnership

CLEAN HYDROGEN JOINT UNDERTAKING

2021 ANNUAL ACTIVITY REPORT

Clean Hydrogen Partnership
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EUROPEAN PARTNERSHIP

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In accordance with Article 26 of Council Regulation (EU) No 2021/2085 establishing the Clean Hydrogen Joint Undertaking and with Article 23 of the Financial Rules of the Fuel Cells and Hydrogen 2 Joint Undertaking as re-adopted by the Clean Hydrogen Governing Board on 17 December 2021 (CleanHydrogen-GB-2021-02).

The annual activity report will be made publicly available after its approval by the Governing Board.

Clean Hydrogen Partnership

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Contents

FACTSHEET

NAME	Fuel Cells and Hydrogen 2 Joint Undertaking (until 30 November 2021) Clean Hydrogen Joint Undertaking (as of 30 November 2021)
OBJECTIVES	*For Fuel Cells and Hydrogen 2 Joint Undertaking (see Council Regulation (EU) No 559/2014 of 6 May 2014)* General objectives: a) to contribute to the implementation of Regulation (EU) No 1291/2013, and in particular the Secure, Clean and Efficient Energy Challenge and the Smart, Green and Integrated Transport Challenge under part III of Annex I of Decision 2013/743/EU; b) to contribute to the objectives of the Joint Technology Initiative on Fuel Cells and Hydrogen, through the development of a strong, sustainable and globally competitive fuel cells and hydrogen sector in the Union. Specific objectives: a) reduce the production cost of fuel cell systems to be used in transport applications, while increasing their lifetime to levels which can compete with conventional technologies, b) increase the electrical efficiency and the durability of the different fuel cells used for power production to levels which can compete with conventional technologies, while reducing costs, c) to increase the energy efficiency of production of hydrogen mainly from water electrolysis and renewable sources while reducing operating and capital costs, so that the combined system of the hydrogen production and the conversion using the fuel cell system can compete with the alternatives for electricity production available on the market; d) to demonstrate on a large scale the feasibility of using hydrogen to support integration of renewable energy sources into the energy systems, including through its use as a competitive energy storage medium for electricity produced from renewable energy sources; e) reduce the use of the EU defined 'Critical raw materials'([1]), for instance through low-platinum or platinum-free resources and through recycling or reducing or avoiding the use of rare earth elements. *For Clean Hydrogen Joint Undertaking (see Council Regulation (EU) No 2021/2085 of 19 November 2021)* General objectives: a) to contribute to the objectives set out in the communication from the Commission of 17 September 2020 on Stepping up Europe's 2030 climate ambition: Investing in a climate-neutral future for the benefit of our people, the European Green Deal and the European Climate Law by raising the Union's ambition on reducing greenhouse gas emissions to at least 55 % below 1990 levels by 2030, and climate neutrality at the latest by 2050; b) to contribute to the implementation of the 2020 Commission's Hydrogen Strategy for a climate neutral Europe; c) to strengthen the competitiveness of the Union clean hydrogen value chain, with a view to supporting, in particular for SMEs [small and medium-sized enterprises], the acceleration of the market entry of innovative competitive clean solutions; d) to stimulate research and innovation on clean hydrogen production, distribution, storage and end use applications.

([1]) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0474&from=EN

	Specific objectives: a) improve through research and innovation, including activities related to lower TRLs [technology readiness levels], the cost-effectiveness, efficiency, reliability, quantity and quality of clean hydrogen solutions, including production, distribution, storage and end uses developed in the Union; b) strengthen the knowledge and capacity of scientific and industrial actors along the Union's hydrogen value chain while supporting the uptake of industry-related skills; c) carry out demonstrations of clean hydrogen solutions with a view to local, regional and Union-wide deployment, aiming to involve stakeholders in all Member States and addressing renewable production, distribution, storage and use for transport and energy-intensive industries as well as other applications; d) increase public and private awareness, acceptance and uptake of clean hydrogen solutions, in particular through cooperation with other European partnerships under Horizon Europe.
FOUNDING LEGAL ACTS	Council Regulation (EU) No 559/2014 of 6 May 2014, OJ L 169, 7.6.2014, p. 108–129 (FCH 2 JU founding regulation) Council Regulation (EU) No 2021/2085 of 19 November 2021, OJ L 427, 30.11.2021, p. 17–119 (Clean Hydrogen JU founding regulation)
EXECUTIVE DIRECTOR	Bart Biebuyck
GOVERNING BOARD	Chair: René Schutte Vice-chair: Rosalinde van der Vlies Current composition: https://www.clean-hydrogen.europa.eu/about-us/organisation/governing-board_en
OTHER BODIES	*For Fuel Cells and Hydrogen 2 Joint Undertaking* States Representative Group, Scientific Committee, Stakeholder Forum *For Clean Hydrogen Joint Undertaking* States Representatives Group, Stakeholders Group
STAFF	24 temporary agents, 3 contract agents and 2 seconded national experts
2021 BUDGET	EUR 15.8 million, of which EUR 10.2 million (in terms of commitment appropriations) allocated to operational activities and EUR 5.6 million to administrative expenses
BUDGET IMPLEMENTATION	98.3 % in terms of commitment appropriations 88 % in terms of payment appropriations
GRANTS	134 signed for a total value of EUR 632.6 million at end of 2021
STRATEGIC RESEARCH AGENDA	Multiannual work plan 2014–2020 Addendum to the work plan endorsed by the Governing Board on 15 June 2018
CALL IMPLEMENTATION	Global project portfolio (since setting up): 155 projects under the seventh framework programme (of which 154 are closed and 1 is open) and 134 signed projects under H2020 (of which 52 are closed and 82 are open) Number and value of tenders (if any): 2 operational procurement activities were contracted in 2021 for a total value of EUR 718k
PARTICIPATION, INCLUDING SMALL AND MEDIUM-SIZED ENTERPRISES (SMES)	Total number of participations in funded projects: 1 544 of which: number of SMEs = 23 % SME funding = 28 % number of large private for-profit companies = 70 %

FOREWORD

2021 was a significant year for the hydrogen community and the continuation of the partnership. It was marked with substantial efforts in order to finalise the transition to a new ambitious policy programme. Hydrogen will be at the forefront of this new era as the European Union strives to transform itself into a modern, resource-efficient and competitive economy.

All these efforts culminated in November 2021, when the Council and the Parliament adopted the regulation establishing the Clean Hydrogen Joint Undertaking (JU). The JU will have the leading role in research activities related to hydrogen, collaborating closely with most of the end use European partnerships on hydrogen applications in the relevant sectors. Its focus will be different from that of the Fuel Cells and Hydrogen 2 JU, shifting to areas related primarily to the production of clean hydrogen, as well as the distribution, storage and end use applications of low-carbon hydrogen in hard-to-abate sectors.

The current report does not only cover the hard work to shape the future path but primarily details the main developments of the JU programme in 2021, major technological developments, insight into participations, statistics, our output and impact, important information on outreach, and details of programme execution and management of the programme office.

You will read about how the JU supported the demonstration of 1 064 fuel cell electric vehicles, with overall positive user satisfaction in terms of performance and refuelling times. Some 350 fuel cell buses for which the purchase prices and running costs have already reached programme targets operate successfully in European streets. The fleet is supported by an expanded network of 113 hydrogen refuelling stations, directly financed by the programme.

You will also notice the significant achievements in the energy sector, with 1 900 fuel cell micro-combined heat and power units deployed in domestic and commercial buildings, indicating the maturity of technology. Electrolysers' capacity has already reached the multi-MW scale and their use in large demonstration projects helps in bringing hydrogen to the centre of EU energy policy as a key enabler of sectoral integration.

The above are perfectly combined in three European territories that already benefit from an integrated system approach that includes hydrogen production, and are searching for storage and distribution solutions.

Among the highlights of the year was the second European Hydrogen Week, which marked the public launch of the Clean Hydrogen Partnership in the presence of the President of the European Commission, Ursula von der Leyen.

With 288 projects, a combined public–private investment of over EUR 2.2 billion has been realised since 2008. The COVID-19 pandemic has had an impact on current projects but we have been able to adjust grant agreements wherever possible in order to address the consequences and to enable projects to remain on track to achieve their objectives.

In 2021, the JU maintained its excellent budget execution rates. Combined with the outstanding leverage effects, it demonstrates that it continues to provide an excellent example of a mature, sound and well-controlled environment.

The Fuel Cells and Hydrogen 2 JU engaged 778 participants (unique beneficiaries) from 43 countries, of which 23 % are small and medium-sized enterprises, showcasing the attractiveness of the programme. This success has been achieved thanks to the hard work and dedication of many people, passionate about tackling climate change by using hydrogen and fuel cell technology, such as colleagues in the European Commission, the Governing Board, the States Representative Group, the Scientific Committee and the many stakeholders who give their valuable inputs on our plans and activities.

Finally, I would like to thank my entire team in the Programme Office, who, every day in these difficult times, give the best of themselves to serve the interests of European citizens.

Enjoy the read!

Bart BIEBUYCK

Clean Hydrogen JU Executive Director

EXECUTIVE SUMMARY

2021 was a year of transition for the Fuel Cells and Hydrogen (FCH) 2 Joint Undertaking (JU) in the context of the adoption by the Council of the EU on 19 November of the regulation establishing the new Clean Hydrogen Joint Undertaking under Horizon Europe. This decision acknowledges the central role played by the FCH 2 JU in the development of hydrogen technologies and mandates its successor to contribute to the objectives set by the European hydrogen strategy published on 8 July 2020 by the European Commission.

This year was marked by intense preparation work and dialogue with all stakeholders to build the new strategic research and innovation agenda (SRIA), which sets the new research and innovation (R&I) priorities for the next decade. The Clean Hydrogen JU SRIA was based on a proposal developed by Hydrogen Europe and Hydrogen Europe Research.

Highlights during the year include the following.

Operational and communication activities

- The JU continued the implementation of its R&I programme, supporting a portfolio of clean and efficient solutions that exploit the properties of hydrogen as an energy carrier and fuel cells as energy converters to the point of market readiness.
- In the transport sector, demonstration of light duty vehicles progressed in 2021, and the number of fuel cell electric vehicles (FCEVs) demonstrated since the beginning of the programme reached 1 064 (a 10 % increase on 2020), with plans to deploy more than 1 200 vehicles in eight countries and 49 hydrogen refuelling stations (HRSs) in five countries. A user survey reported most fleet operators and drivers having positive overall experiences with FCEVs, based on the vehicle performance and refuelling time, which meet their operational needs.
- Fuel cell (FC) bus demonstration activities have grown considerably from earlier projects, reaching 350 FC buses in operation in 2021 [2]. The European flagship projects JIVE and JIVE 2 alone have ordered 274 buses out of the 310 planned, and 80 % were in operation at the end of 2021. The bus prices, hydrogen price and maintenance costs have reached the FCH 2 JU multiannual work programme (MAWP) targets, considering their time horizon of 2023. Fuel cell buses are getting ready for commercialisation. Twelve European bus manufacturers are offering or preparing to offer fuel cell buses for sale or lease [3]. This shows an improvement compared with previous years.
- The geographical coverage of HRSs continues to expand, providing the necessary support to the increasing number of FCEVs being deployed. The total number of HRSs funded had already reached 113 [4] by early 2021. By the end of 2021, the total number of HRSs in Europe monitored by the JU-funded European HRS availability system (https://h2-map.eu) had reached 179 (some of them not funded by the FCH 2 JU).
- In the energy sector, fuel cells have demonstrated great potential to provide combined heat and power (CHP) in buildings with high energy efficiency. As of November 2021, the four European manufacturers involved in the PACE project had already deployed 1 900 FC micro-scale combined heat and power (μ-CHP) units in domestic and small commercial building sectors, with 900 additional units expected to be installed by the end of 2022. The technological development of μ-CHP installations is mature, but scaling-up of production is still needed to bring further cost reduction.
- In the medium-sized installations, the ComSos project aims to validate and demonstrate the advantages of medium-sized solid oxide fuel

[2] Total number of buses included in the projects High V.LO-City, HyTransit, 3EMOTION, JIVE and JIVE 2.
[3] https://assured-project.eu/storage/files/jive-presentation-user-group-11062019-element-energy-jive-assured-ug-meeting.pdf
[4] Including two discontinued stations.

cell (SOFC)-based CHP systems in industrial or utility service environments. Concerning off-grid applications, the projects Remote, RoRePower and Everywh2ere aim to produce results that could be applied in new fields where there is a need for storage of local renewable energy sources, such as grid balancing and the production of hydrogen for mobility.

- Support for electrolysis research and demonstration continued to deliver good results, providing a solid basis for the support of the EU hydrogen strategy and the European hydrogen value chain. The support for game-changing low-temperature electrolysers has significantly improved the techno-economic characteristics of this technology. Moreover, the FCH 2 JU supported three projects on anion exchange membrane electrolysers (AEMELs), a low-technology readiness level (TRL) technology alternative to the two main low-temperature electrolyser technologies (alkaline and proton exchange membrane (PEM)).
- At the same time, high-temperature electrolysis is starting to find its place in the industrial arena, facilitating strategic partnerships. The JU supports both lower-TRL projects, such as SElySOs, SWITCH and GAMER, aiming to improve the performance of these electrolysers, and demonstration projects in industrial environments, such as a steel plant (GrInHy2.0) and a bio-refinery (MultiPLHY).
- In terms of size, demonstration of large electrolysers has reached the multi-MW scale. In the last decade, electrolyser capacity increased 500 times and funding per MW installed reduced by a factor of 100. The large demonstration projects in refineries (Refhyne), the steel industry (H2FUTURE) and the chemical industry (Djewels) have proved electrolysers to be a reliable enabler of sectoral integration and helped bring renewable hydrogen to the centre of EU energy policy.
- The area of hydrogen storage, distribution and purification has been receiving an increasing amount of attention and funding in recent years. The HySTOC project aims to develop and demonstrate a transport and storage system for HRSs using liquid organic hydrogen carriers. The HyCARE project is developing a prototype large-scale hydrogen storage tank based on solid-state storage. The HyGrid project aims to develop, scale up and demonstrate a novel membrane-based hybrid technology for the direct separation of hydrogen from natural gas grids. The MEMPHYS project aimed to develop a low-energy hydrogen purification system.
- All the above areas are also demonstrated together in an integrated system approach through the hydrogen valleys. Currently, the JU supports three hydrogen territories, BIG HIT in the northern Scottish islands of Orkney, HEAVENN in the northern regions of the Netherlands and Green Hysland on the island of Majorca (Spain). Although they vary significantly in size, they all have in common integrating hydrogen production from renewable electricity and the search for various storage and distribution solutions that are specific to each territory, the amount of hydrogen produced, the type of end use and the distance to the end uses.
- The above R&I actions are complemented by a number of cross-cutting activities related to pre-normative research; input into regulations, codes and standards; education and training; and safety aspects. The comprehensive portfolio of FCH 2 JU activities strengthens the whole FCH sector and supports the market uptake of hydrogen technologies.
- Knowledge management activities focused on improving the annual programme review exercise and the quality of information provided through the Fuel Cells and Hydrogen Observatory. The duration of the programme review, covering 85 projects, was reduced by 6 months, permitting the programme review report to be published during the programme review days. In parallel, the FCHO extended its content, publishing more information, including a new module on the levelised cost of hydrogen.
- Dissemination and exploitation of results is an important part of the JU's work. It participates actively in several initiatives: the Horizon Results Platform ([5]), the Innovation Radar ([6]) and the Horizon Results Booster. By the end of 2021, 25 FCH 2 JU project results had been uploaded to the Horizon Results Platform. Moreover, in 2021, 24 participants in five FCH 2 JU projects submitted 10 innovations to the Innovation Radar, which were included in the platform. The European Commission's Horizon Results Booster was launched in 2019; so far eight projects have applied for or already benefited from these services.
- Communication activities focused on two main areas in 2021: promoting the results of the

([5]) https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform
([6]) https://www.innoradar.eu

FCH 2 JU and developing the communications framework of its successor, the Clean Hydrogen JU. This last part included the development of a new brand and visual identity, the new website (www.clean-hydrogen.europa.eu) and a new newsletter. A communication campaign was launched around the new partnership, generating media coverage and awareness among various stakeholders.

- An important element supporting the implementation of the European hydrogen strategy is the reinforcement of synergies among European funding instruments and actions to close the innovation gap in Europe. Synergies are needed to pull together resources, align priorities and ultimately maximise the impact of clean hydrogen R&I investments. In this context, the JU held discussions with relevant parties, including other European partnerships that will use clean hydrogen as an enabler of the decarbonisation of their specific sectors, and even with Member States and regions.
- The second edition of the European Hydrogen Week brought together over 2 000 participants from the public and private sectors across Europe and beyond to review progress and look ahead to new opportunities for the production and use of hydrogen throughout the economy. The event marked the public launch of the Clean Hydrogen Partnership in the presence of the President of the European Commission, Ursula von der Leyen.
- The European Hydrogen Week concluded with the FCH 2 JU programme review days, which presented the progress of projects it supported and technological developments in the transport and energy sectors.

Support activities and internal control environments

- Budget execution further improved to 98.3 % in terms of commitment appropriations, recording the best performance in the JU's history, and reached 88 % in terms of payment appropriations. The administrative budget showed the best rates in JU history at 93 % in terms of commitments and 78 % in terms of payments.
- Time to pay improved for a third consecutive year for operational payments, and for a fifth consecutive year for administrative payments.
- By the end of 2021, the JU had supported 134 projects under the Horizon 2020 programme for a combined public–private investment close to EUR 1.2 billion. Together with its additional activities, the FCH 2 JU managed to achieve a combined amount of private–public investment for the Horizon 2020 programme of over EUR 2.2 billion.
- Because of persistent systemic errors in declared personnel costs, particularly on the part of small and medium-sized enterprises (SMEs) and new beneficiaries (who are more error-prone than other beneficiaries), the JU had already strengthened its internal control to address the increased risk regarding SMEs and new beneficiaries. The results of these measures were evident for the first time in 2021 and contributed to significantly lowering the representative error rate from SMEs and new beneficiaries in the last 2 years.
- The significant preparatory work, in support of the Commission, for the transition to the new programme was successfully concluded with the first meeting of the Governing Board, allowing the JU to continue operating as from 30 November 2021.

1. Implementation of the Annual Work Plan 2021

1.1. Key objectives for 2021 and associated risks

Horizon 2020 programme

The overall objective of the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) was to implement an optimal research and innovation (R&I) programme at EU level to develop a portfolio of clean and efficient solutions that exploit the properties of hydrogen as an energy carrier and fuel cells (FCs) as energy converters to the point of market readiness. This will provide feedback and related support to EU policies on sustainable energy and transport, climate change, the environment and industrial competitiveness, as embodied in the Europe 2020 strategy, and job creation. It will also help to achieve the EU's overarching goal of smart, sustainable and inclusive growth. The overall direction of the programme was guided by the multiannual plans: the multiannual implementation plan for 2008-2014 under the seventh framework programme (FP7), and the multiannual work plan (MAWP) for 2014–2020 under Horizon 2020 (H2020). These plans specify targets for the state of hydrogen technologies in Europe (covering cost, durability and performance) and specific key performance indicators (KPIs). The programme's progress and therefore scientific/technological achievements are always assessed according to the progress towards achieving these targets and KPIs. As the technology has progressed substantially in recent years and new applications have begun to emerge, these KPIs (fixed in 2014) were revised and included in an addendum to the MAWP, endorsed by the Governing Board (GB) on 15 June 2018. The main objectives and achievements are presented in Section 1.2.

Horizon Europe programme

The launch of the new EU Clean Hydrogen Joint Undertaking (JU) [7] was announced during the opening keynote speech by President von der Leyen at the European Hydrogen Week 2021, and officially established in November 2021 with Council Regulation (EU) 2021/2085 [8]. The new JU aims to bring together the European Commission, the hydrogen industry, researchers and innovators as well as policymakers from the Member States, building on the joint efforts of the FCH 2 JU.

The direction of the programme will be guided by a new strategic research and innovation agenda (SRIA), replacing the MAWP, which was adopted by the Clean Hydrogen JU GB on 25 February 2022 [9].

The overall objective of the Clean Hydrogen JU is to support R&I activities in the Union in clean hydrogen solutions and technologies, under EU's new funding programme for research and innovation, Horizon Europe, in synergy with other EU initiatives and programmes. The research and innovation activities of the Clean Hydrogen JU will address areas related primarily to the production of clean hydrogen, as well as the distribution, storage and end use applications of low carbon hydrogen in hard to abate sectors. They will be guided to a large extent by EU's Hydrogen Strategy and the policy developments in this context, contributing to its implementation.

[7] In this report and for clarity purposes, references will be made in general to JU, meaning the activities carried out by FCH JU, FCH 2 JU and its legal successor Clean Hydrogen JU. When there are specific references, they have the purpose to clarify the legal framework to which they refer to.

[8] Council Regulation (EU) 2021/2085 of 19 November 2021 establishing the Joint Undertakings under Horizon Europe and repealing Regulations (EC) No 219/2007, (EU) No 557/2014, (EU) No 558/2014, (EU) No 559/2014, (EU) No 560/2014, (EU) No 561/2014 and (EU) No 642/2014 (OJ L 427, 30 November 2021, p. 17).

[9] https://www.clean-hydrogen.europa.eu/about-us/key-documents/strategic-research-and-innovation-agenda_en

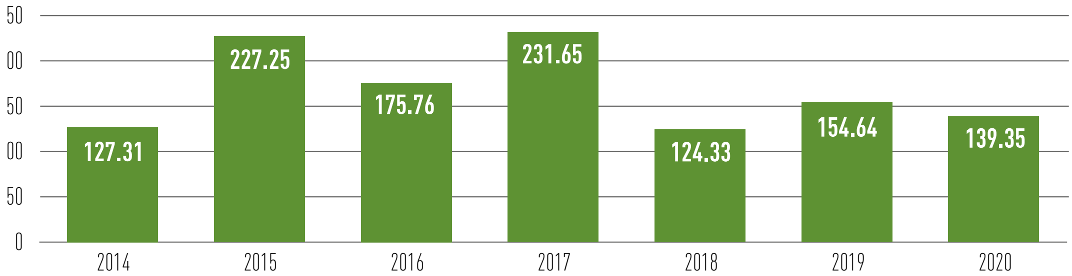
Leverage effect in Horizon 2020 programme

A key objective and measure of the JUs' success is their capacity to leverage private funding.

The Council regulation establishing the FCH 2 JU [10] explicitly mentions the minimum target leverage effect over the whole 2014–2020 period as 0.57 [11].

By the end of 2021, under the H2020 programme, the JU had supported **134 projects** for a combined public–private investment close to **EUR 1.2 billion** (Figure 1.1) [12].

Figure 1.1: Total committed private and public investment of EUR 1.2 billion in JU actions over 2014–2020 (million EUR) – FCH 2 JU grants

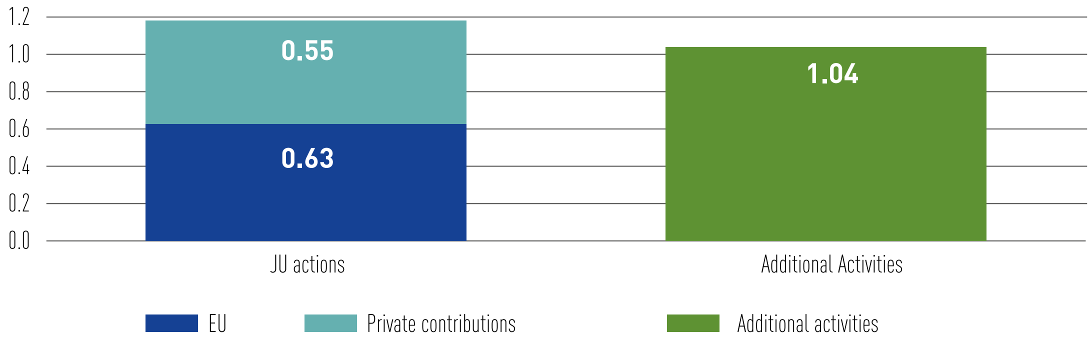


In addition, in 2021, industry and research members made **in-kind contributions in additional activities (IKAA) to the value of EUR 1.04 billion** (covering 2014–2020). Owing to this high amount of certified IKAA, no new IKAA plan was adopted for 2021 under H2020.

This demonstrates the huge success of the H2020 programme in the sector and a continuous willingness to invest and grow.

By combining committed EU and private funds in the JU actions with the amount of the certified additional activities for 2014–2020, at the end of 2021 a total EUR 2.22 billion programme can be observed (Figure 1.2).

Figure 1.2: EU/private investments in JU actions compared with IKAA, 2014–2021 (billion EUR)



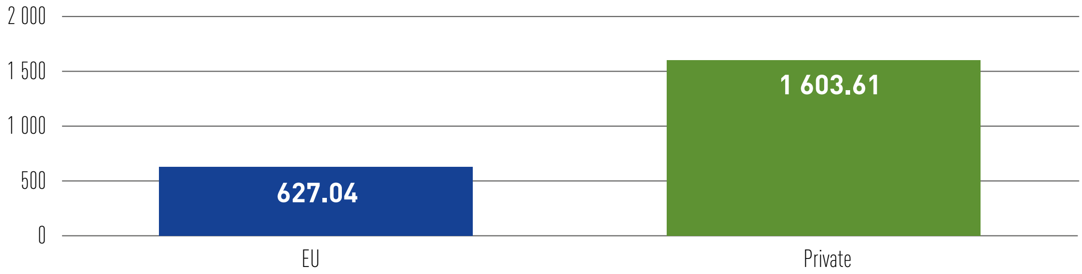
[10] Council Regulation (EU) No 559/2014 of 6 May 2014 establishing the Fuel Cells and Hydrogen 2 Joint Undertaking (OJ L 169, 7 June 2014, p. 108).

[11] Total minimum contribution from members other than the EU (EUR 380 million) divided by the total EU contribution (EUR 665 million).

[12] Committed European Commission contribution together with committed private contributions (members and non-members) in the overall portfolio of 134 signed projects for the H2020 programme in the FCH 2 JU of EUR 1.180 billion.

Values of leverage effect for the calls concluded by December 2021

Figure 1.3: Total committed private and public investment in JU, 2014–2021 (committed private funding in all signed FCH 2 JU actions and certified additional activities; million EUR)



NB: Leverage effect 2.56.

This overall level of the leveraged funding (Figure 1.3) clearly demonstrates a huge commitment on the part of the private sector, significantly **exceeding the targets set in the FCH 2 JU Council regulation.**

Leverage effect in Horizon Europe programme

The new Council regulation ([13]) is based on the principles and criteria set out in the Horizon Europe regulation ([14]), including openness and transparency, a strong leverage effect and long-term commitments by all the parties involved.

According to the new Council regulation (Article 171), the JUs must organise the continuous monitoring and reporting of the management and implementation of their activities and periodic reviews of the outputs, results and impacts of the funded indirect actions implemented in accordance with Article 50 of and Annex III to the Horizon Europe regulation. That monitoring and reporting is to include (among other things) information on quantitative and qualitative leverage effects, including on financial and in-kind contributions committed and actually provided, visibility and positioning in the international context, and the impact of private sector investments on R&I-related risks.

Annex III to the Horizon Europe regulation requires that **the financial or in-kind contributions from members other than the Union should be at least equal to 50 % and may reach up to 75 % of the aggregate JU budgetary commitments.**

The Union should be in a position to reduce its contribution if members other than the Union fail to fulfil their commitments.

For the Clean Hydrogen JU, specific leverage targets have been defined as follows.

- **Union financial contribution (Article 76):** 'The Union financial contribution to the Clean Hydrogen Joint Undertaking, including EEA appropriations, to cover administrative and operational costs shall be up to EUR 1 000 000 000, including up to EUR 30 193 000 for administrative costs.'
- **Contributions from members other than the Union (Article 77):** 'The members of the Clean Hydrogen Joint Undertaking other than the Union shall make or arrange for their constituent or affiliated entities to make a total contribution of at least EUR 1 000 000 000, including up to EUR 30 193 000 for administrative costs, over the period [ending 31 December 2031].

More details on in-kind contributions for additional activities can be found in Section 1.7.

([13]) Council Regulation (EU) 2021/2085.
([14]) Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, and repealing Regulations (EU) No 1290/2013 and (EU) No 1291/2013 (OJ L 170, 12 May 2021).

Risk assessment in 2021

Risk management is a crucial part of the strategic decision-making process. Robust risk management frameworks help to ensure that taxpayers' money is used effectively and efficiently, that potential risks to achieving objectives are identified in a timely fashion and that appropriate mitigating action is taken.

All members of staff, regardless of their level, share responsibility for risk management. The Executive Director is accountable to the GB and is ultimately responsible for the management of the JU's activities and achievement of objectives, and must ensure that the JU's critical risks are known and appropriately managed.

Relationship with the internal control framework

On 16 August 2018, the JU GB adopted a new internal control framework (ICF) stemming from the most up-to-date internationally acknowledged Committee of Sponsoring Organizations of the Treadway Commission model of internal control, in line with the European Commission's ICF.

Risk assessment is one of the five key ICF components and consists of four principles, Nos 6–9 (Table 1.1).

Table 1.1: ICF components and principles – risk assessment

6. The organisation specifies objectives with sufficient clarity to enable the identification and assessment of risks relating to objectives.
7. The organisation identifies risks to the achievement of objectives across the entity and analyses the risks as a basis for determining how the risks should be managed.
8. The organisation considers the potential for fraud in assessing risks to the achievement of objectives.
9. The organisation identifies and assesses changes that could significantly impact the system of internal control.

Risk identification and assessment

In November 2021 an annual risk assessment exercise was conducted for the purpose of identifying, analysing and responding to key risks (including fraud risks) across all of the areas of responsibility of the JU programme offices (POs), for the purposes of establishing the first version of the 2022 annual work programme, related to continuation of the JU activities under the new Clean Hydrogen partnership.

The risk identification started with the assessment of the relevance of the risks identified in the previous risk-assessment exercises and continued with the identification of any new relevant risks (related to continuation of the JU operations under the Horizon Europe programme, including transitional risks).

The aim of this annual exercise was **to identify risks that could hinder achieving the H2020 objectives**, including (among others) operational, financial and compliance risks.

Owing to the continuation of COVID-19-related circumstances, the risk assessment exercise in November 2021 also evaluated existing risks and action plans related to COVID-19.

During the exercise, the following aspects of all the risks presented in AWP 2021 were assessed (in view of COVID-19):

- **Relevance of the risk:** Is the risk still present? Has it materialised?
- **Rating the risk:** Did the rating (in terms of impact/likelihood) increase or decrease?
- **Relevance and fulfilment of the action plan:** Should we continue/expand/reduce action plans?

In addition to the regular risk assessment exercise, **a special brainstorming session**, taking into account input from all members of staff, chaired by the Executive Director, was conducted **to identify any new emerging risks related to transition to the new partnership.**

Based on the discussions, the risks were either removed (when considered no longer relevant) or modified, while the action plans were reviewed for adequacy and completeness.

Table 1.2 provides a summary of the outcome of the exercise on risks and fulfilment of the action plans, as at 31 December 2021.

Table 1.2: Fulfilment of the action plans

RISK LEVEL	RISK IDENTIFIED (AWP 2021)	ACTION PLAN (AWP 2021)	ACTION PLAN – STATUS AS AT 31 DECEMBER 2021
MEDIUM	Owing to limitation of H2020 *ex ante* controls (trust-based approach with minimum amount of default checks), representative error rate for FCH 2 JU may increase. Consequently, there is a risk of obtaining a qualified opinion and of not getting the discharge from the European Parliament because the Court of Auditors' threshold for a residual representative error rate stays at the level of 2 %. (NB: H2020 *ex ante* control strategy envisaged level of the residual error rate in the range between 2 % and 5 %.)	Annual analytical risk – assessment at beneficiary level and subsequent introduction of the targeted *ex ante* controls for the projects/ beneficiaries with higher identified inherent risk. Application of the feedback from *ex post* audits and lessons learned on *ex ante* controls, for instance from accompanying auditors on missions for FCH audits. Continuation of interactive financial webinars for complex projects or where there are numerous newcomers in the consortia in the first 12 months of the project duration. Additional review of potential financial risks within FCH 2 JU top beneficiaries, followed up by bilateral teleconferences.	In 2021, we executed the action plan accordingly and results were positive. High risk beneficiaries were identified based on the lessons learned. Individual bilateral financial webinars were set up to prevent and detect early any potential financial errors. Impact analysis showed that several possible misstatements were corrected *ex ante* and that the error rate, especially in the riskiest categories of the beneficiaries (small and medium-sized enterprises, and newcomers) has progressively decreased. *Ex ante* control strategy for Horizon Europe further supports a risk-based oriented *ex ante* approach. Many newcomers and new beneficiaries are entering our programme. For H2020, the screening will focus on the projects from call 2020, which will report their costs for the first time in 2022.
MEDIUM	Owing to COVID-19, the FCH 2 JU is highly dependent on safe and proper functioning of the IT tools and network connection to ensure business continuity. These are becoming increasingly vulnerable to potential cyberattacks, performance inefficiencies and connection failures due to increased traffic, different levels of security connection and increased levels of pirate attacks and phishing. Unknown weaknesses in the systems may pose higher risks of failures of the operations, and they may also create opportunities for fraudulent behaviour.	Mitigating actions include raising staff awareness and mechanisms to prevent attacks, including: • improved *ex ante* and *ex post* security systems controls against automated attacks; • increased level of controls, implemented with the Computer Emergency Response Team for the EU Institutions, bodies and agencies; • increased level of security and advanced protection adopted. Further training and awareness sessions for increased security measures should be put in place.	In 2021, we continued training and awareness sessions on cybersecurity, phishing, etc. The IT systems have been continuously updated. Thanks to numerous actions adopted in 2021, we are in a position to reduce impact and likelihood, therefore reducing the residual level of the risk from medium to low.

RISK LEVEL	RISK IDENTIFIED (AWP 2021)	ACTION PLAN (AWP 2021)	ACTION PLAN – STATUS AS AT 31 DECEMBER 2021
MEDIUM	Risk that programme objectives will not be achieved fully and on time due to delays in project execution attributed to COVID-19.	Mitigating actions are in place for monitoring of any delays in the project, restructuring of the projects, if necessary, granting project extension in average of 6 months due to COVID19 via amendment process.	In 2021 we had concrete examples of these issues in our projects – mainly demonstration projects (e.g. delays in component supplies, change of investment strategies, lack of skilled people, and turnover and mobility of talent). Because of the increased amount of activities in the sector, there is higher demand on experts and we may suffer from lack of their availability. Rating of the risk: we will keep this risk at medium for at least 1 more year, and re-evaluate it next year.
MEDIUM	Risk of disruption of the operations if a substantial number of people are infected with COVID-19, combined with a risk of staff disengaging from the culture of the organisation.	Adequate backup systems, coaching sessions and regular virtual team meetings are in place.	In 2021, mitigating measures were implemented, including vaccinations, limits on the number of people physically in the office, increased use of teleworking, adopting new ways of hybrid working, etc. No distortions of the operations were observed, partly thanks to the virus becoming less strong. Therefore, we are reducing the impact and likelihood of the risk, moving the residual level of the risk to low.

The outcomes of the 2021 risk assessment workshop on new or continuing risks for 2022 are included in the 2022 AWP.

1.2. Research and innovation activities

1.2.1. Scientific and technological achievements

The overall objective of the FCH 2 JU is to implement an optimal R&I programme at EU level to develop a portfolio of clean and efficient solutions exploiting the properties of hydrogen as an energy carrier and FCs as energy converters to the point of market readiness. Thanks to the partnership between leading research organisations and industrial companies, the activities of the JU cover all stages of product development from low-TRL research up to large demonstration projects.

Section 1.2.1. Scientific and technological achievements presents the main achievements for all activities, as identified by the PO with support from the Joint Research Centre (JRC) of the European Commission during the 2021 annual review [15] of the programme [16], with some additional recent data from 2021 – when available – that were presented in the 2021 programme review days [17]. For easier reading, these are split into the main pillars of transport and stationary applications, hydrogen production, hydrogen storage, distribution and purification, and cross-cutting activities.

[15] https://www.clean-hydrogen.europa.eu/media/publications/programme-review-report-2020-2021_en
[16] The 2020–2021 programme review report covers 2019–2020.
[17] https://www.clean-hydrogen.europa.eu/knowledge-management/programme-review-days/prd-2021_en

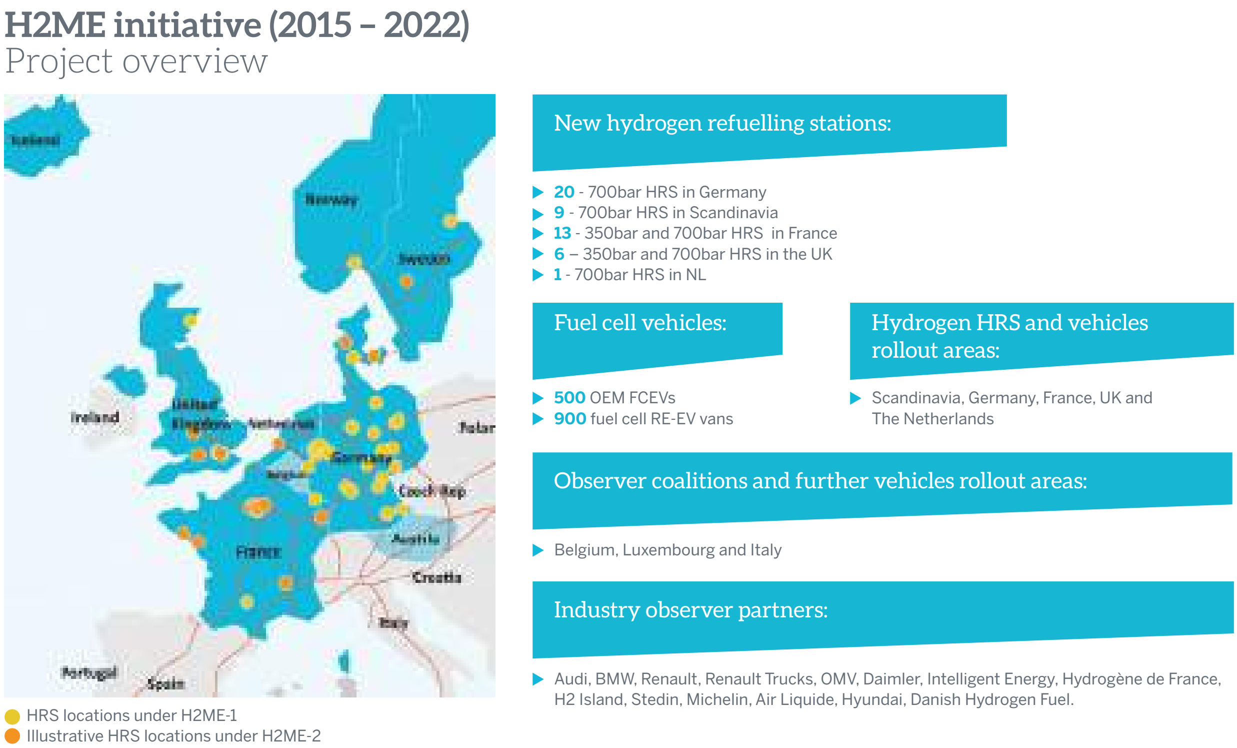
1.2.1.1. Transport applications

The actions in this field aim to prove the technology's readiness, reliability, robustness, fuel efficiency and sustainability. Historically, demonstration activities have focused on road transport, based on cars and buses, but are now shifting towards heavy-duty road, rail and maritime transport.

Light-duty vehicles

The projects dedicated to demonstrating FC cars are H2ME, H2ME2, SWARM and ZEFER. H2ME and H2ME2 are the largest European deployment initiatives to date for hydrogen mobility, with plans to deploy more than 1 200 vehicles in eight countries and 49 HRSs in five countries (Figure 1.4). The number of fuel cell electric vehicles (FCEVs) demonstrated since the beginning of the programme has reached 1 064, a 10 % increase on 2020. A users' survey reported most fleet operators and drivers having positive overall experiences with FCEVs, based on the vehicle performance and refuelling time, which meet their operational needs.

Figure 1.4: Overview of H2ME initiative, January 2021



Source: https://h2me.eu

H2ME finished in 2020 and H2ME2 will go on until 2022, both having already deployed 687 vehicles and 38 HRSs in total by the end of 2020. Project H2ME deployed 311 vehicles and 29 new HRSs in Germany, Scandinavia, France and the United Kingdom. H2ME2 has already deployed 376 FC electric vehicles from five original equipment manufacturers, and nine HRSs.

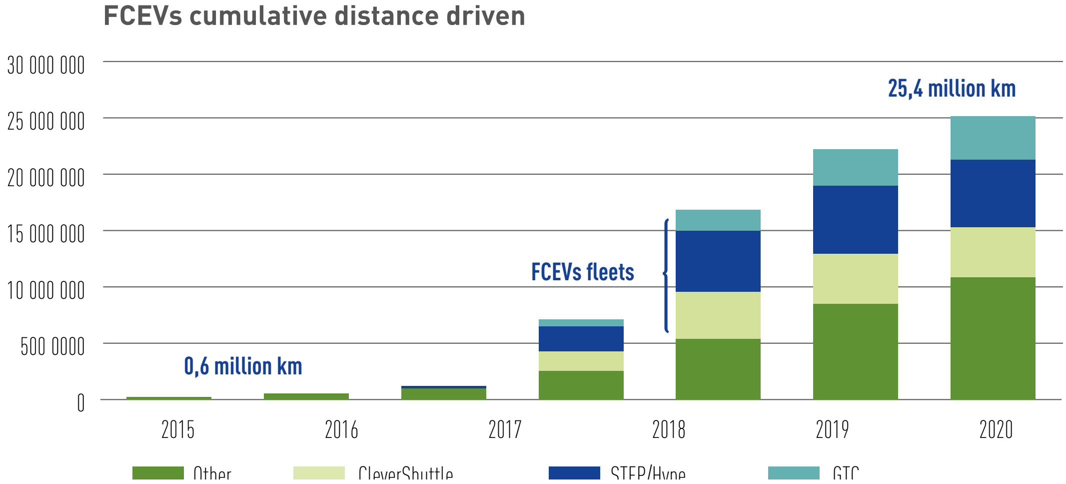
ZEFER started in 2017 with the aim of demonstrating viable business cases for captive fleets of FCEVs (taxi, private hire and police services) and will continue until 2022. Of the 180 FCEVs planned, 117 are already in operation (57 in Paris and 60 in London).

In 2020, a total of 607 cars were reported in Technology Reporting Using Structured Templates (TRUST) [18], close to the 597 cars reported in 2019. In 2020, they drove slightly more than 4.9 million km and consumed 52.7 tonnes of hydrogen, which are around half of the amounts reported in 2019, when 8.9 million km were driven and 91.5 tonnes of hydrogen consumed. These differences can be explained partly by the COVID-19 pandemic, which

[18] The TRUST data collection platform is used for the purposes of monitoring technology progress against the state of the art, but also to identify how each of the projects contributes to the Clean Hydrogen JU targets, objectives and indicators described in the SRIA. For more information see its web page (https://www.clean-hydrogen.europa.eu/knowledge-management/technology-monitoring-trust_en).

had a direct impact on the operation of taxi fleets (in practice, operating only from January to March 2020), which is responsible for half the difference above (taxis drove 0.7 million km in 2020 instead of 2.8 million in 2019). The other half is mainly due to structural changes in the fleets, whereby a number of cars that had driven significant distances in 2019 (2.5 million km) were sold in the first half of 2020 and thus did not report in TRUST. The cumulative distance driven is shown in Figure 1.5.

Figure 1.5: Distribution of FCEVs deployed by FCH 2 JU demonstration projects

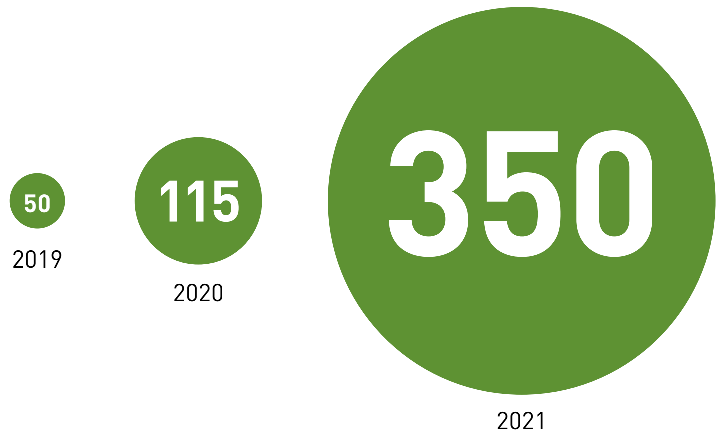


Note: The 2021 figure is an estimate.

Fuel cell bus demonstration projects

European demonstration activities have grown considerably from earlier projects to the most recent, as shown in Figure 1.6. In 2019 and 2020, JU fuel cell bus (FCB) demonstration activities concerned the projects High V.LO-City, HyTransit, 3EMOTION, JIVE and JIVE 2.

Figure 1.6: Trend in FCBs in operation in the EU



Note: The 2021 figure is an estimate.

Bus demonstrations supported by JU grants involve 350 vehicles in 11 countries. 3EMOTION, JIVE and JIVE 2 are ongoing and progressing. The European flagship projects JIVE and JIVE 2 alone have ordered 274 buses out of the 310 planned for 22 cities across Europe (Figure 1.7), with 80 % in operation at the end of 2021. The local fleets range from 5 to 50 FCBs, typically 10 to 20.

Figure 1.7: FCB demonstrations in Europe

Note: Including national initiatives and Interreg-funded demonstrations.

Source: https://www.fuelcellbuses.eu/

In 2019–2020, 119 buses were in operation in seven cities. From the bus demonstration projects that were reporting in TRUST between 2016 and 2020, a total distance of over 8.9 million km was accumulated, with almost 1 million km accumulated in 2020 alone. Over the last 5 years (2016-2020), over 602 tonnes of hydrogen were consumed. In 2020, the average fuel consumption was 10.42 kg H_2 / 100 km, while the minimum reported was 8 kg H_2 / 100 km, meeting the 2020 MAWP target (8–10.2 kg H_2 / 100 km). The 2020 MAWP targets for FC system cost and vehicle cost, which had already been achieved in 2018, were also met in 2020.

In 2020, the average FCB availability was 82 %, with a number of buses greatly exceeding this percentage (the maximum availability reported was 96.1 %). The low average availability value is explained by the longer period observed for receiving replacement parts for the gradually ageing FCB fleets from international suppliers due to the pandemic. In addition, a teething period of a few months is usually observed at the start of FCB operation on sites previously unfamiliar with FCBs, which adversely affects their availability.

Truck demonstration projects

JU demonstration activities on heavy-duty trucks started in 2018 with the REVIVE project, which aims to demonstrate 15 heavy-duty refuse trucks in eight sites across Europe. It was enlarged in 2019 with the addition of the H2Haul project. REVIVE will set the basis and state-of-the-art (SoA) reference for future heavy-duty refuse truck demonstration projects. Its activities include the life cycle analysis of the project performance in terms of CO_2 emissions, air pollution and noise reduction.

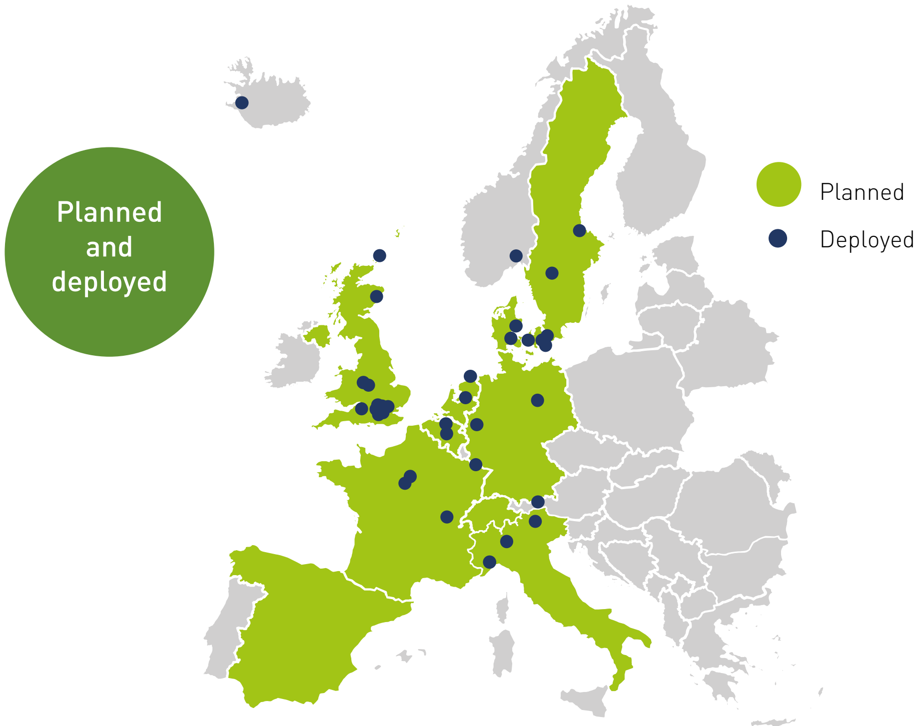
H2Haul will lead to the demonstration of 16 trucks, in four European countries. In addition, three new HRSs for truck refuelling will be deployed in Belgium, France and Switzerland. The project is currently in the planning and pre-deployment phase. The design of three new types of FC trucks (including rigid and articulated vehicles up to 44 tonnes) is ongoing, and specifications are being prepared as per specific customer requirements and mission profiles. These two projects will establish policy recommendations to foster the deployment of FCH trucks. The HRSs that will support the truck fleet are also being demonstrated or upgraded.

Hydrogen refuelling infrastructure for cars and buses

The geographical coverage of hydrogen refuelling infrastructure continues to expand, supporting the increasing number of FCEVs being demonstrated (see Figure 1.8). The total number of HRSs funded under the transport pillar is 113 ([19]), of which 64 (53 for cars and 11 for buses) have already been deployed, dispensing hydrogen at a pressure of 700 bar, and have been integrated into petrol forecourts; 13 also have 350-bar dispensers. The European HRS availability system (https://h2-map.eu), an initiative funded by the JU, provides a portal giving live information on the availability of each HRS in Europe, and available on any mobile application or tool for the convenience of FCEV users. Currently, 179 fuelling stations (some not funded by the JU) are both connecting and sending live data.

([19]) Including two discontinued stations.

Figure 1.8: Distribution of HRSs co-funded by the JU



To date, the JU-funded HRS network for cars covers ten countries. In 2020, it delivered 58.8 tonnes of hydrogen in 25 060 refuelling operations. This amount represents 40 % of the total amount of hydrogen used for refuelling since 2016. The average HRS availability for cars in 2020 was 90 %. The major causes of station downtime are compressor failures and scheduled maintenance/upgrades, which highlights the need for research and development (R & D) in this area, such as the projects COSMHYC and COSMHYC XL (described in the next section). H2ME reported that with, the increasing number of HRSs, chiller cooling hydrogen to the level required by the protocol SAE J2601 is also becoming a reason for downtime.

Car demonstration projects have reported that 66 % of dispensed hydrogen was certified as low carbon from guarantee of origin (GO) schemes for green and low-carbon hydrogen, such as CertifHy (see Section 1.2.6). Of this, renewable hydrogen accounted for 57 %. The average reported cost of renewable hydrogen was EUR 11.31/kg H_2, which means the related 2020 MAWP target of EUR 11/kg H_2 was almost achieved. More research is needed through the coming years into reducing the average capital expenditure (CAPEX) for hydrogen stations, which is still more than 50 % higher than the expected 2020 MAWP targets.

The JU has also funded the installation of 23 refuelling stations for buses in 10 European cities, 16 of which have been demonstrated. The amount of hydrogen dispensed between 2016 and 2020 was almost 529.8 tonnes, 16 % of which was consumed in 2020 in 5 917 refuelling operations. Of this dispensed amount, 63 % is certified as renewable hydrogen.

Demonstration projects are still suffering from a lack of experience among local authorities and the absence of standardised processes for reviewing and approving HRS permit authorisation. However, with the help of such projects (and related awareness), difficulties encountered when requesting permits for HRSs are declining, with the lead time for commissioning an HRS in Germany falling from 24 to 12 months.

New developments in compression for hydrogen refuelling stations

COSMHYC and COSMHYC XL are developing a hybrid compression solution (1–1 000 bar) by combining a metal hydride compressor and a mechanical diaphragm compressor. This new design allows a reduction in CAPEX and operational expenditure (OPEX), less noise, greater availability and therefore better hydrogen delivery efficiency in HRSs (COSMHYC) and extra-large HRSs able to serve heavy-duty vehicles (COSMHYC XL). H2REF developed and tested a novel hydraulic-based compression and buffering system, using bladder accumulator technology. Both have high potential for improving techno-economic parameters for hydrogen compression at refuelling stations.

Hydrogen storage/tanks – innovative technologies for on-board storage

The objective of this topic is to improve the gravimetric and volumetric capacity of hydrogen storage tanks on board vehicles by using new materials and innovative manufacturing techniques. The projects TAHYA and THOR are addressing these goals, they are in the early development phase, with a TRL range of 4 to 6.

TAHYA aims to develop a complete, competitive and innovative European hydrogen storage system. The tank is developed and is undergoing design qualification tests. Fire tests need completion, as do the integration of structural health monitoring and the optimisation of the filling nozzle.

THOR develops high-pressure thermoplastic composite hydrogen tanks (moving from TRL 4 to TRL 6) based on thermo-plastic resins. The tank, based on a new design, requires prototype testing. The final tank has the potential to be a breakthrough technology for hydrogen storage, with reduced material use and costs.

Waterborne applications

Hydrogen in the maritime sector is nowadays a topic of great interest because of the expected changes in emissions regulations in the near term. Fuel cells and hydrogen have been demonstrated in e.g. submarines, small inland and coastal vessels and auxiliary power for supply vessels, proving the viability of the technology at small scale. Demonstration projects are underway to highlight the viability of hydrogen to power ships using FCs and modified combustion engines (see Figure 1.9).

Figure 1.9: Maritime projects, evolution of technologies and main challenges

CESNI, Committee for drawing up standards in the field of inland navigation; HT, high-temperature; IMO, International Maritime Organization; LH_2, liquid hydrogen; SOFC, solid oxide fuel cell.

Three projects demonstrating zero-emission FC ships and hydrogen in maritime ports started in 2019–2020, all having common issues in hydrogen safety, issuing permits for ships and infrastructure, and standards.

FLAGSHIPS will demonstrate two FCH vessels in commercial operation: one fluvial cargo vessel in France and one fluvial cargo vessel in the Netherlands. In addition, FLAGSHIPS will perform a techno-economic analysis of European marine FC power systems.

The ShipFC project is developing a 2-MW ammonia-powered FC and will operate a retrofitted offshore vessel. ShipFC aims to prove that long-range zero-emission voyages with high power are possible on large ships. In addition, the project is providing input into alternative shipping fuel life cycle assessments (LCAs) and is studying how to set up a certification scheme for green ammonia.

H2Ports will demonstrate hydrogen as an alternative fuel in maritime ports. It will carry out pilot tests in the Port of Valencia, under real operation conditions, for a hydrogen-powered reach stacker in a port container terminal, a fuel cell yard tractor for container transport and ro-ro loading/unloading operations, and a mobile hydrogen supply station.

Hydrogen-powered aviation

FLHYSAFE [20] seeks to demonstrate a cost-efficient modular FC system for replacing most critical safety systems and for an emergency power unit to be used on board a commercial aeroplane. The final technological demonstration aims to demonstrate enhanced safety functionalities and the ability to integrate it into current aircraft designs respecting both installation volumes and maintenance constraints. So far the project has completed the design for FC integration into airborne applications, as well as the emergency power system architecture and a virtual reality tool allowing design optimisation and maintenance instructions. FC short stack testing (using oxygen instead of air) and start/stop cycle stack degradation analysis are in progress.

HEAVEN [21] focuses on demonstrating the airworthiness and economic viability of an FC / liquid hydrogen (LH_2)-powered four-passenger aircraft and gathers reliability data for future certification. It produced the conceptual design of the overall powertrain by adapting two 45-kW PEM FC systems. It also intends to integrate them with optimised balance of plant components using cryogenic hydrogen storage technology and without using a battery. Meeting the main aircraft requirements is particularly difficult, as no aviation regulation yet exists for LH_2. Failure hazard assessment, including the identification of hazardous and catastrophic events, was also performed.

1.2.1.2. Research-oriented activities for transport applications

Fuel cell components

Research activities focus on the development of novel materials, processes, architectures and optimised interfaces. In particular, projects are exploring the development of non-platinum group metals (PGMs) or low-cost catalysts (PEGASUS [22], CRESCENDO [23]).

PEGASUS is working on a promising route towards the removal of platinum and other critical raw materials from PEM FCs. Their replacement with non-critical elements and structures should still provide stable electro-catalysis conditions, and the development of appropriate uses of platinum-alternative and competitive cathode catalysts.

CRESCENDO is developing diagnostic methods for determining active site density and turnover frequency, and is realising successful approaches to the stabilisation of non-PGM cathode catalysts during operation, as well as advancing research on non-PGM and ultra-low-PGM hydrogen oxidation catalysts.

APU, auxiliary power unit.

Figure 1.10: Hydrogen potential for use in aviation, taking the steps to zero emission aviation

[20] https://www.fch.europa.eu/page/transport#FLHYSAFE
[21] https://www.fch.europa.eu/page/transport#HEAVEN
[22] https://www.fch.europa.eu/page/transport#PEGASUS
[23] https://www.fch.europa.eu/page/transport#CRESCENDO

Vehicle stacks

The project GAIA is developing components (electrocatalysts, membranes, gas diffusion layer and microporous layer) and is aiming to improve their interfaces to minimise polarisation resistance in next-generation membrane electrode assembly (MEA). This will lead to reduced costs, increased power density and greater durability, while accommodating higher operating temperatures. It has delivered a beginning-of-life power density of 1.8 W/cm^2 at 0.6 V, thereby achieving its performance target.

CAMELOT is investigating the performance of ultra-thin and ultra-low-loading layers required by future MEAs by combining numerical modelling with innovative *in situ* characterisation, and is developing a scientific understanding of the limitations of advanced MEAs, achieving an open-source model accessible to the global FC community.

DOLPHIN is exploring an unconventional, highly innovative route towards a newly designed cell architecture featuring a dual-core single repeat unit delivering a lightweight and compact FC stack architecture. By using mechanically strong and corrosion-resistant structures redesigned for more coherent cell-internal interfaces to delay ageing and increase system reliability compatible with automotive durability targets, it is aiming for stack production costs of less than EUR 20/kW.

FURTHER-FC builds upon the PEMICAN[24] project. It is aiming to improve gas and proton transfer near catalytic structures, and to investigate and validate performance limitations resulting from the coupling of electrochemical and transport issues in the cathode catalyst layer. It has progressed with the characterisation of reference catalyst layers and direct numerical simulations.

Manufacturing

Five projects are related to manufacturing processes, with the following goals:

- to advance the critical steps of the PEM FC assembly processes and associated in-line quality control and end-of-line test (DIGIMAN);
- to industrialise stack production, delivering affordable FC systems in large quantities that are able to meet the demands of the emerging market, and building new manufacturing machines allowing for serial stack production (Fit-4-AMandA);
- to develop and integrate the most advanced critical PEM FC stack components into an automotive stack showing a beginning-of-life performance of 1.5 W/cm^2 at 0.6 V, less than 10 % power degradation after 6 000 hours, and costing less than EUR 50/kW at an annual production scale of 50 000 units (INSPIRE);
- to scale up PEM manufacturing and reduce the cost (INLINE and INN-BALANCE).

DIGIMAN's main outputs are a proof of process and a blueprint design for beyond-current-state European manufacturing of automotive PEM FCs. The demonstrator equipment for the uplifted cell assembly automation process has been manufactured and validated.

Fit-4-AMandA completed the assembly and validated the machine for serially producing PEM FC stacks using automatic assembly methods. For a 90 % automated production process, it demonstrated stack production in less than 30 minutes' throughput time for one stack on a small scale.

INSPIRE designed and tested three generations of stack prototypes. The project met its performance and durability targets, and the estimated stack costs are within 10 % of its target.

INLINE and INN-BALANCE started in 2017. Their goals include the scale-up of PEM manufacturing, balance of plant definition (identifying and developing efficient and reliable components to reduce overall system costs), and the development of quality control practices for manufacturing and assembly procedures. At the same time, they should reduce the life cycle environmental impacts of stacks and components.

INLINE aimed to reduce the cycle time for production of an entire FC system from 15 hours to under 2.5 hours, thanks to continuous improvements in the production process. INN-BALANCE will develop highly efficient and reliable FC balance of plant components and therefore reduce the cost of current market products using FCs.

1.2.1.3. Trials and deployment of fuel cell applications for energy

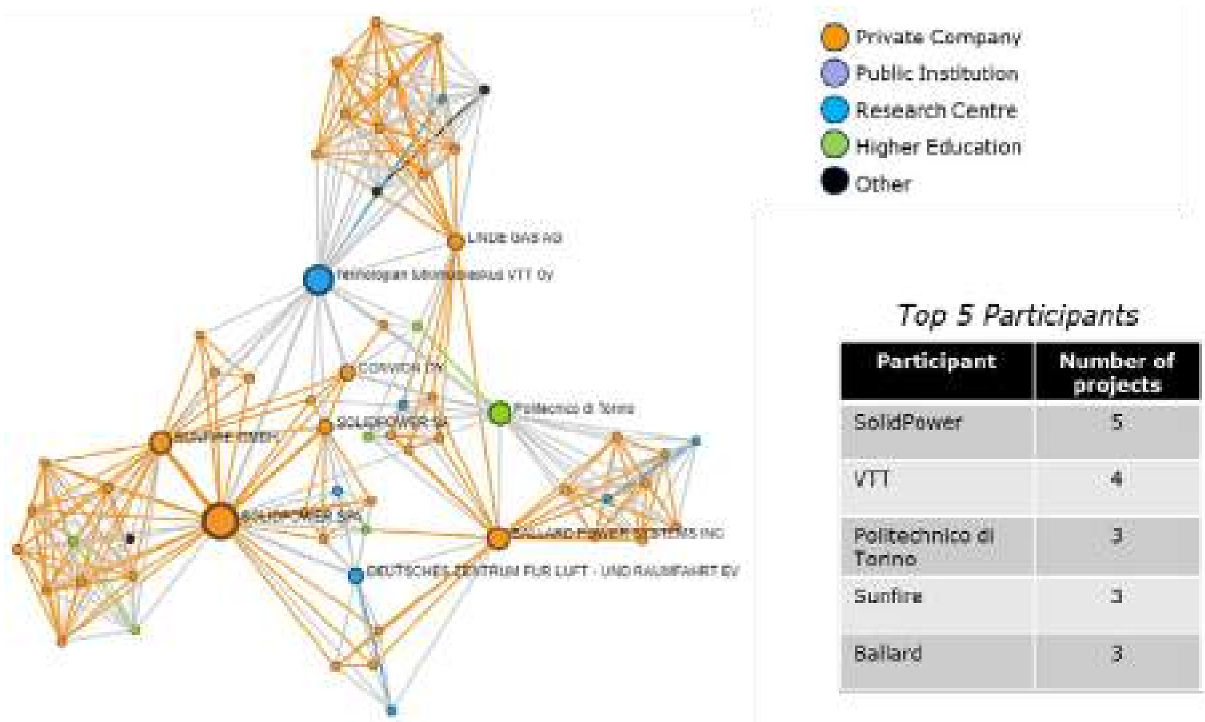
The JU supported projects for all ranges of stationary power applications, from residential micro-scale combined heat and power (μ-CHP) for domestic and small commercial buildings (0.3–5 kW), through medium-sized installations for commercial and larger buildings (5–400 kW), to large-scale FC installation demonstrations (0.4–30 MW). FCs are showing great potential for the provision of heat and power in domestic and small

[24] https://cordis.europa.eu/project/id/256798/es

commercial buildings. They have the advantages of high electrical and total efficiencies, and they are able to run on conventional heating fuels.

Figure 1.11 shows the connections between partners present in the demonstration projects using the program Tools for Innovation Monitoring (TIM). For clarity, only the partners involved in the largest numbers of projects are named. TIM software indicates clusters of partners by colour using its own algorithm. As shown in the figure, the key partners present in multiple projects are the FC stacks/system providers (SOLIDpower, Sunfire, Ballard), the Politecnico di Torino and the research institute VTT. These projects are higher-TRL demonstration projects and private companies are predominant among the participants.

Figure 1.11: TIM plot showing the participants in the 10 projects on FC application for energy



Combined heat and power for residential applications, micro-scale combined heat and power (< 5 kWe)

The PACE [25] project plans to move the market towards mass commercialisation with up to 2 800 FC μ-CHP units expected to be installed and demonstrated by the end of the project. As of November 2021, the four European manufacturers involved in the project had already deployed 1 900 FC μ-CHP units in domestic and small commercial building sectors, making PACE Europe's largest μ-CHP project to date, with the remaining units expected to be installed by the end of 2022.

The project also aims to reduce the average unit costs to below EUR 10 000 per small FC system (< 1 kWe) and to EUR 10 000/kWe or below for systems above 1 kWe, through more automated production and introduction of next-generation systems. The technological development of μ-CHP installations is mature, but scaling-up of production is still needed to bring further cost reduction. Figure 1.12 shows the deployment of μ-CHP units in Europe by March 2021, resulting from JU funding and support from the German national programmes.

[25] http://www.pace-energy.eu

Figure 1.12: Deployed and planned FC μ-CHP Installations across the EU

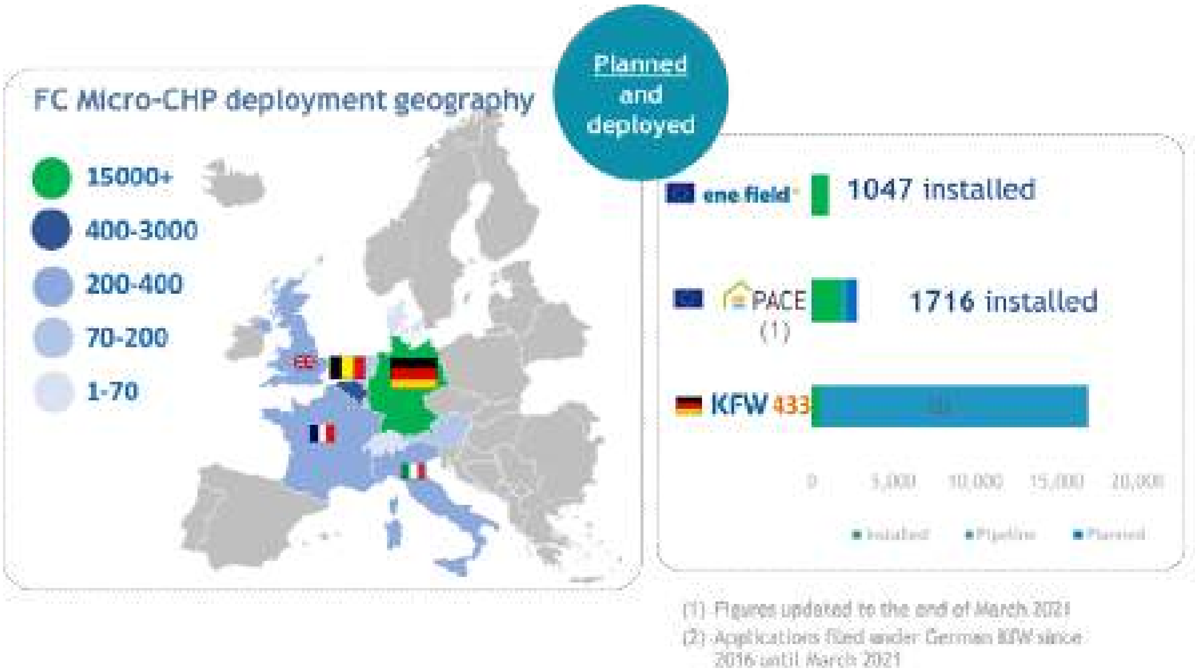
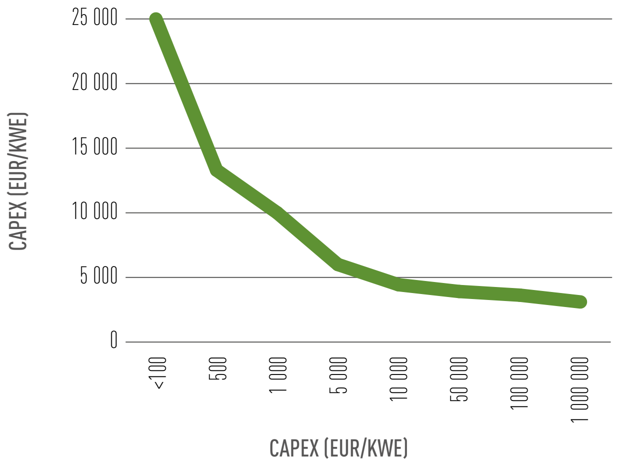


Figure 1.13 shows how the cost reduction curve can be expected to progress with increasing manufacturing volumes.

Figure 1.13: Cost reduction with market scale-up in the focus area μ-CHP demo (< 5 kWe)



Combined heat and power for medium-sized applications (5–400 kWe)

In the mid-size installations focus area, the DEMOSOFC project, completed in October 2020, aimed to demonstrate the technical and economic feasibility of installing a 174-kWe solid oxide fuel cell (SOFC) system at a wastewater treatment plant in the Turin area (Italy). This would have supplied ~ 30 % of the site's electricity needs and almost 100 % of its thermal energy consumption. Ultimately, the project was only able to install two SOFC modules (one 58 kWe and one 44 kWe) as a result of delays to the final module. Despite this reduction in size, the overall goal of demonstrating an industrial-size biogas-fed SOFC plant has been achieved. The lessons learned have informed the design of the next generation of units developed under the R&I project INNOSOFC. These next-generation units are expected to be demonstrated in real-world installations in the ComSos project. Further reductions in CAPEX and OPEX have been identified as essential for market uptake.

The main objective of the ComSos project is to validate and demonstrate the advantages of medium-sized SOFC-based CHP systems in industrial or utility service environments. Three different sizes of mini and commercial-size FC-CHP are being demonstrated in the power ranges of 10–12 kW, 20–25 kW and 50–60 kW. The consortium plans to install 23 demo systems.

Combined heat and power for large-scale applications (> 400 kWe)

The ClearGenDemo [26] project aimed to demonstrate a 1-MWe PEM FC system utilising refinery by-product hydrogen and using the FC to produce electricity for the Martinique public electricity grid (French overseas territory). Installation of the FC system and component was completed, along with integration in the refinery systems. Owing to the

[26] https://www.cleargen.eu/

COVID-19 travel ban, it was not possible to complete commissioning within the project's lifetime (which ended in September 2020). The system achieved 50 % electrical efficiency in the factory acceptance test, which exceeded its target (48 %). The lessons learned from ClearGenDemo will be taken up by a power-to-power project in French Guiana, which is being developed by one of the partners, Hydrogène de France. ClearGenDemo intends to report on system performance once it has been commissioned, even if the project has ended.

Demonstrations – off-grid, backup and generator set

This area gathers together three demo projects – Remote, RoRePower and Everywh2ere – focused on off-grid applications, both in remote places and in temporarily powered event areas.

The Remote project is demonstrating the technical and economic feasibility of FC technologies combined with renewable energy sources and hydrogen storage solutions on island grids or in remote areas. In 2020, two demonstrations were installed in Norway and Greece and are now operational. The third new demonstration site will be in the Canary Islands (Spain). Detailed engineering and the permit-issuing procedures are currently being developed.

A number of MAWP targets have been successfully achieved: rated PEM electrolyser efficiency of 50.5 kWh/kg, rated alkaline electrolyser efficiency of 50.6 kWh/kg, rated PEM FC efficiency of 45 % lower heating value, 15 years lifetime for the FC and 20 years lifetime for the balance of plant equipment. Remote was awarded the title of best renewable energy project in the European Sustainable Energy Week 2020 Awards in the Innovation section.

In general, project results could be applied in new fields where there is a need for storage of local renewable energy sources, not only for power production but also for hydrogen use in different sectors. Grid balancing and the production of hydrogen for mobility could be potential fields of application.

The aim of the RoRePower project is to further develop and demonstrate SOFC systems for off-grid power generation in markets, such as gas and oil infrastructure, in remote regions with harsh climate conditions (from – 40 °C to + 50 °C), and the power supply for telecommunication towers, especially in emerging countries. Twelve RoRePower units have been installed at customer sites. The Sunfire-remote 400 and 900 units have passed design freeze and have been introduced on to the market. The first RoRePower unit has been installed for a telecom application in Alaska, with the aim of gathering reliable field data and demonstrating the technology.

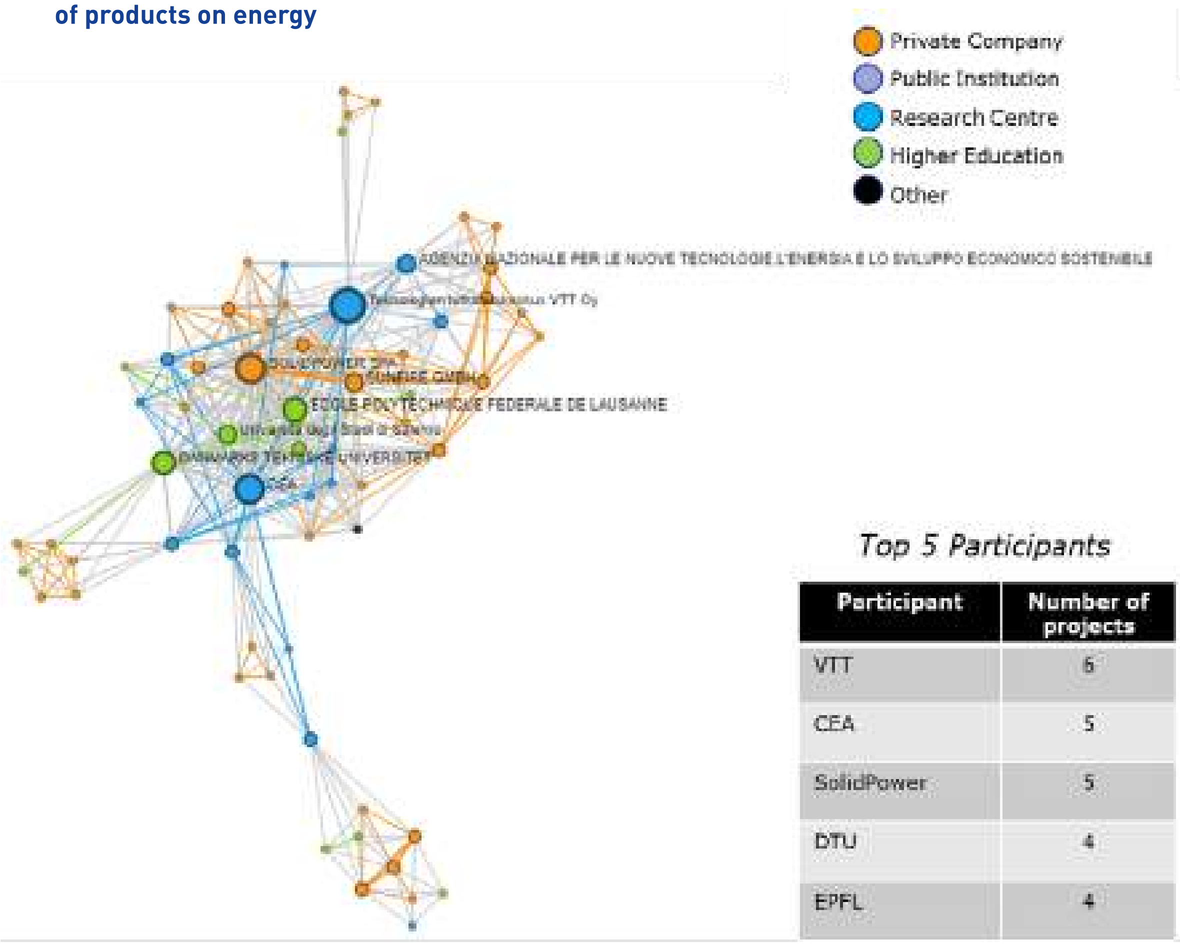
The Everywh2ere project aims to demonstrate FC generator sets at TRL 8 to replace diesel-fuelled generators for temporary power at construction sites, music festivals, exhibition centres, etc. Two prototypes (one 25 kW and one 100 kW), together with their hydrogen storage bundles, have currently been commissioned and started demonstration in June 2021.

1.2.1.4. Next generation of products – energy

Following the calls between 2008 and 2020, the JU supported 54 projects with a total JU contribution of about EUR 124.9 million plus a contribution from partners of EUR 76.7 million.

Figure 1.14 shows the connections between partners present in these projects. The size of the node (circle) represents the number of projects a partner is involved in, while the thickness of the lines linking the nodes represents the number of projects two partners have in common. For clarity, only the partners involved in the largest numbers of projects are given. TIM indicates clusters of partners by colour using its own algorithm. The figure includes one large cluster around the projects dealing with SOFC technologies (INSIGHT, Waste2Watts, NewSOC, etc.), while the smaller cluster at the bottom of the figure contains two PEM FC projects (MAMA-MEA and GRASSHOPPER). In this low-TRL research area a good mix of private companies, universities and research centres are present. VTT is the most active participant, followed by CEA and SOLIDpower.

Figure 1.14: TIM plot showing the participants in all projects related to the next generation of products on energy



Top 5 Participants

Participant	Number of projects
VTT	6
CEA	5
SolidPower	5
DTU	4
EPFL	4

Manufacturing

Only one project in this area (MAMA-MEA) focuses on PEM FC manufacturing; the rest investigate SOFC manufacturing options (qSOFC, Cell3Ditor and NewSOC). The projects' overall goal is to enable the efficient manufacturing of large volumes of FC technologies with improvements on current costs, FC performances and environmental impact. Noticeable improvements have been achieved by FC products developed using innovative manufacturing methods. Even though improvements can be detected in many KPIs linked to performance and CAPEX, they remain a long way from the target values. Cost projections (especially for smaller FC applications such as µ-CHP) highlight the potential savings offered by scaling up manufacturing volumes. The reported rated electrical efficiency for SOFC has reached an impressive maximum of 74 % at stack level.

MAMA-MEA (finished in 2021) developed an innovative additive layer deposition process using a single, continuous roll-to-roll MEA manufacturing process for the PEM FCs. The first two MEA prototypes have been assembled into rainbow stacks and their testing has been performed successfully.

Cell3Ditor developed a 3D printing technique for the fabrication of SOFCs. A hybrid industrial printing machine, now commercially available, is able to print complete cells and stacks. The environmental impact of the new 3D printing method has been assessed through LCA and deemed more favourable than conventional SOFC-manufacturing techniques.

NewSOC is aiming to significantly improve the performance, durability and cost competitiveness of solid oxide cells and stacks compared with the current SoA. The project has five industrial partners offering SOFC products. It will develop several actions aiming to develop innovative architectures based on conventional materials. It will also test new materials with enhanced performance, and new manufacturing processes providing products with excellent durability and better environmental performances, using less raw materials.

By increasing the automation level of the production process, the qSOFC project has significantly driven down the production cost of SOFCs for an Elcogen SOFC design. A purposely developed new automated machine vision inspection system was used to improve the quality assurance processes. Through modifications and streamlining of stack conditioning procedure, a 75 % reduction in conditioning time was achieved, leading to 60 % reduction of CAPEX costs related to stack conditioning.

The finished INNOSOFC project has developed an innovative 50-kW SOFC system based on an all-European value chain (an Elcogen stack and Convion system). The project identified three niche applications with EU market potential under current energy prices: small server rooms, smart-grid CHP and bio-CHP. System calculations and preliminary field tests confirm that the targeted performance of the 50-kW SOFC system developed has been achieved with 61.4 % electrical and 81 % CHP system efficiencies. In addition (and based on successful results in the JU projects), Elcogen has received a EUR 12 million European Investment Bank quasi-equity loan facility for expanding research capacity and manufacturing. A new factory with a capacity target of 50 MW/year will be located in Tallinn (Estonia).

Degradation, performance and diagnostics

In this area, projects are aiming to bring the TRL for the investigated technological solutions up to 7 from an initial level of 3.

The INSIGHT project built on knowledge developed by past consortia with a well-defined constant core of participants developing different diagnostic tools for SOFCs and PEM FCs across several already finished projects (GENIUS, D-CODE, DESIGN, DIAMOND and HEALTH-CODE). The project is finished, and positive technical results have been achieved. The combined project targets – a 5 % lifetime increase at the expense of a maximum increase of 3 % in system cost – have been reached. A significant experimental result from INSIGHT is the build-up of a library of data linked to typical faults and associated mitigation measurements.

Demonstrating the advantages of the large-scale introduction of these diagnostic instruments for both PEM and SOFCs now lies with the RUBY project, which should bring the TRL above 7. Involving two FC system manufacturers, RUBY is continuing the long sequence of concluded projects for INSIGHT, described in the previous paragraph. At the end of the project, the tools developed are expected to be integrated into a commercial FC system.

The OxiGEN project is developing an all-ceramic stack design and specifications for a modular hotbox for an innovative SOFC platform. It is aiming to build a prototype µ-CHP system with an electrical power capacity of 1 kW. Detailed market specifications for residential and small commercial applications have already been defined.

LOWCOST-IC is aiming to apply SoA large-scale roll-to-roll manufacturing to increase the reliability and reduce the cost of interconnects in SOFC. The selection of suitable new materials for metallic interconnects also has the goal of increasing SOFC stack lifetime. The project's main goal is to select more resistant and cheaper steels that can be incorporated in available Sunfire and SOLIDpower FC stacks.

GRASSHOPPER aims to test a new concept for a MW-sized PEM FC plant unit. The objective is to provide more cost-effective and flexible grid support in its power output. Modelling and validations have been completed and have been instrumental in achieving an innovative stack design. The targeted CAPEX is below EUR 1 500/kWe for the FC at a yearly production rate of 25 MWe. The newly developed MEA has higher durability with lower-platinum loadings. The pilot plant 100-kW prototype system is expected to be fully tested soon.

Waste2Watts will design and engineer an integrated biogas–SOFC CHP system with minimal gas pre-processing, focusing on low-cost biogas pollutant removal and optimal thermal system integration. The project is addressing unutilised biogas produced by millions of farms, and bio-wastes from municipalities. The aim is to perform a test campaign using representative test gases with viable reforming catalysts and SOFC stacks. EMPOWER is aiming to develop a micro-CHP system fed by methanol and based on high-temperature PEM FC. The project is still designing and testing subcomponents.

1.2.1.5. Hydrogen for sectoral integration

The projects in this area contribute towards achieving the techno-economic objectives of making hydrogen production from renewables competitive, demonstrating hydrogen as a medium for energy storage, and sector coupling. This part of the energy pillar is aimed mainly at reducing costs and improving the efficiency of hydrogen production, with a clear focus on demonstrating large-scale electrolysers. The topics supported by FCH 2 JU were:

- low-temperature electrolysis
- high-temperature electrolysis (including co-electrolysis)
- other production routes
- hydrogen storage and distribution, purification, and admixture
- hydrogen territories.

Following the calls between 2008 and 2020, the JU supported 74 projects relevant to this area with a total contribution of EUR 239.3 million plus a contribution of EUR 227.1 million from partners. As shown in Figure 1.15, 59 % of JU funding went to electrolysis (38 % of JU funds supported low-temperature electrolysis and 21 % supported high-temperature electrolysis).

Figure 1.15: Funding for hydrogen for sectoral integration, 2008–2020

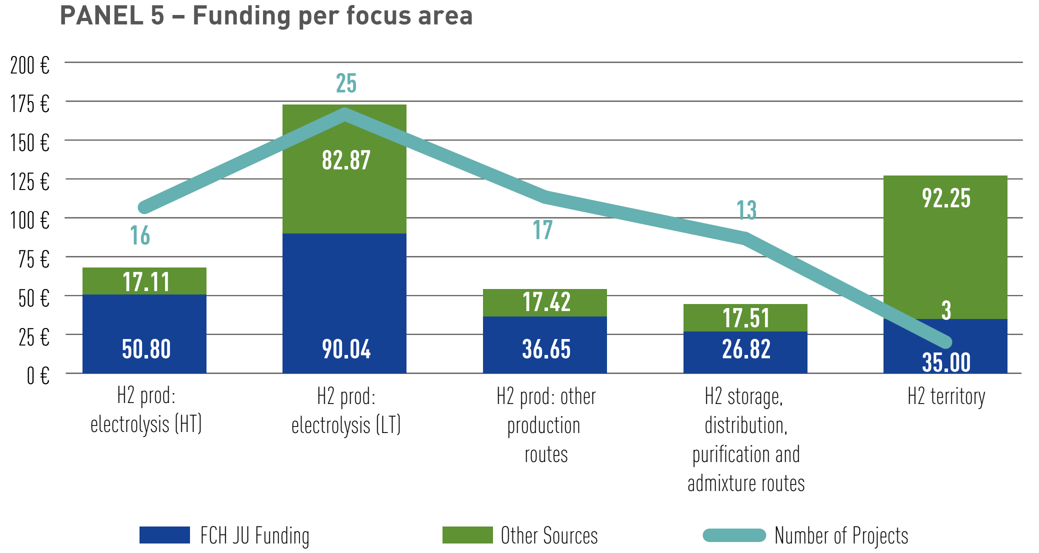
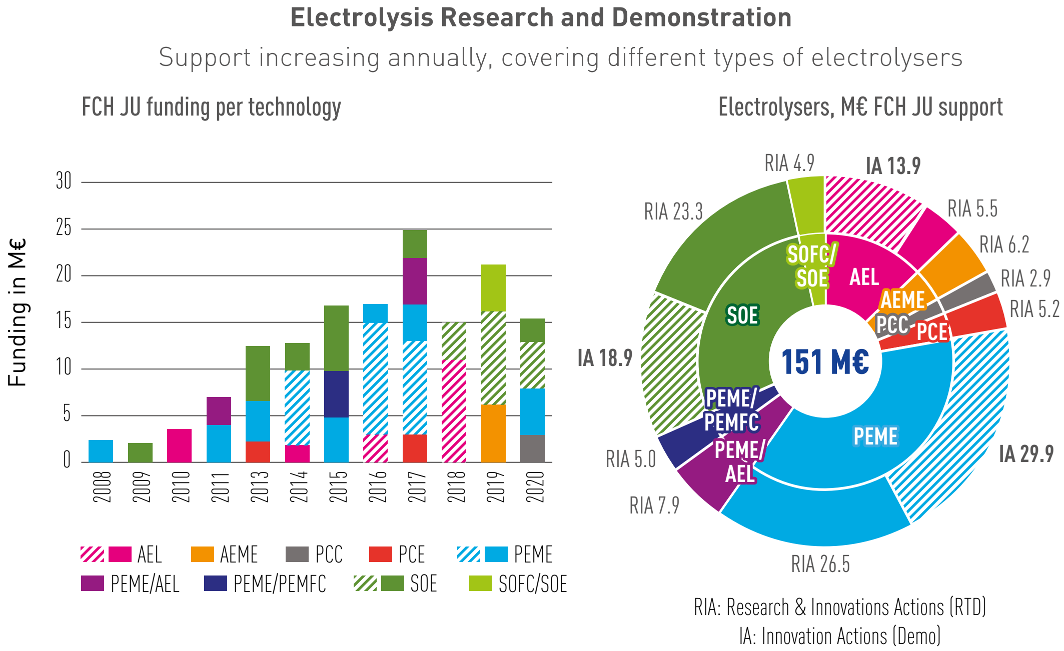


Figure 1.16 provides an overview of some of the most relevant electrolysis demonstration projects. In 2011, the activities of the JU started with the project DON QUICHOTE ([27]) (PEM technology electrolyser), with a capacity of 150 kW; eight years later Refhyne ([28]) installed a 10-MW PEM electrolyser, which is an increase of almost two orders of magnitude. The Djewels ([29]) project will install an alkaline electrolyser with a capacity of 20 MW. Over the same period, JU support per MW installed has reduced by a factor of 100.

Figure 1.16: Funding for electrolysis research and demonstration since 2008 under FCH JU and FCH 2 JU

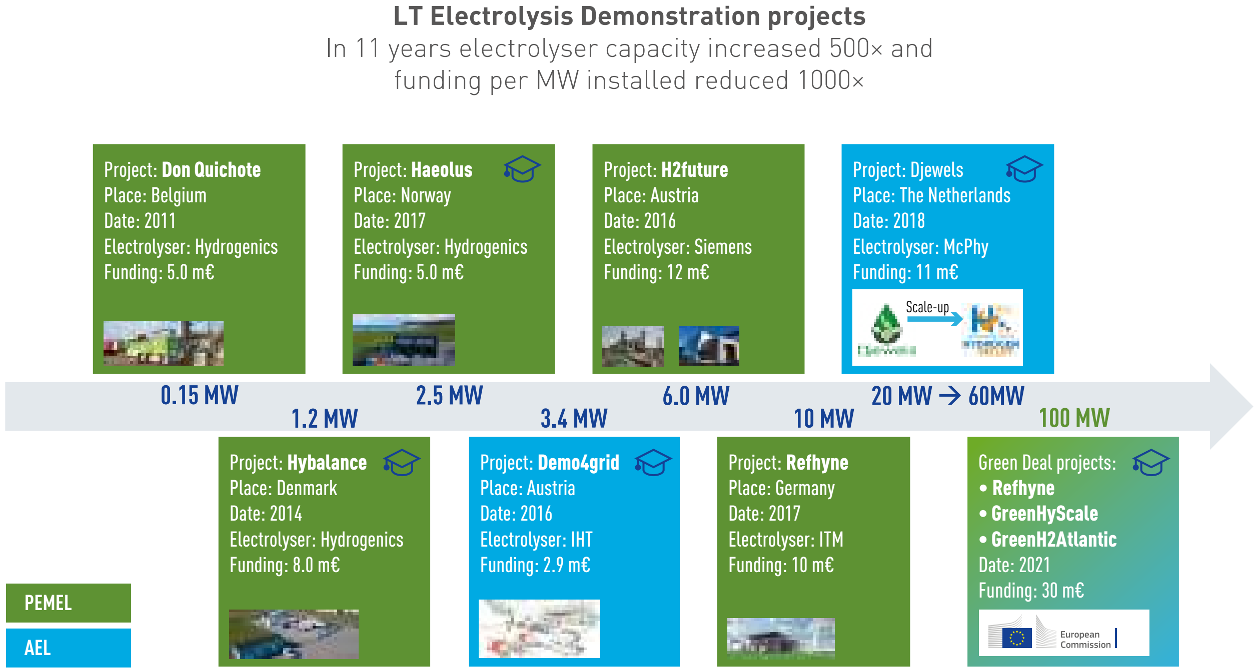


([27]) https://www.fch.europa.eu/page/hydrogen-production-and-distribution#Don%20Quichote

([28]) https://www.fch.europa.eu/page/energy#REFHYNE

([29]) https://www.fch.europa.eu/page/energy#Djewels

Figure 1.17: Key low-temperature electrolysis demonstration projects



This area currently consists of 12 projects, including 3 on anion exchange membrane electrolysis, 2 on alkaline electrolysis and 6 on PEM electrolysis. One project is focused on the development of testing protocols for grid services. Hydrogen production through electrolysis has also been supported in the transport pillar, where low-temperature electrolysers have been deployed to provide hydrogen for HRSs.

Alkaline electrolysis

The Djewels project is building and demonstrating a 20-MW electrolyser for the production of renewable methanol in Delfzijl industrial park in the Netherlands. The design envisages a system efficiency of 75 %, which would make a significant contribution towards reaching the 2024 MAWP targets. The stacks should have an operating range of 20–110 %, and the system a hot ramp idle time of 30 seconds. A current density of 0.9 A/cm^2 can be implemented through the development of novel electrodes. The project is currently at the engineering phase and the construction of the 1-MW stack testing facility has been completed. Once operational, Djewels may reach the 2024 electricity consumption target of 49 kWh/kg H_2.

The Demo4Grid project is preparing to install a 3.1-MW pressurised alkaline electrolyser, which will supply hydrogen near Innsbruck to demonstrate grid services and produce green hydrogen for industrial purposes and mobility. The project has carried out an assessment of potential business cases, with a focus on power-to-heat and mobility markets. The former will become interesting when natural gas prices are high and electricity costs low.

Proton exchange membrane electrolysis

The intention is that the electrolysers demonstrated should have a rapid response time (of a few seconds) in order to participate in the primary and secondary grid-balancing markets. A key challenge has been to upscale the PEM electrolysers (PEMELs) to multi-MW level, and much progress has been made in this respect.

The HyBalance project, which ended in 2020, installed and commissioned a 1.25-MW PEMEL in Hobro in northern Denmark, providing hydrogen for industrial and mobility customers. The stack operates at 30 bar with an efficiency of 72 %. As certified by the Danish transmission system operator Energinet.dk, the plant can provide grid services on the energy market. The overall energy demand of the plant per kg of hydrogen produced has reached 56.5 kWh/kg H_2, in line with the project target of 57.5 kWh/kg H_2.

Through the H2FUTURE project, a 6-MW PEMEL from Siemens has been operating at the Voestalpine Linz steel plant in Austria since October 2020. The hydrogen produced will support fossil fuel-based steelmaking technology as part of a stepwise decarbonisation approach to steel production proposed by the steel manufacturer. In future, the direct reduction of iron ore by hydrogen will decrease the footprint of steelmaking significantly.

Refineries need hydrogen for upgrading fuels and removing sulphur components. The Refhyne project will provide bulk quantities of hydrogen to the Shell Rhineland refinery in Germany (currently supplied by two steam methane reformers). With a capacity of 10 MW, it is Europe's largest electrolyser (ITM Power). It began operations in July 2021 and will produce 4 000 kg H_2/day at a pressure of 20 bar. The second phase of the project has been selected in the Green Deal call to expand the capacity of the electrolyser from 10 MW to 100 MW.

HAEOLUS is combining a 2.5-MW PEMEL and a 100-kW FC in the remote harbour of Berlevåg, Norway. The aim of the project is to test control strategies for each mode of operation in wind-hydrogen systems: energy storage, mini-grid and fuel production. The results will be relevant to many wind farms across Europe and worldwide. The two components were installed in the remote harbour in May 2021, the objective being to optimise the use of wind power in this challenging location close to the Arctic Circle.

Game-changer proton exchange membrane electrolysers

Hydrogen costs must be reduced for the large-scale provision of hydrogen to industry. While OPEX is inextricably linked to the local cost of electricity, CAPEX reductions could be realised by increasing current density or improving efficiency by operating at higher pressures. The two projects funded – NEPTUNE and PRETZEL – focused on increasing the current density and output pressure of PEM electrolysers.

The NEPTUNE project aims to reduce CAPEX for PEMEL, by increasing both hydrogen production rates and the output pressure in order to enhance efficiency. The goals are to achieve a current density of 4 A/cm^2 at low-PGM loading and an increase in output pressure to 100 bar, while retaining the nominal energy consumption of < 50 kWh/kg H_2. The project includes developments at cell, stack and system levels resulting in a final demonstration at 48 kW capacity.

The PRETZEL ([30]) project is aiming to develop an innovative game-changer PEMEL. A maximum 25-kW system generating 4.5 m^3/h of hydrogen at rated power, with a feed water temperature up to 90 °C and 100-bar output pressure, is the project's ultimate goal. The stack is based on a hydraulic system of pressurisation whereby it is contained within a pressure vessel, which should ensure homogeneous pressure and even current density distribution, and should minimise degradation. This means that the targeted oxygen output pressure is also 100 bar. The targeted current density (4 A/cm^2) required by the call goes well beyond the 2020 MAWP target (2.2 A/cm^2).

Testing protocols

The testing and qualification of electrolysers is essential to assess their ability to operate dynamically and perform electricity-balancing grid services. The QualyGridS project has developed testing protocols for AEL and PEMELs taking into consideration a variety of different grid services as well as multiple hydrogen end users. The scope was to identify the systems' capability to provide grid services as well as to indicate possible gaps. Testing protocols have been defined and applied for three alkaline and two PEMEL systems. The project ended successfully in 2020. The results showed that protocols are clear and implementable, and that all PEM water electrolysis and alkaline water electrolysis can meet most of the grid services' requirements. A report compiling testing protocols for five different low-temperature electrolysers in various locations in Europe was submitted to the International Organization for Standardization (ISO) Technical Committee 197 and formally approved by its members, which constitutes a great success for the project.

Anion exchange membrane electrolysers

In addition to the two main low-temperature electrolyser technologies (alkaline and PEM electrolysis), recent years have seen the development of AEMELs, which operate in alkaline media but use a solid electrolyte. In principle, this means they can combine the use of non-PGM catalysts with the production of high-purity hydrogen due to the presence of the solid electrolyte.

However, this technology is currently at a low TRL and has yet to achieve the performance and durability of other water electrolysis technologies. To date, there is only one AEMEL manufacturer (Enapter) in the market, and three projects are funded by the JU: CHANNEL, ANIONE and NEWELY. The objectives of all three projects are similar: to develop high-performance, cost-effective and durable AEMEL technology, by developing 2-kW prototype stacks.

The consortium behind CHANNEL has performed a market and cost analysis of the 2-kW prototype to develop a cost reduction strategy towards a capital cost of < EUR 600/kW for a 500-kW system. ANIONE has successfully developed anode catalysts that

([30]) https://www.fch.europa.eu/page/energy#PRETZEL do not use critical raw materials but achieve the project's performance and durability targets, while work is ongoing to improve the performance, in particular the durability, of novel cathode catalysts under investigation. NEWELY's novel catalysts (but with a commercial membrane) have already achieved very good performance results, with the project recently submitting its first patent applications and publications.

High-temperature electrolysis

This area covers the R & D projects SElySOs, GAMER and SWITCH, as well as the demonstration projects GrInHy2.0, MultiPLHY, REFLEX and Waste2GridS.

R & D projects

The SElySOs project is testing modified nickel-based and nickel-free cathodes and new air electrodes, seeking to enable the development of new solid oxide electrolyser cells (SOECs) that are less prone to degradation and have improved performance and stability. Experimental work is combined with theoretical modelling to understand reaction mechanisms and processes that cause degradation.

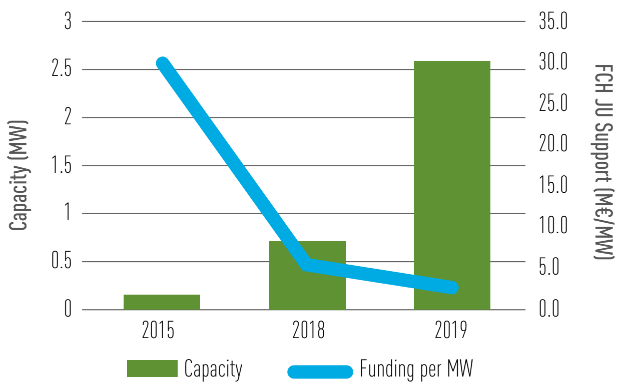
The SWITCH project seeks to develop a reversible system able to operate in both SOEC and SOFC mode, with a capacity of 25 kW (SOFC) or 75 kW (SOEC) and a minimum operating time of 5 000 hours. In FC mode, other feedstocks (natural gas, biomethane, etc.) can be used to produce hydrogen when renewable electricity prices are high.

The GAMER project seeks to develop and operate a 10-kW tubular proton ceramic electrolyser, producing hydrogen at 30 bar at a high level of electrical efficiency of up to 77 % for the system, provided there is an external steam source. It has demonstrated a single engineering unit in pressurised electrolysis mode at 600 °C at up to 10 bar. If maintained at the final stage, the performance and degradation results achieved to date at the small scale would make tubular stack configuration a game changer for proton ceramic electrolysis.

Demonstration projects

In recent years, there has been a marked increase in the capacity of HTE demonstration projects, while they have received lower funding per MW (see Figure 1.18). HTEs are now being demonstrated in industrial environments such as a steel plant and a bio-refinery.

Figure 1.18: Capacity of HTE demonstration projects (MW) versus funding (million EUR per MW)



The GrInHy2.0 project is the successor to the GrInHy project's electrolyser installed at the Salzgitter steel production plant. This will be the world's biggest high-temperature electrolyser, with a capacity of 720 kW AC and an electrical efficiency of 84 % lower heating value. The aim is to achieve production of at least 100 tonnes of hydrogen over 13 000 operational hours with a system availability of 95 % by the end of 2022.

To date, the manufacturing of the system's electrolyser and hydrogen-processing units has been completed and they have been installed on site. The first-time injection of about 100 Nm³/h of hydrogen took place during commissioning. The CAPEX target of EUR 4 500/(kg/day) was met by the project mainly thanks to the integration of multiple stacks in one system.

Building on GrInHy and GrInHy2.0 results, the MultiPLHY [31] project aims to install and operate the world's first high-temperature electrolyser system at the multi-MW-scale (~ 2.4 MW), at a chemical refinery in Salzbergen (Germany) to produce hydrogen (≥ 60 kg/h) for the refinery's processes.

In May 2021, the MultiPLHY project successfully tested a 225-kW high-temperature electrolysis module, consisting of 60 stacks with 1 800 cells. This module will be part of a 2.7-MW system for a total of 12 modules for the 2.2-MW electrolyser, with

[31] https://www.fch.europa.eu/page/energy#MultiPLHY

a power consumption of less than 40 kWh/kg H_2. The electrolyser will be demonstrated in a biorefinery in Rotterdam (Netherlands). The project is seeking to demonstrate that solid oxide electrolysis technology is reducing the TRL gap (by bringing it to TRL 8) between high-temperature electrolysis, on the one hand, and PEMEL and AEL, on the other, by installing and operating a multi-MW system. It is aiming for a design enabling CAPEX of ≤ EUR 2 400/(kgH_2/d), in line with the 2024 MAWP target.

The REFLEX project is developing reversible solid oxide cell (rSOC) technology to be implemented as an integrated energy storage solution (smart energy hub) at community/district level. The project has developed improved rSOC component cells, stacks, power electronics and heat exchangers. The performance and durability target were achieved in rSOC operation at cell scale as well as with enlarged cells (200 cm^2). A current density of 1.25 A/cm^2 was achieved in SOEC mode (target 1.2 A/cm^2). Several other objectives were partially achieved.

The aim of the Waste2GridS project is to identify the most promising industrial pathways for waste gasification and solid oxide technology integrated plants. Biomass sources being considered are agricultural wastes, forest residues and municipal solid waste. Waste2GridS is proposing a novel concept of a triple-mode grid-balancing plant enabled by biomass gasification and rSOC technology. These plants can provide a grid-balancing service by switching between (i) power-generation mode, converting waste to electricity for the grid; (ii) power-storage mode, using the grid electricity to convert waste into methane; and (iii) power-neutral mode, converting waste into methane with no grid interaction. Feasible business cases were identified for power generation and power storage operations of over 3 500 hours. The project concluded that Waste2GridS plants could be feasible economically with five years' payback time and a significant cost reduction in stack costs to < EUR 1 600/kWe.

Other hydrogen production routes

In addition to electrolysis, the FCH 2 JU is supporting R & D projects to explore alternative hydrogen production technologies, such as BioROBURplus, BIONICO, HYDROSOL-beyond and PECSYS.

Reforming

The BIONICO and BioROBURplus projects are aiming to develop the decentralised production of renewable hydrogen by reforming biogas at capacities of around 100 kg H_2/day. The goal of the BioROBURplus project is to demonstrate a biogas fuel processor for decentralised hydrogen production based on oxidative steam reforming. The focus is on increasing the efficiency of the reactor to 72 % (higher heating value). An extensive testing programme was carried out to identify a suitable catalyst. If the testing campaign proves successful, this technology should reach TRL 6. The demonstration unit has been installed in a biogas facility and is being commissioned.

The BIONICO project (ended in 2019) developed and tested a catalytic membrane reactor system to produce pure hydrogen from raw biogas (containing CO_2) in a single step (reforming and purification). The project's achievements include the development of a novel reforming catalyst and support. The lab experiments demonstrated the stability of both catalyst and membrane in fluidised bed conditions. The performance of palladium–silver–gold membranes was measured in the presence of hydrogen sulphide, showing improved performance for the membrane with higher gold content.

Thermochemical hydrogen production

Solar thermochemical production has much promise thanks to its potentially high solar to hydrogen efficiency (35–50 %, compared with around 12 % for photovoltaic plus electrolysis). The HYDROSOL-beyond project, a 750-kW solar plant in Almeria, Spain, is currently the only large-scale solar thermochemical hydrogen production unit in the world. The concept is based on redox-structured monolithic solar reactors for the production of hydrogen from water. HYDROSOL-beyond is aiming to address material and component issues encountered in its predecessor, HYDROSOL-PLANT. The project should double the current SoA of 5 % solar-to-hydrogen efficiency through novel design solutions, in particular a more efficient heat exchanger to improve heat recovery.

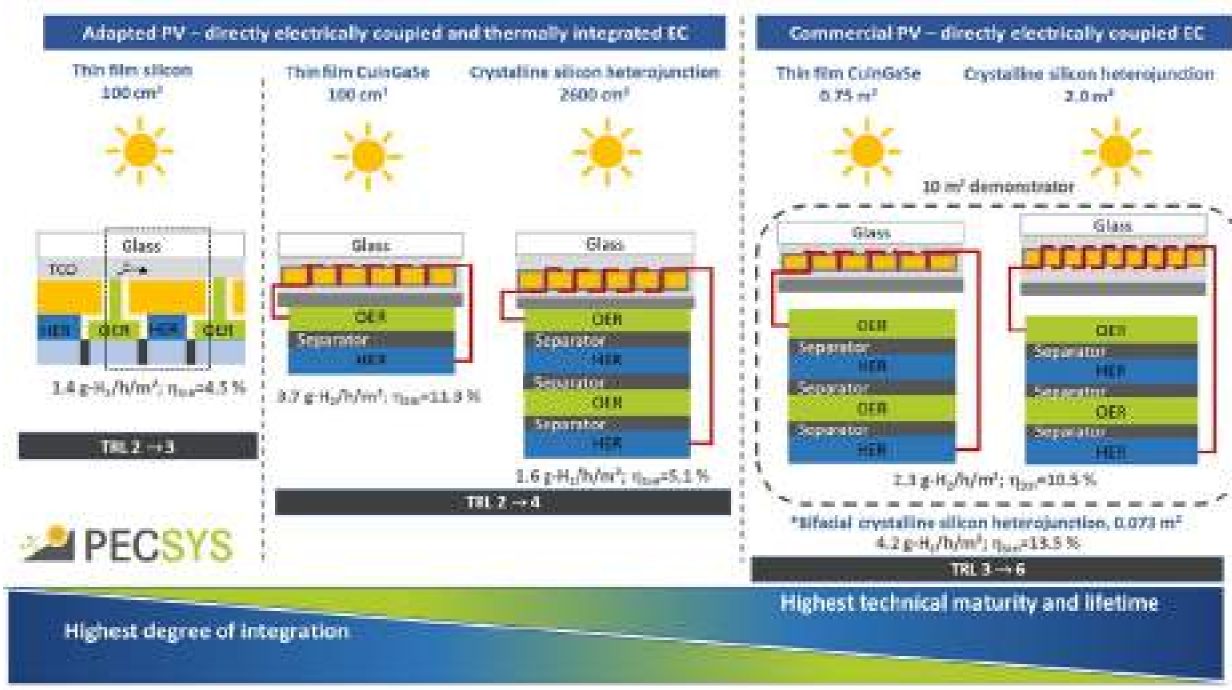
Photoelectrochemical hydrogen production

The PECSYS project, which ended in 2020, developed and tested an integrated photo-electrochemical cell hydrogen generator at various prototype scales. Several concepts were explored for the direct coupling of an electrolyser to photovoltaic panels (see Figure 1.19). For a smaller device, a solar to hydrogen conversion efficiency of up to 13 % (ambient conditions 1 000 W/m^2, 25 °C) for a 100-

cm[2] copper indium gallium selenide / nickel oxide / nickel, molybdenum and vanadium unit has been reached. Overall, the project achieved TRL 6; the demonstrator achieved an average efficiency of 10 % and produced 22 kg of hydrogen during its 9 months of operation. The final 10-m² demonstrator consisted of an array of copper indium gallium selenide and silicon heterojunction photovoltaic modules directly coupled to an electrolyser stack. A hydrogen production rate of 2.3 g/h/m², almost double that of the current SoA, has been achieved.

The cost and lifetime issues may limit the potential of this technology for its intended application, namely to be deployed on residential rooftops in remote areas. More operational data would be needed for the JU programme to assess the prospects of this technology.

Figure 1.19: PECSYS concepts



Source: https://www.helmholtz-berlin.de/projects/pecsys

1.2.1.6. Hydrogen storage, distribution and purification

This area covers the projects HySTOC, HyCARE, HyGrid, MEMPHYS and HIGGS.

The HySTOC ([32]) project aims to develop and demonstrate a transport and storage system for HRS using a liquid organic hydrogen carrier. These compounds, which are able to release or accept hydrogen, have similar properties to crude oil and can be stored and transported over long distances in ambient conditions in large oil tankers without significant losses. According to a recent study by the JRC ([33]), hydrogen carrier systems can be among the lowest-cost options for the long-distance transportation of hydrogen. The liquid organic hydrogen carrier under consideration is dibenzyltoluene, which has advantageous properties in terms of storage and transport efficiency: a high storage density and little or no need for cooling and compression or purification. Currently, the project is close to finalising the commissioning of a hydrogen release plant that will be able to release up to 20 kg of hydrogen per day; the hydrogenation plant is already operational.

The HyCARE ([34]) project is developing a prototype large-scale hydrogen storage tank based on solid-state storage (ferro-titanium). If successful, this system will be the largest demonstration of stationary solid-state hydrogen storage, with a capacity of 50 kg of hydrogen stored. This storage technology also has advantages in terms of safety due to the low storage pressure of less than 50 bars.

([32]) https://www.fch.europa.eu/page/energy#HySTOC
([33]) https://ec.europa.eu/jrc/sites/default/files/jrc124206_assessment_of_hydrogen_delivery_options.pdf
([34]) https://www.fch.europa.eu/page/energy#HyCARE

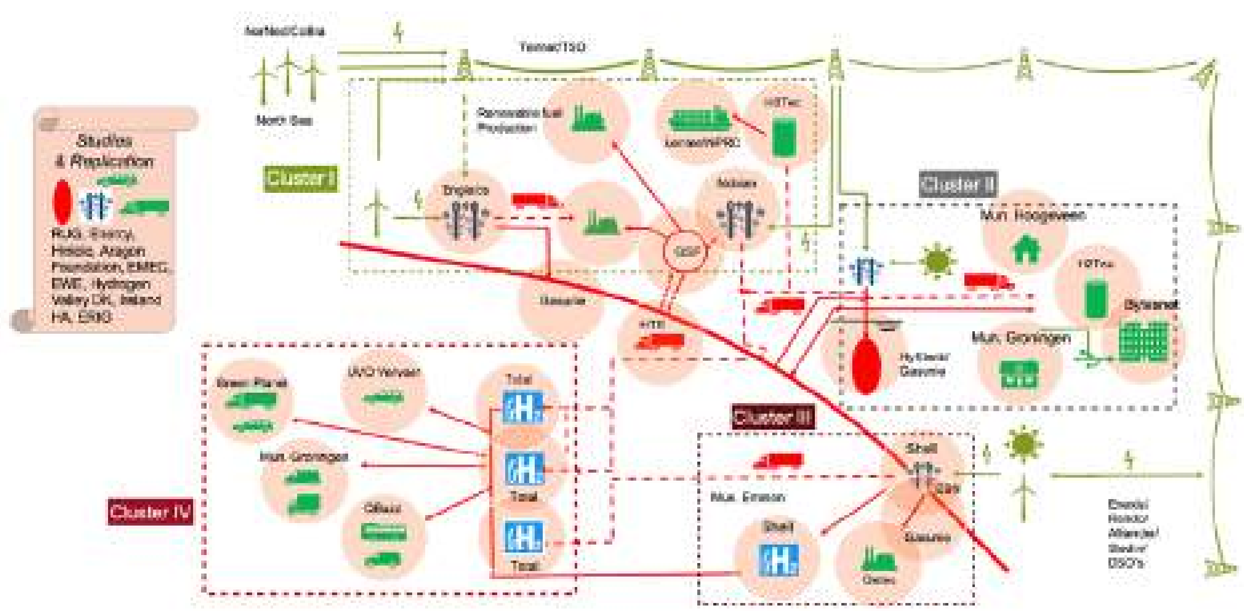
The HyGrid [35] project aims to develop, scale up and demonstrate a novel membrane-based hybrid technology combining membranes, electrochemical separation and temperature swing adsorption for the direct separation of hydrogen from natural gas grids. The objective is to reduce the cost of hydrogen separation to < EUR 1.5/kg H_2 for recovery rates > 95 % and with an energy consumption of < 5kWh/kg H_2. These targets are for hydrogen concentrations of < 10 % by volume in natural gas. All relevant components of the prototype are ready and the project can start to test the concept. The development of membranes has led to the creation of a new company involving TECNALIA and TU Eindhoven, namely H2SITE, for the manufacturing and commercialisation of the technology.

The MEMPHYS [36] project, which ended in 2019, targeted the development of a low-energy hydrogen purification system based on electrochemical hydrogen purification. The focus was on high contaminant tolerance (carbon monoxide) at low system cost, making the system suitable for different applications. The main project targets were to purify 5 kg H_2/day with an energy consumption of < 5 kWh/kg H_2 and a hydrogen recovery rate of > 90 %. The best performance of the third-generation stack fell significantly short of the project targets with an energy demand of 6.4 kWh/kg H_2 at an 83 % recovery rate.

1.2.1.7. Hydrogen territories

The JU is working together with European regions to realise their potential to demonstrate hydrogen technologies. Part of a larger regional initiative in the Netherlands, the HEAVENN hydrogen valley is seeking to promote and enable the use of green hydrogen across the whole value production chain, distribution, storage and end use. The project comprises four clusters (see Figure 1.20), which are at various stages of implementation. For cluster IV, the first vehicles have been procured, including garbage trucks, and the HRS will open soon. A 4-MW electrolyser, for which the concept design has been completed, will be deployed as part of cluster III. The hydrogen pipeline will be designed to enable a future connection to the hydrogen backbone. In cluster II, activities for the salt-cavern hydrogen storage have commenced with the first test set-ups.

Figure 1.20: Schematic of the HEAVENN project



Green Hysland is the first southern European hydrogen valley and will showcase the ability of hydrogen to decarbonise islands at an unprecedented scale. It will generate, distribute and use at least 300 tonnes of renewable hydrogen locally per year, produced from solar energy on the island of Majorca. Green hydrogen will have multiple applications on the island, including the fuel supply

[35] https://www.fch.europa.eu/page/energy#HyGrid
[36] https://www.fch.europa.eu/page/energy#MEMPHYS

for a fleet of FCBs and FC rental vehicles, the generation of heat and power for commercial and public buildings, the supply of auxiliary power for ferries and port operations, and the creation of an HRS. The estimated duration for the Green Hysland project will be from 2021 to 2025 and it will aim to reduce the CO_2 emissions of Majorca by up to 20,700 tonnes per year by the end of the project.

The Building Innovative Green Hydrogen Systems in Isolated Territories (BIG HIT) project is in the process of creating a hydrogen ecosystem in the Orkney Islands (Scotland), which will help to minimise the curtailment of renewable electricity. The hydrogen produced is used locally in cogeneration and transport applications. The project has achieved several milestones by deploying five hydrogen trailers (250 kg hydrogen storage), a hydrogen catalytic boiler (30 kW), a 1-MW electrolyser (ITM Power), five hydrogen FC vans and a 75-kW FC system for cogeneration. The electrolyser is operating and capable of providing hydrogen for the FC vans, and 833 refuelling actions were performed in 2020.

1.2.1.8. Support for market uptake – cross-cutting activities

Cross-cutting activities are related to:

- pre-normative research (PNR) and input into regulations, codes and standards (RCS)
- education and training
- safety aspects.

To date (in calls from 2008 to 2020), the JU has supported 48 projects relevant to these activities with a total contribution of EUR 67.5 million complemented by EUR 28.8 million of other contributions.

Pre-normative research / regulations, codes and standards

This area of PNR/RCS comprises five PNR projects: HYDRAITE, ID-FAST, AD ASTRA, THyGA and PRHYDE.

HYDRAITE (2018–2021) studied the effects of hydrogen contaminants on FC systems in automotive applications, building on the results of the earlier project HyCORA. A major achievement of the HYDRAITE project is the development of three laboratories in Europe capable of measuring hydrogen quality according to European and international harmonised standards.

ID-FAST (2018–2021) developed accelerated stress tests for PEM FCs for automotive applications and a methodology able to predict ageing. The test carried out in the ID-FAST project will contribute to the development of a new standard by the International Electrotechnical Commission Technical Committee 105 on FC technologies. With a similar approach to ID-FAST, AD ASTRA (2019–2022) is developing accelerated stress test protocols for solid oxide cell stacks, operating in both FC and electrolysis modes. The final product will test protocols able to predict the degradation of solid oxide cells and their integration into a future standard.

THyGA (2020-2022) is testing how domestic and commercial gas appliances perform in the presence of hydrogen up to 60 % by volume in natural gas. It will then establish the hydrogen concentration limit below which hydrogen can be added to natural gas without changing the current certification of boilers, burners and cookers. THyGA will propose revisions of the existing standards section within the European RCS framework covered by the gas appliances regulation (Regulation (EU) 2016/426).

PRHYDE (2020-2022) is studying the parameters and components required for the hydrogen refuelling of heavy-duty vehicles, such as trucks and buses, to identify the optimal solutions for minimising filling time, maximising travel autonomy and, at the same time, guaranteeing safety. The final output will be the recommendation of a non-proprietary filling protocol.

Education and training

Four projects are dedicated to education and training: NET-Tools, TeacHy, FCHgo! and HyResponder.

The NET-Tools project focuses on the development of new e-education methods based on IT tools, enhancing the knowledge, productivity and competitiveness of those interested in FCH technology deployment. The project's tangible output is an e-learning platform based on open-source software.

The TeacHy project is developing learning tools and materials mainly for university students (undergraduates and postgraduates), although it also includes vocational training. Its overarching goal is to give students across Europe access to high-quality and harmonised training material. Its major aim is a European MSc course on FCH technologies.

The FCHgo! project is focusing on school pupils by developing educational tools aimed at the rising generations. FCHgo! outputs include a toolkit with narrative explanations of the technology, workshops in classrooms, a website and an annual award for the best ideas.

The HyResponder project builds on the previous project, HyResponse (2013–2016), which targeted first responders and developed a physical platform for this purpose. This new project will provide a 'train the trainer' programme in hydrogen safety for responders across Europe. The European emergency response guide developed by HyResponse will be revised and expanded to include strategies and tactics for liquefied hydrogen applications.

Safety

The two projects on safety issues are PRESLHY and HyTunnel-CS. PRESLHY, the first European project in over 10 years completely dedicated to the study of LH_2, looked into the safety of LH_2 release under accidental conditions. It provided information and data on release, ignition and combustion under realistic conditions, which have been used to improve and validate the physical models and simulations used for describing releases. The results will be used by the newly formed ISO Technical Committee 197 Working Group (WG) 29 to review and update obsolete ISO standard on liquid and cryogenic hydrogen.

HyTunnel-CS is focusing on the public and environmental safety of hydrogen vehicles in semi-confined spaces, such as tunnels and public garages. The project identifies hazards and risks, and reviews the safety measures already in place, including emergency response strategies. The final goal is to propose a new safety approach to this public infrastructure, which could become the basis for a standard within the framework of the European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC) Joint Technical Committee 6 on hydrogen in the energy systems.

1.2.2. Knowledge management

Knowledge management activities have continued to monitor technology progress, with TRUST ([37]) being used as the central data collection platform enabling comprehensive data collection and analysis, complemented by the Fuel Cells and Hydrogen Observatory (FHCO) ([38]) monitoring of the deployment of hydrogen technologies and the developments in the sector.

Programme review / annual data collection exercise

The annual programme review exercise (supported by the JRC – see further details in Section 1.2.5) continued to be the main source of knowledge for the JU. It includes the annual data collection exercise, which monitors the progress towards the technology KPI targets, and the programme review report, which presents the findings of the exercise. An effort was made to reduce the duration of the exercise, bringing the reporting period forwards and enriching the report with more information valuable to its readers. In practice, the ongoing projects (85 in total) were asked to provide data concerning their R&I results generated in 2020 almost 1.5 months earlier than previously, on 1 March 2021. This allowed the JRC to start working much earlier on the programme review, thus permitting the programme review report to be published during the programme review days, in December 2021 (more than 6 months earlier than previous reports). Consequently, a single programme review report was published for 2020–2021 (one report for both years).

The submission of the data was performed through TRUST, concerning technology-related indicators (78 projects reporting), and through an EU survey questionnaire (85 projects reporting). Projects were encouraged to share their data as public as much as possible (facilitating the effort to make public the relevant KPIs reached), while all confidential data were appropriately cleaned and anonymised.

The data collection exercise was completed successfully, with all projects answering the questionnaires and providing timely input on most of the queries. TRUST data collection activities continued to be streamlined with the annual programme review exercise, which provides a detailed analysis of the projects' results.

The results and reported progress were included as content during the portfolio analysis part of the 2021 programme review ([39]), with a summary of its results presented in Section 1.2.1. Scientific and technological achievements as well as in the programme review days event, including the project officers' portfolio overviews and project posters ([40]).

Fuel Cells and Hydrogen Observatory

The JU contributes to monitoring the deployment of hydrogen technologies, the adoption of related

([37]) https://www.clean-hydrogen.europa.eu/knowledge-management/technology-monitoring-trust_en
([38]) https://www.fchobservatory.eu/observatory
([39]) https://www.clean-hydrogen.europa.eu/media/publications/programme-review-report-2020-2021_en
([40]) https://www.clean-hydrogen.europa.eu/knowledge-management/programme-review-days/prd-2021_en

policies, academic activities and research results through the FCHO. The FCHO is an open platform providing data and up-to-date information about the entire hydrogen sector, aiming to address the lack of data publicly available at EU and national levels concerning the uptake of FC and hydrogen technologies on the EU market and the absence of a coordinated methodology for how to monitor changes in the market for them.

In 2021 the FCHO updated and further increased the data made available on its platform, most notably including a module for the calculation of the levelised cost of hydrogen and information about hydrogen pipelines. The data on the portal were updated to the latest available statistical data, while a set of six reports was published [41] on all the main information and data tracked by the FCHO:

1. technology and market
2. hydrogen supply and demand
3. EU and national policies
4. standards
5. patents
6. education and training.

1.2.3. Regulations, Codes and Standards Strategy Coordination Group

The industry-led Regulations, Codes and Standards Strategy Coordination Group (RCS SCG) is composed of 18 representatives from Hydrogen Europe and Hydrogen Europe Research. It is supported by the JRC and the JU programme office.

The RCS SCG coordinates the strategy on RCS within the JU, with a focus on the identification of strategic themes for RCS development and their proposed follow-up. The goal of this work is to provide the JU programme with an evidence-based analysis of urgent priorities for PNR and standardisation needs supporting the design of the future annual work plans (AWPs).

In general, RCS activities consist of identifying and prioritising RCS needs of strategic importance for the EU. In addition, the necessary PNR activities to support the RCS priorities are identified.

In 2021, the RCS SCG members centred their activity around two main items.

- Support to set out the section devoted to the RCS SCG on the 2021–2027 SRIA of the Clean Hydrogen JU [42], supporting the provision of a clear framework for the RCS SCG activities in the years to come. As a result, the continuation of the works for the RCS coordination within the Clean Hydrogen JU programme have been discussed and agreed, and the streamlined continuation of the activities has been outlined for effective RCS strategy coordination in the next programme.
- Follow-up and support of activities going on in 2021 regarding standardisation in support of European legislation, and the Sector Forum Energy Management (SFEM) WG Hydrogen. In this regard, RCS SCG members have been involved in the mapping of standards deemed necessary in the future in the general area of hydrogen. In addition, RCS SCG members have participated and supported the preparatory works of the SFEM WG Hydrogen task force on industrial needs hydrogen quality, and the preparation of three expert workshops on maritime use, heavy-duty vehicles and LH_2, scheduled for early 2022.

1.2.4. European Hydrogen Safety Panel

The European Hydrogen Safety Panel (EHSP) initiative was launched by the JU in 2017. The mission of the EHSP is to assist the JU at both programme and project levels in ensuring that hydrogen safety is adequately managed, and to promote and disseminate a hydrogen safety culture within and outside the JU programme.

The EHSP is composed of a multidisciplinary pool of experts – 15 experts in 2021 – grouped in ad hoc WGs (task forces) according to the tasks to be performed annually and to expertise. Collectively, the members of the EHSP have the necessary scientific abilities and expertise covering the technical domain needed to make science-based recommendations to the JU.

The following sections provide a summary of the activities performed by the EHSP during 2021, each section covering one task force.

[41] https://www.fchobservatory.eu/index.php/reports

[42] https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20 %28ID%2013246486 %29.pdf

Support at project level

ESHP activities in this category aim to coordinate a package of measures to avoid any accidents by integrating safety learning, expertise and planning in the JU-funded projects by ensuring that all projects address and incorporate the SoA in hydrogen safety appropriately.

In 2021, the EHSP published a new guidance document for safety planning and management in EU hydrogen and fuel cell projects ([43]). Building on the first safety-planning guidance document, published in 2019, the new document provides further information on safety planning, monitoring and reporting for hydrogen and FC projects in Europe, and provides an integrated approach to project safety planning, monitoring and reporting needs to best address technical and organisational aspects of hydrogen safety, supporting EU projects to incorporate SoA hydrogen safety by integrating safety learning, expertise and planning.

In addition, the EHSP activities in 2021 continued with the assessment of all JU projects from a safety-related perspective. Building on this assessment, about 10 safety plans of JU-funded projects have been reviewed, providing recommendations for their improvement where necessary. In addition, the EHSP has continued to provide support to any project consortium that did not have its own safety expertise or wishes an independent view. For example, the REFLEX project has benefited from the EHSP advice and support, which facilitated receiving the permits for the installation of the SOFC targeted within the project.

Last, among the activities carried out in supporting specific projects, an online workshop on safe storage of compressed gas hydrogen in road transport applications and related infrastructure, focused on the safety aspects, was held on 18 November 2021 with the participation of the 15 JU projects involving hydrogen storage in road transport applications and related infrastructure. The projects presented their project-specific approaches and experiences regarding safety planning, RCS, risk assessment and incidents specifically related to hydrogen storage. In total, more than 90 participants were connected online, and a summary report alongside the presentations will be hosted on the EHSP page on the JU website for public dissemination.

Support at programme level

EHSP work in this category includes a set of activities intrinsically linked with the activities of the previous task force but with a broader and cross-cutting dimension, focused on the JU programme itself and how safety-related aspects can be enhanced within the overall programme and activities.

The activities within this task force in 2021 were focused on support to set out the section devoted to the EHSP on the 2021–2027 SRIA of the Clean Hydrogen JU ([44]), providing a clear framework for the EHSP activities in the years to come. In addition, following the activities initiated in 2020, the EHSP has supported the JU in identifying safety issues, and researching what might still require support from the programme to better understand and assess the current and near-future needs in hydrogen safety.

Moreover, as part of the activities within this task force, the EHSP has continued to develop a procedure for an incident response, aiming to provide a structured response to any incident or safety threat to a project.

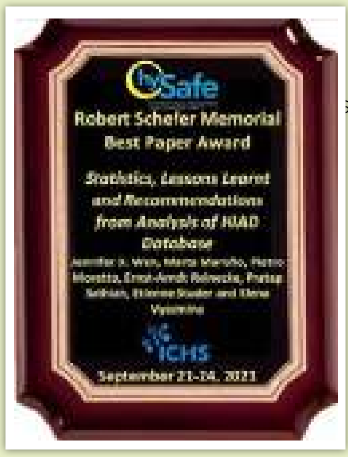
Moreover, the EHSP is keeping in touch with the International Association for Hydrogen Safety; the American Hydrogen Safety Panel, traditionally supported by the US Department of Energy's Fuel Cell Technologies Office; and the Hydrogen Council. It seeks synergies and topics of mutual interest. For example, the EHSP participated in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) Hydrogen Safety Forum held on 22 June 2021, supporting a better understanding of the international systems in place that are supporting, researching and continuing to improve hydrogen safety in production, transmission and use, and making a joint presentation with the American Hydrogen Safety Panel. Last, further systematic cooperation with these organisations is planned from 2022.

Data collection and assessment

As learning from others is an essential element of a high-level safety culture, activities in this category are centred on the collection and analysis of hydrogen safety-related data to derive lessons learned and provide further general recommendations to all stakeholders. Together with fundamental safety research and applied studies, one of the most fruitful methods used in industry to develop and

([43]) https://www.clean-hydrogen.europa.eu/get-involved/european-hydrogen-safety-panel-0/reference-documents-ehsp_en

([44]) https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20 %28ID%2013246486 %29.pdf



; document was presented at the ninth International Conference on Hydrogen Safety by the EHSP, which received the Best Paper award.

Last, preliminary lists of the phenomenological models, risk assessment approaches and computational fluid dynamics models developed from JU projects and elsewhere by the international hydrogen safety community have been compiled, with links to relevant published documents.

improve safety strategies for a specific technology is the return of experience obtained from its previous deployments. In the case of hydrogen, the level of penetration in the market and society has been low, so reliable statistics cannot yet be generated, and in-depth knowledge of incidents and near misses is still lacking. It is, therefore, important to collect and structure all available information on how people behave when accidents happen with hydrogen along its supply chains, up to end uses, to maximise the lessons learned from the past and develop future-proof safety strategies to help ensure safe handling of hydrogen and inform standards and regulations.

In close collaboration with the JRC, the EHSP continued to enlarge the Hydrogen Incidents and Accidents Database (HIAD) 2.0 in 2021. The number of validated events increased from 272 in 2018 to 706 in 2021, and the overall quality of the published events has also been improved.

Furthermore, the EHSP has conducted statistical analysis to identify trends in the type of incident/accident, origin, causes, severity, violation of relevant safety principles, etc. The statistics gathered informed the subsequent analysis to derive lessons learned and formulate recommendations that can be drawn from the events to improve hydrogen safety in different sectors. During this process, the EHSP formulated internal guidance to help harmonise the analyses by the individual experts. As a result, in 2021, the EHSP published a new document with the statistics, lessons learned and recommendations from the analysis of HIAD 2.0 ([45]).

These form the basis of the planned work in 2022 towards developing a one-stop-shop for hydrogen safety engineering, which will include comprehensive lists of phenomenological models, risk assessment approaches and computational fluid dynamics models for hydrogen safety engineering applications.

Public outreach

As part of the intended broad information exchange, in 2021 the EHSP concluded its communication strategy. This internal document outlines specific considerations for the communication strategy for the EHSP and the inherent challenges associated with the safe implementation of hydrogen as an energy carrier in society. It suggests clear and measurable communication goals and objectives, and provides an analysis of the target audience for communication, prioritised by groups. It also provides a summary of relevant communication channels and a list of key messages.

In line with the communication strategy, the EHSP has established regular meetings with the communication team at the JU PO and has performed a comprehensive revision of the EHSP page on the website of the Clean Hydrogen JU ([46]).

In addition, in cooperation with the JRC, the EHSP has developed a specific research thematic for hydrogen safety on TIM ([47]).

Last, outreach activities of the EHSP in 2021 included presentations at several events, such as the Fire and Blast Information Group seminar on 21 April, the Safety Forum of the IPHE on 22 June, the ninth International Conference on Hydrogen Safety on 21–24 September, and the European Hydrogen Week on 29 November–3 December.

([45]) https://www.clean-hydrogen.europa.eu/get-involved/european-hydrogen-safety-panel-0/reference-documents-ehsp_en

([46]) https://www.clean-hydrogen.europa.eu/get-involved/european-hydrogen-safety-panel-0_en

([47]) https://www.clean-hydrogen.europa.eu/knowledge-management/tools-innovation-monitoring-tim-0_en

1.2.5. Collaboration with the Joint Research Centre

The JRC undertakes high-quality research in the FCH field, which is of considerable relevance to the implementation of the JU's activities.

In 2016, a framework contract between the JU and JRC was drawn up for the H2020 programme. The scope of this framework contract covers the activities the JRC provides at the level of the JU programme. These activities are outlined in annual rolling plans, which also detail the specific deliverables to be provided against payment (heading B of Article 2 in the framework contract).

The 2021 annual rolling plan constituted part of the 2021 AWP, with an indicative budget of EUR 990 000 from the JU operational budget, but incurring in the end EUR 786 200 because of differences in the services provided. The JRC activities covered by the framework contract were planned and agreed between the JRC and the PO, with the involvement of one representative each from Hydrogen Europe and Hydrogen Europe Research.

In line with the JRC's mission, these support activities have primarily contributed to the formulation and implementation of the JU's strategy and activities in the areas of RCS, safety, harmonisation of testing protocols, and technology monitoring and assessment.

Joint Research Centre support to the formulation and implementation of the regulations, codes and standards strategy

The JRC supports the industry-led RCS SCG. In general, RCS activities should consist of identifying and prioritising RCS needs of strategic importance for the EU. In addition, the necessary PNR activities to support the RCS priorities should be identified. The activities of the RCS SCG are described in Section 1.2.3. Regulations, Codes and Standards Strategy Coordination Group.

The Joint Research Centre's direct contribution to implementing the regulations, codes and standards strategy

The JRC ZERO∇CELL is a piece of single-cell PEM FC-testing hardware. Its development was initiated based on a request from automotive original equipment manufacturers to the FCH 2 JU's WG on harmonisation of PEM FCs for automotive application. The JRC efforts are summarised in the JRC technical report *Development of reference hardware for harmonised testing of PEM single cell fuel cells*, published in February 2021 [48]. The design documentation of the JRC ZERO∇CELL is publicly available under CERN-OHW-v2 licence [49].

The JRC is also leading the initiative to set up a harmonised EU terminology for hydrogen generated by electrolysis. A technical report has been produced and agreed with the WG on harmonisation activities for high temperature electrolysers. Following considerable efforts to resolve the extensive comments received in the public stakeholder consultation, and once approval was granted for the use of many terms defined by ISO, International Electrotechnical Commission and the International Bureau of Weights and Measures, the report was published on the JU website and in the JRC's repository [50].

In view of the harmonisation activities for low-temperature electrolysis, a JRC technical report on EU harmonised protocols for testing low-temperature water electrolysis was eventually finalised and published [51]. This followed the resolution of several expert comments and, consequently, an extensive revision of the structure and layout of the report to improve user guidance and comprehension of the various aspects of low-temperature water electrolysis testing.

The Joint Research Centre's contribution to programme monitoring and assessment

In collaboration with the knowledge management team of the JU, the JRC has populated and revised the TIM system with customised FCH technology fields.

The JRC performed the 2020/21 annual programme review. As the timeline of the programme review was brought forward, in order to have the public version of the report ready for the programme review days, the 2020 and 2021 reports were merged. The resulting report was used to prepare the public version, which can be accessed on the website of the JU.

The Joint Research Centre's contribution to sustainability

The JRC was invited to the meetings of the SH2E project's working party 3 to discuss the implementation of a material criticality indicator. That has enabled it to provide feedback and suggestions for the ongoing methodological work.

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[48] https://publications.jrc.ec.europa.eu/repository/handle/JRC123219
[49] https://data.mendeley.com/datasets/c7bffdv7yb/1
[50] https://data.europa.eu/doi/10.2760/293538
[51] https://data.europa.eu/doi/10.2760/502481

In the meantime, the JRC started reviewing the existing scientific publications on LCA and social LCA applied to hydrogen and FC technologies.

The JRC has been invited by the CertifHy consortium to provide a scientific support on the greenhouse gas (GHG) emissions accounted for by hydrogen produced in the various sectors. The aim was to assess, by means of a comprehensive, internationally accepted methodology, the carbon footprint of hydrogen produced as a main product or by-product. The JRC's discussions with project partners focused on the available LCA methodologies and their assumptions as regards system boundaries, allocation criteria and input data. In 2021, members of JRC.C.2 and JRC.C.1 attended several WG2 meetings as observers, and helped the CertifHy consortium to assess various methodologies for allocating emissions from hydrogen production in different case studies.

The Joint Research Centre's contribution to safety and safety awareness

The JRC operates two databases dedicated to hydrogen-related incidents: Hydrogen Events and Lessons Learned, and HIAD 2.0.

Hydrogen Events and Lessons Learned is a repository of events occurring during the lives of JU projects. Access to it is restricted. It is a JU tool for the monitoring and control of safety during the execution of the programme. The JRC collects and analysed all reported incidents and informs the PO through the annual report.

HIAD 2.0 is used for collecting publicly available information about safety-related events regarding hydrogen technologies, supply chain and applications. The 2021 activities continued along the same lines as the work delivered in 2020:

- identification of new hydrogen-related events and input into the database,
- continuous improvement of already existing data,
- relations with stakeholders and sharing of the data.

Approximately 30 new events were added to HIAD 2.0 in 2021. Since the beginning of 2021, HIAD 2.0 is no longer accessible online. This is due to new Commission security rules, which make it very complex and expensive to make an online service completely accessible to the public. The JRC has created a database batch export function, which creates Excel files for offline analyses. This has become a great success. It has helped the EHSP's assessment work, and users can gain access to the function upon request. It facilitates statistics and enables full textual searches, something impossible in the previous online version.

1.2.6. Support to joint undertaking policies and funding / financial engineering

Policy support and feedback

Throughout its mandate, the JU has contributed to a large number of diverse activities for multiple European Commission services (and accordingly provided the necessary feedback for further policy development). Although contributions have varied in content and format, they all share the common goal of providing fact-based information on the SoA of hydrogen technologies and their contribution to EU initiatives and policies, especially in the energy, transport and industry sectors, to competitiveness and growth, and to environmental policy.

In practical terms, the JU's support to policies meant taking part in a number of technical groups organised by the European Commission and other international bodies, taking an active role during the meetings, providing written technical input, organising events, and ensuring that hydrogen technologies are properly represented in the relevant sectors and in the files of policymakers.

As in previous years, supporting the Directorates-General (DGs) for Energy, Research and Innovation, Mobility and Transport, and Climate Action, the JU continued to actively follow and contribute to the European Strategic Energy Technology Plan activities during 2021, Action 6 'Energy efficiency for industry' and Action 8 'Renewable fuels and bioenergy'. In 2021, work for the implementation WG for Action 6 was facilitated by the consultancy Ecorys and focused on establishing a structure around thematic groups. A cross-cutting thematic group on enablers was set up, covering hydrogen, renewables and CO_2, and may be expanded to ammonia and energy storage. This group is currently engaging with Member States and industry. Action 8 work is being facilitated by the SET4BIO [52] project and is focused on synergies among the various WGs. The JU is included in the core group of the action.

The JU also continued to work on developing a GO scheme for green and low-carbon hydrogen, an effort that started back in 2014 with the first CertifHy project [53]. A procurement procedure was launched in 2020 and a framework contract signed in order to pursue the following key objectives:

- support further the establishment of an independent and self-sustainable community that will deal with all hydrogen certification issues (GOs and target compliance);
- support and accelerate the establishment of harmonised and mutually recognised GO schemes for renewable and non-renewable hydrogen across Member States while ensuring compliance with Article 19 of the revised renewable energy directive;
- design a hydrogen certification system that is able to demonstrate compliance with revised renewable energy directive targets for the share of renewables following the specific requirements that are applicable in each case;
- engage in communication and outreach activities with hydrogen consumers, traders and policymakers with the aim of increasing the use of GOs, thereby adding to their market value.

In 2021, the ongoing procurement continued this work in what can be considered the third phase of CertifHy. During this third phase, CertifHy has become an observing member of the Association of Issuing Bodies, effectively working towards the harmonisation of the hydrogen GO market in Europe by working directly with future issuing bodies. One of the most important highlights from the work of CertifHy in 2021 is the decision of Vertogas, which was appointed as the hydrogen GO issuing body in the Netherlands, to adopt the CertifHy scheme for renewable and low-carbon hydrogen regarding renewability and GHG footprint methodology. Harmonised calculation of GHG emissions is especially important to avoid any market distortion. In the absence of any well-established international standard for GHG footprint assessment, CertifHy has provided guidance through its work with the CertifHy stakeholder platform.

CertifHy has laid the foundation for the development of a future EU voluntary scheme recognised by the European Commission to provide 'renewable fuels of non-biological origins' certificates to hydrogen producers and fuel suppliers, working towards the target of 14 % renewable fuels by 2030 set by the revised renewable energy directive. In practice, CertifHy has developed an architecture to accommodate the complex framework for hydrogen certification, considering not only the above certificates but also GOs and the future Union database [54].

During the second half of 2021, the tender 'Study on impact of deployment of battery electric vehicles (BEV) and fuel cells electric vehicles (FCEV) infrastructure' was awarded to the consultancy McKinsey. The purpose of the tender is to produce a comprehensive study to describe the possible optimal blend of infrastructure for FCH mobility and BEVs. The implementation of the study is meant to conclude at the end of March 2022. Representatives of the industry as well as of the European Commission are involved in the steering group, ensuring that all relevant stakeholders can contribute and that policy recommendations emerging from the study are taken on board by policymakers.

In the maritime sector, the absence of RCS for hydrogen as a maritime fuel has been the focus of regular exchanges and meetings between the JU, the DGs for Research and Innovation and for Mobility and Transport, the European Maritime Safety Agency, the JRC, the European Zero Emission Water Transport Partnership and CEN/CENELEC. Of particular importance are the contributions from the projects MARANDA [55], FLAGSHIPS [56] and e-SHyIPS [57] on their work on RCS and gaps analysis for the IGF Code correspondence group of the International Maritime Organization (IMO) (through the European Commission). In 2021, the IMO Sub-Committee on Carriage of Cargoes and Containers endorsed draft interim guidelines for ships using FCs, and it will develop guidelines for the safety of ships using hydrogen as a fuel. The contribution of the projects above will help this second stream of work from the IMO.

The JU's support to European Commission policymakers goes beyond energy and transport. During 2021, it continued working closely with DG Energy and other DGs. Building on this good collaboration with various European Commission services, it provided extensive evidence-based policy

[52] https://www.etipbioenergy.eu/set4bio
[53] https://www.certifhy.eu/
[54] According to the RED II Implementing Rules for voluntary schemes.
[55] https://www.clean-hydrogen.europa.eu/projects-repository/maranda_en
[56] https://www.clean-hydrogen.europa.eu/projects-repository/flagships_en
[57] https://www.clean-hydrogen.europa.eu/projects-repository/e-shyips_en

input that was incorporated in various ways into new European Commission communications, namely 'Fit for 55' [58], the gas decarbonisation package [59] and other subsidiary measures [60].

During 2021, the JU continued exchanges with DG International Partnerships and the EU Global Technical Assistance Facility for Sustainable Energy [61] to explore potential synergies in Africa [62] and in Chile, including through the Team Europe initiative.

Moreover, in 2021, the JU provided regular updates on its activities related to RCS and PNR to the DGs for Research and Innovation, for Energy, and for Internal Market, Industry, Entrepreneurship and SMEs [small and medium-sized enterprises], as well as updates on the situation with respect to FCH standardisation at European and international levels. Furthermore, the JU has provided DG Research and Innovation with information on areas for PNR on hydrogen safety in the maritime sector, has provided DG Internal Market, Industry, Entrepreneurship and SMEs with inputs on strategic supply chain vulnerabilities of hydrogen production and FCs, has provided the JRC with information on the JU activities related to LCA with a view to strengthening the links between projects and the JRC activities in this field and supporting European Commission activities, and has provided DG Research and Innovation with updates concerning the JU´s latest activities on RCS and safety for reporting to the IPHE (IPHE country updates).

Collaborations with other agencies and joint undertakings

The JU has continued exchanges that include executive agencies managing other parts of H2020 and Horizon Europe in areas relevant to hydrogen technologies. For example, in the transport sector, it continues to work with the European Climate, Environment and Infrastructure Executive Agency on activities related to FC buses, maritime fuels and HRS. In 2021, in order to support and accelerate the wide roll-out of hydrogen mobility options in 2022, they worked together on the preparation of support to be provided by two ambitious flagship projects, one on trucks and one on vessels [63]. For the refuelling infrastructure in these two projects, synergies with the Connecting Europe Facility for Transport programme are also expected. Similarly, collaboration is ongoing in the energy sector. A number of hydrogen-related European Climate, Environment and Infrastructure Executive Agency projects presented their progress in the 2021 edition of the JU programme review days (during the European Hydrogen Week in December 2021).

The JU has also remained proactive in taking up opportunities for collaboration with other partnerships, EU agencies, initiatives and actions with the potential for synergy with its research agenda. In particular, the JU cooperated closely with other partnerships in an effort to align their work programmes and identify synergies. When possible, they developed common roadmaps, aiming to better coordinate the planned activities of each partnership in the context of R&I in hydrogen technologies. This common planning should prevent overlaps, enable synergies and lead to a more effective allocation of funds towards hydrogen technologies in the context of the Horizon Europe programme [64]. In addition, the JU has continued exchanges with the European Defence Agency on transport and energy. This has consisted in raising awareness among the defence

[58] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*, COM(2021) 550 final, European Commission, Brussels, 14 July 2021 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=EN).

[59] On 15 December 2021, the Commission adopted legislative proposals to decarbonise the EU gas market by facilitating the uptake of renewable and low-carbon gases, including hydrogen, and to ensure energy security for all citizens in Europe (https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6682).

[60] Including State aid for environmental protection and energy – revised guidelines (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12616-State-aid-for-environmental-protection-and-energy-revised-guidelines_en); Reducing carbon emissions – review of emission standards for heavy-duty vehicles (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13168-Reducing-carbon-emissions-review-of-emission-standards-for-heavy-duty-vehicles_en); and the TEN-E regulation on new rules for cross-border energy projects (https://www.consilium.europa.eu/en/press/press-releases/2021/12/22/ten-e-council-and-parliament-reach-provisional-agreement-on-new-rules-for-cross-border-energy-projects).

[61] https://ec.europa.eu/international-partnerships/projects/eu-global-technical-assistance-facility-sustainable-energy-eu-gtaf_ro

[62] To foster cooperation with Africa, it was agreed that the Clean Hydrogen JU would support a topic in its 2022 call aiming to create enabling conditions for the development of renewable hydrogen technology and a renewable hydrogen market that would contribute to the social, economic and environmental transition of the African continent.

[63] The first one will lead to the deployment a minimum of 150 heavy-duty vehicles (trucks) across along the Trans-European Transport Network corridors. It calls for at least three original equipment manufacturers and six operators to engage in this action. For waterborne applications, the focus is on inland waterway vessels. Support will be provided for the deployment of a first of its kind sizeable fleet of at least five inland vessels with fuel power > 500 kW and preferably at 1-MW scale.

[64] More details on the common roadmaps can be found in Annex 7 to the Clean Hydrogen JU SRIA.

community and directing its attention to the potential role of hydrogen technologies in the defence sector. The JU has also created bridges between the defence sector and the FCH industry and research community by bringing all the players together.

Working with regions

As part of the FCH-Regions initiative ([65]), the JU study on *Fuel cells and hydrogen for green energy in European cities and regions*, published in 2018, identified project implementation intentions in excess of EUR 1.8 billion over a 5-year period. Since then, the JU has been working closely with regions to realise this potential.

Since then, the JU has facilitated the creation of a growing European Hydrogen Valleys Partnership ([66]) working across the hydrogen value chain and aiming to enhance the role of green hydrogen in the European energy transition process. In 2021, the JU continued to collaborate with this partnership's activities.

In 2021, the **FCH-Regions' Hub** ([67]) was further updated, to keep on helping regional and local authorities to develop their concepts for regional hydrogen projects and turn them into detailed work plans. The hub centralises the relevant information gathered within the projects, studies and initiatives of the JU. It also offers links to specific external sources and complementary initiatives capable of helping authorities to deploy regional FCH plans and projects.

Project development assistance for regions

In addition, in 2019, the JU launched a pilot **project development assistance** (PDA) ([68]) facility to help develop detailed project planning in regions and cities with a lower maturity level, with a special focus on central and eastern Europe. The final report covering the results of this initiative was presented in a webinar on 19 October 2021 ([69]), with the participation of some of the regions involved and representatives from the European Commission and the European Investment Bank. The PDA initiative supported 11 selected regions to develop detailed work plans for the implementation of hydrogen projects. It concluded in June 2021. The report contains summaries of the project plans and work undertaken in each of the selected regions, the activities delivered as part of the observer network, and the next steps after the end of the PDA support period. The pilot PDA for hydrogen in regions sets the path for further such initiatives, possibly targeting regions that are not yet involved in the development of hydrogen projects and could make use of the encompassing advantages of hydrogen as a green energy carrier to ensure local, sustainable and integrated energy solutions. Its follow-up PDA was provided for in the 2022 AWP, with a clear focus on countries targeted by the Cohesion Fund, outermost regions and islands. The tender was published in December and the award is expected in Q1 2022.

Hydrogen valleys and ecosystems

Building on projects developed since the 2015 AWP, the hydrogen valley concept has gained traction among our community. Projects such as BIG HIT ([70]) (2015 call), HEAVENN ([71]) (2019 call) and Green Hysland ([72]) (2020 call) have become flagships of this concept. Hydrogen valleys are another success of the JU policy feedback, with the European Commission backing support for such projects until the hydrogen market becomes fully regulated in 2030 (see for example the gas decarbonisation package published in December and mentioned under the section on 'Policy support and feedback' above).

In 2021, the JU released the **Hydrogen Valley Platform** ([73]) under the umbrella of Mission Innovation's 'Renewable and clean hydrogen' innovation challenge. The platform was launched publicly on 19 January 2021 ([74]), gathering more than 1 000 participants from across the world. The platform presents the existing regional clusters and connects them with 36 hydrogen valleys from over 18 countries already featured. It is aimed primarily at project developers but is also raising awareness among policymakers and is intended to inspire others willing to replicate similar projects. The contract ended in May 2021 but a new tender has been launched (December 2021) to give continuity to it and contribute to the European Commission's role

([65]) See the web page for more information (https://www.fch.europa.eu/page/fch-regions-hub).
([66]) https://s3platform.jrc.ec.europa.eu/hydrogen-valleys
([67]) https://www.fch.europa.eu/page/fch-regions-hub
([68]) https://www.fch.europa.eu/news/project-development-assistance-kicks-selected-regions
([69]) https://www.clean-hydrogen.europa.eu/media/news/project-development-assistance-cities-and-regions-summary-report-now-available-2021-10-19_en
([70]) https://www.bighit.eu
([71]) https://www.fch.europa.eu/page/energy#HEAVENN
([72]) https://www.fch.europa.eu/page/energy#GREEN%20HYSLAND
([73]) https://www.h2v.eu
([74]) https://www.fch.europa.eu/page/mission-innovation-hydrogen-valleys-platform

under the renewed Mission Innovation 2.0 [75] and, more specifically, to its leadership of the second pillar: hydrogen valleys. The platform will be further updated, developed and enhanced to become a dynamic and interactive platform, contributing decisively to the clean hydrogen mission objectives of reaching at least 100 hydrogen valleys by 2030 and at least 3 per member of Mission Innovation.

Synergies, funding and financial engineering

Despite the COVID-19 disruptions in face-to-face events and meetings, which are essential for establishing trust between partners, in 2021 the JU's activity on funding and financial engineering did not lose momentum. While the development of the EU strategy and policy framework gave further clarity and business certainty to investors and financiers alike, the various stimulus packages brought forward during the year, including the Innovation Fund, the Recovery and Resilience Facility and the Just Transition Fund, boosted activity in project development in Europe. The introduction of technologies stemming from the JU projects on to the market and the acceleration of their deployment are helping to further establish the JU as a partner providing advice and support to prospective or past beneficiaries of JU projects. The goal is to help large project ideas combine funding from various programmes, and optimise structured finance operations.

Furthermore, raising awareness among the banking and investor community has become a regular JU activity. This has taken place in various formats, namely in dedicated meetings and brainstorming with bank / investor / project developer teams in specific virtual presentations around the state of play of hydrogen-related activities and studies promoted by the JU.

Strong cooperation is key to deal with bigger, yet fragmented, EU funds to meet the EU's Green Deal ambition. New challenges emerge when hydrogen projects evolve and grow from research, development and innovation to large demonstrations and full market deployment. An important element supporting the implementation of the European hydrogen strategy is the reinforcement of synergies among European funding instruments and actions to close the innovation gap in Europe. Synergies are needed to pull together resources, align priorities and ultimately maximise the impact of clean hydrogen R&I investments. In view of the prominent role that synergies play in the 2021–2027 multiannual financial framework, 2021 was the year in which the seeds for effective cooperation between different EU funds gained decisive momentum. In preparation for the 2022 call and the SRIA of the Clean Hydrogen JU, discussions were held with all members of the JU – the European Commission, Hydrogen Europe and Hydrogen Europe Research – but also with other European partnerships that will use clean hydrogen as an enabler of the decarbonisation of their specific sectors, and even with Member States and regions. Building on the mandate provided in the Single Basic Act, the SRIA [76] that was adopted on 25 February 2022 properly frames these activities (see SRIA Section 4.1. Interface with EU policies and other programmes (Synergies)). A toolbox to generate funding synergies was identified and cooperation mechanisms to deliver synergies between different stakeholders were established, using the advisory bodies of the newly created Clean Hydrogen JU among other resources (see Section 3.3 'States Representatives Group' and Section 3.6 'Preparation of Stakeholders Group' below for more detail on the advisory bodies of the JU).

1.2.7. International cooperation

Given the importance of international cooperation in science and technology, explicitly recognised in the EU's Innovation Union flagship initiative [77] and the H2020 programme, and described in the communication 'Enhancing and focusing EU international cooperation in research and innovation: a strategic approach' [78], the JU has continued to be active at international level in order to align with, facilitate and accelerate the worldwide market introduction of FCH technologies.

As the deployment of FCH technology is carried out globally and key partners of the JU are involved in these developments, the JU has continued to develop links with the major deployment programmes globally, mainly through the IPHE but also through Mission Innovation's innovation challenge 8 'Renewable and clean hydrogen' [79] to harmonise standards and regulations and to accelerate market preparation.

[75] Mission Innovation 2.0 was launched on 2 June 2021, catalysing a decade of action and investment in research, development and demonstration to make clean energy affordable, attractive and accessible for all (http://mission-innovation.net/missions/hydrogen).

[76] https://www.clean-hydrogen.europa.eu/media/news/research-and-innovation-priorities-clean-hydrogen-2022-02-28_en

[77] https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/innovation-union_en

[78] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0497&from=en

[79] http://mission-innovation.net/our-work/innovation-challenges/renewable-and-clean-hydrogen/

In this respect, the JU continued its straight collaboration with European Commission representatives on Mission Innovation's clean hydrogen mission and, during 2021, developed a hydrogen valley platform under the umbrella of innovation challenge. As mentioned in 'Hydrogen valleys and ecosystems' above, the platform was publicly launched on 19 January 2021 [80] and gathered more than 1 000 participants from across the world. It presents and connects the existing regional clusters, with 36 hydrogen valleys from over 18 countries already featured. It is aimed primarily at project developers but is also raising awareness among policymakers and is intended to inspire others willing to replicate similar projects. A new contract to further develop the successful hydrogen valley platform is to be awarded in the first half of 2022.

In support of the JRC, the JU continued to contribute to the activities of the International Energy Agency's Hydrogen Technology Collaboration Programme executive committee to optimise and share the effort. In particular, it completed its contribution to the tasks related to power-to-X (task 38) and maritime applications (task 39), while it continued its contribution to data and modelling [81] (task 41). Moreover it agreed to support JRC in the WGs on renewable hydrogen, hydrogen underground storage and hydrogen export value chains.

1.3. Calls for proposals and grant information

In the 2020 AAR, one grant agreement (GA) was indicated as ongoing from 2020 call for proposals, because it requested an extension of the time to grant deadline, on account of exceptional circumstances:

- 101007108 – MegaSyn: the GA was signed on 2 March 2021.

Moreover, budget became available in addition to the **leftover call budget** (see 2020 AWP Section 3.3 'Call management rules – budget flexibility'). Therefore, two proposals from the reserve lists have been promoted to the main list. Thus, two additional GAs from the 2020 call were signed in 2021:

- 101006632 – HyUsPRe: the GA was signed on 7 July 2021;
- 101007170 – MORELife: the GA was signed on 17 July 2021.

1.3.1. Progress against key performance indicators / statistics (Annexes 5, 6 and 7)

Not applicable, as there had been no call for proposals in 2021.

1.3.2. Evaluation: procedures and global evaluation outcome, redress, statistics (number of evaluators, gender, area, etc.)

Not applicable, as there had been no call for proposals in 2021.

[80] https://www.fch.europa.eu/page/mission-innovation-hydrogen-valleys-platform

[81] The JU hosted a task 41 (data and modelling) definition meeting on 29 August 2019 in Brussels. Topics of discussion included how to model hydrogen in the value chain and improve current methods, experiences from other tasks, and data consolidation of parameters describing hydrogen technologies.

1.4. Calls for tender

On the basis of the 2021 AWP, the FCH 2 JU and, as of 30 November 2021, the Clean Hydrogen JU, launched the following new operational procurements in 2021.

1. Study on hydrogen in ports and industrial coastal areas

The aim of the study is twofold: foresight and community building. On foresight, the study will take into consideration the fact that the ports and the industrial coastal areas need to have a medium- and long-term view of the market potential of hydrogen, and a clear roadmap to implement it. It will build community among 'hydrogen ports' by addressing common issues at European level for collaborative resolution, and developing case studies that can act as blueprints for other ports and thus accelerate the uptake of financial assistance by ports and industrial coastal areas.

The contract for the implementation of the services was signed on 13 November 2021 for a period of 24 months and a budget of EUR 518 000.00. It included, among other requirements, the provision of a final publishable report at the end of the contract.

2. PDA for countries targeted by the Cohesion Fund, outermost regions and islands

There are four general objectives in this procurement. (i) It aims to further widen the Clean Hydrogen JU's geographical coverage by selecting a set of at least 15 projects from Cohesion Fund, outermost regions and islands in general, bringing new hydrogen flagships to a high level of preparedness. (ii) It aims to provide regions and cities with the necessary technical, financial and legal services. (iii) It aims to further develop the existing interregional, inter-island and cross-city networks in which both the selected regions and cities and their observer network could benefit from tools, methods and expertise gathered in both the first and the current PDA. This objective should be accomplished by helping foster collaborations from interested public authorities with a view to indirectly assisting otherwise less mature projects and therefore enhancing their chances of becoming reality in the future. (iv) It aims to boost the chances of grant funding and financing support by raising awareness among the relevant regional and national managing authorities of the European Structural and Investment Funds as well as any promotional bank or specifically tailored commercial bank willing to increase its exposure to hydrogen projects with a local impact.

The call for tenders was published in December 2021 and is currently ([82]) under evaluation. The maximum value of the contract is EUR 1 million.

In view of the request from the discharge authority([83]), the JU includes in the present report the fact that the launch of the study in question is accompanied by a detailed internal and external market research, whose aim was to find the most accurate market price for the contract.

3. Technical assistance support to generate synergies with Member States / Regions

Although the drafting of tender specifications for the study was initiated immediately after the financing decision was in place, the scope of synergies evolved significantly throughout 2021 until the approval of the SRIA of the new JU. This led to an unavoidable delay in the approval of the technical specifications of this procurement. Consequently it is expected to be published in the first half of 2022.

4. Procurement of services in 'Support to Mission Innovation 2.0 – Clean Hydrogen Mission H2.0 Valley Platform'

Based on (i) a lean and effective cooperation between the FCH 2 JU and the Mission Innovation co-leads to co-design and steer the previous procurement (the steering committee) and (ii) the lessons learned during the first 2 years of operation of the Hydrogen Valley Platform (phase 1), the FCH 2 JU (now the Clean Hydrogen JU) launched a new procurement to take the hydrogen valley concept to the next level and develop the H2.0 Valley platform. H2.0 Valley will serve as a tool to help project developers and to promote the concept among policymakers and private stakeholders.

The call for tenders was published in December 2021 and is currently ([84]) under evaluation. The maximum value of the contract will be EUR 500 000.00.

([82]) March 2022.
([83]) Draft Report 2021/2153(DEC) available at: https://www.europarl.europa.eu/doceo/document/CONT-PR-698996_EN.pdf
([84]) March 2022.

In view of the request from the discharge authority[85], the JU includes in the present report the fact that the launch of the study in question is accompanied by a detailed internal and external market research, whose aim was to find the most accurate market price for the contract.

5. Public opinion survey

The public survey to be conducted under this contract is to provide a rapid assessment of the state of public opinion EU-wide, and contribute to the development of a baseline (benchmark). In terms of geographic scope, the survey is to cover all Member States of the EU. One main objective of the public survey is to gain insights into perceptions of the use of FCH technologies relating to a number of aspects: overall awareness, acceptance and uptake of hydrogen technologies; awareness and acceptance relating to the safety of hydrogen technologies; awareness and acceptance of hydrogen as an efficient and sustainable energy vector; and uptake of possible applications of hydrogen technologies. The others are to understand the state of awareness and acceptance of FCH technologies on the part of the public and identify differences relating to a set of specific criteria (e.g. age, gender, nationality, regions); to draw up a benchmark (baseline) that will make it possible to monitor changing perceptions in the European population; and to evaluate the results obtained and provide strategic advice derived from them, with a focus on possible communication activities, on how to raise awareness of and build confidence in further use of FCH technologies among the general public.

The call for tenders was published in July 2021. The contract for the implementation of the services was signed in March 2022 for a period of 11 months and a budget of EUR 385 000.00.

The procurement was added to the work programme of the JU through the GB decision of 31 May 2021, adopting the second amendment of the 2021 AWP.

In view of the request from the discharge authority [86], the JU includes in the present report the fact that the launch of the study in question is accompanied by a detailed internal and external market research, whose aim was to find the most accurate market price for the contract.

6. Study on the impact of deployment BEV and FCEV infrastructures

The objective of this tender is to provide evidence, through a comprehensive study, of the possible optimal blend of electric recharging and hydrogen refuelling infrastructure, covering the full spectrum of road transport applications. The study should make it possible to assess, both by Member State and at European level, the best way to deploy these infrastructures, their synergies and interactions with other existing ones.

In 2020, due to reasons external to the JU, as reported in the corresponding AAR, the study was transferred to the public procurements in 2021 from the AWP 2020.

The contract for the implementation of the services was signed on 1 September 2021 for a period of 8 months and a budget of EUR 200,000.00. Final results are expected by the end of May 2022.

[85] Draft Report 2021/2153(DEC) available at: https://www.europarl.europa.eu/doceo/document/CONT-PR-698996_EN.pdf

[86] Draft Report 2021/2153(DEC) available at: https://www.europarl.europa.eu/doceo/document/CONT-PR-698996_EN.pdf

1.5. Dissemination and information about project results

Closely aligned with the knowledge management objectives, the monitoring of the dissemination and exploitation (D&D) activities of JU projects continued during 2021, as well as following closely the European Commission's activities in preparation for the post-H2020 period and Horizon Europe. The JU will continue to support efforts in the same direction.

Internal dissemination and exploitation guide: In H2020, the JU strongly and actively supported the initiatives of the European Commission to reinforce the D&E of the results of the projects. However, during an audit performed in 2020 to assess the adequacy of the design and the efficiency and effectiveness of the internal control system in place in the JU for the implementation of grant agreements under the H2020 programme, the Internal Audit Service (IAS) made a recommendation concerning the monitoring of project dissemination, exploitation and communications. The action plan included verification steps for the POs to follow up the submission during the periodic assessment of an updated D&E plan, assessing its quality and adequacy, and the peer-reviewed publications and communication material by project partners to fulfil the requirements set out in the grant agreement. In addition, the JU should include instructions for the project coordinators to emphasise D&E during the kick-off meetings and, finally, share its general observations and recommendations concerning the implementation of the D&E plans with the director of the Common Implementation Centre (CIC).

As part of the action plan, in June 2021 the JU sent a letter to the CIC to ask for guidance on monitoring the implementation of the D&E plans, during the projects and after they end. The CIC replied focusing on the European Commission's ecosystem of tools and services provided to support the projects (Horizon Results Booster (HRB), Horizon Results Platform (HRP) etc.) and additional tools to be developed by the D&E Group for the monitoring of D&E after the end of the projects under Horizon Europe.

Moreover, the JU has developed an internal D&E guide for the project officers and the officials of the Operations and Communications Unit to serve as a flexible guidance framework to monitor D&E obligations under H2020 and Horizon Europe. As an integral part of the action plan, this guide outlines the good D&E-monitoring practices that are already implemented for the projects during and beyond their lifetime and what additional steps are planned to enhance the monitoring of the D&E at project level under H2020 in a concrete, structured manner. A list of consecutive steps to follow is provided, followed by detailed guidelines for each step, which extends from the call for proposals and the model grant agreement [87] provisions to 4 years after the end of the project. This project-level approach is being complemented by a thorough mapping of overarching activities that the JU currently performs to support the D&E function at programme level. A training session focused on the new guidance and the implementation of the steps for the POs will take place in 2022.

New activity for ended projects: One of the main issues regarding project implementation remains the continuation of the D&E activities of the project beneficiaries after the end of the funding period and the last payment. According to Article 28(1) of the H2020 model grant agreement, beneficiaries have to take measures aiming to ensure 'exploitation' of its results up to 4 years after the end of a project.

The new internal D&E guide came into force in November 2021 when specific correspondence was sent through COMPASS (EC internal workflow tool linking business applications (such as SEP, SyGMa, EMI/ECS, PDM, etc) and validation workflows) to seven projects whose funding had concluded approximately 18 months before (in the first half of 2020). It is a means to collect information on the D&E activities of the projects after the final payment and to motivate them to proceed with the exploitation of their results using all the available European Commission tools and services (such as the HRP and HRB). This activity is expected to be performed at least twice a year to comply with the provisions of the internal D&E guide.

Horizon groups: Under the new D&E strategy [88] for Horizon Europe, a revamped and streamlined governance system (replacing the former D&E network configuration and its six WGs) for the implementation of the D&E policy during 2021–2027 was established and implemented during 2021. The governance structure consists of the following coordination groups:

- the Horizon D&E Group
- the Horizon Feedback to Policy Group.

[87] https://ec.europa.eu/research/participants/data/ref/h2020/other/mga/jtis/h2020-mga-fch_en.pdf

[88] https://op.europa.eu/en/publication-detail/-/publication/947ac741-b94c-11ec-b6f4-01aa75ed71a1/language-en/format-PDF/source-254851831

For each of the groups, four meetings a year are scheduled. However, in 2021 only two meetings of each group were held. The JU has appointed representatives for each group, following their activities closely, while contributing to the periodical meetings.

Following the preparations to establish an integrated D&E ecosystem of tools and services for Horizon Europe, and based on the work done by the former WGs, the kick-off meeting of the D&E Group was held in July 2021 to discuss the progress report on 2020–2021 and the D&E action plan for 2021-2022. The second meeting took place in October 2021 to discuss the state of play of the action plan, and the best existing or planned D&E practices of the implementing bodies, focusing especially on monitoring the D&E activities of the projects after the end of the funding period.

The Feedback to Policy Group's kick-off meeting was held in July 2021, and the second in October 2021. The key issues were related to the implementation of the new feedback-to-policy framework. The main steps of the action plan consist of setting up the joint team at the level of cluster 5, defining the feedback-to-policy plans within the cluster, gradually developing of an ecosystem of tools to support the team, and training and activities to enable cultural change in the institutions and implementing bodies.

Horizon Results Platform ([89]): The HRP is a D&E tool launched by DG Research and Innovation in 2019, a dedicated platform for projects to present their results to targeted audiences (e.g. business partners, angel investors, venture capitalists, policymakers or business development assistance organisations) and help the projects' beneficiaries establish fruitful partnerships. By the end of 2021, 25 project results in total had been uploaded to the platform. All JU projects have been encouraged to make use of this new tool and its benefits, and encouraged to upload their results.

Horizon Results Booster: The European Commission's Horizon Results (Dissemination and Exploitation) Booster, an initiative based on the successful paradigm of the completed Support Services for Exploitation of Research Results, was launched in 2019. The HRB services are available not only for ongoing projects; completed projects can also apply to reinforce their efforts. So far, eight projects have applied or already benefited from these services. D&E of project results start even before signature of the grant agreement, during its preparation, and are closely monitored throughout its duration.

Innovation Radar (IR): This platform collects high-potential innovations and the key innovators in H2020 projects. Usually, during the project mid-term reviews, a dedicated expert is mandated to identify potential innovations and to fill out a questionnaire with the aim of providing information about them in a structured manner. With the help of the questionnaire, the IR expert provides concrete recommendations on the innovation aspects of the project and for individual innovator organisations within the consortium. The purpose of the IR exercise is not only to identify promising entities with the potential to grow, but also to stimulate and propel them to 'make it happen' faster and more efficiently. The IR exercise was linked mainly to the mid-term review exercise; when applicable, these recommendations were also integrated into the formal review report. However, in June 2021 the IR exercise was incorporated into the workflow of project monitoring, enabling the projects to proceed with submitting questionnaires across the whole lifetime of the project, regardless of the project-monitoring milestones (even without using an expert), or updating previously analysed innovations if needed.

The JU projects have participated in the IR since its pilot in 2018. So far, innovations of 59 JU projects in total has been analysed: a total of 153 innovations (more than half of which are considered 'very innovative' or 'obviously innovative and easily appreciated advantages to customer'), attributed to 273 innovators, have been identified and uploaded to the platform (Figure 1.21). In 2021, 24 participants in five JU projects submitted 10 additional innovations, which have been analysed and included on the platform.

([89]) https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform

Figure 1.21: Total number of innovations analysed and presented in IR and the innovators related to the JU projects.

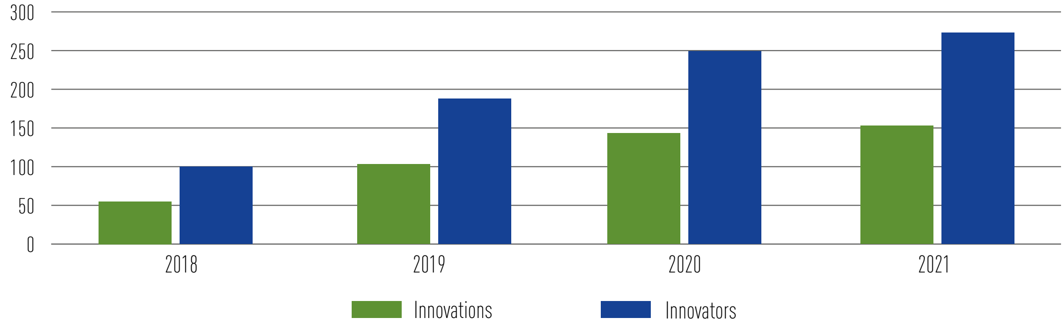
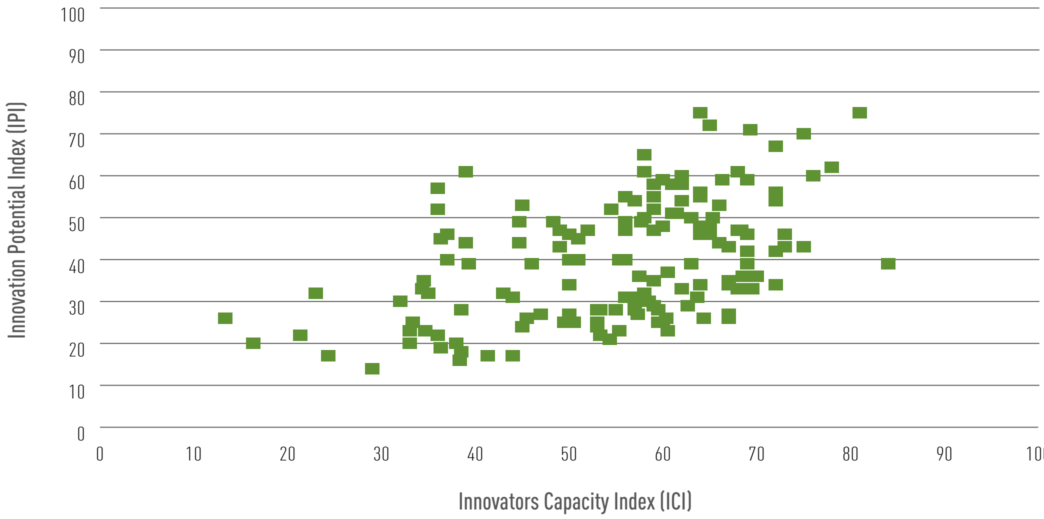
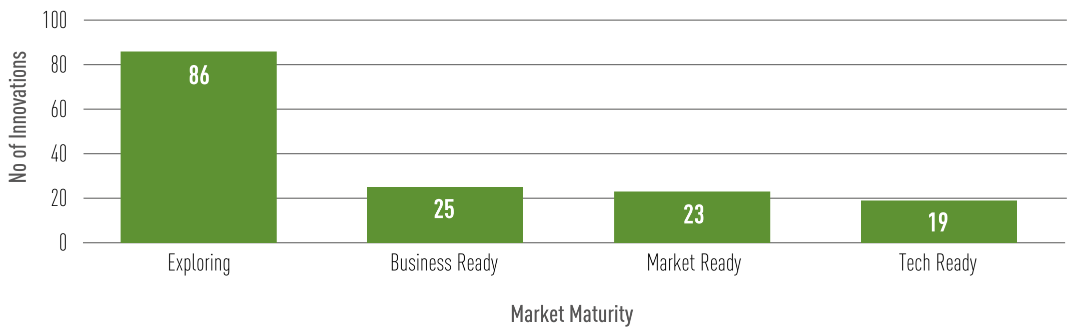


Figure 1.22: Ranking of the different innovations based on their innovator capacity scores and innovation potential indices



These innovations are displayed based on the IR methodology, categorised as 'exploring', 'business ready', 'market ready' and 'tech ready' (Figure 1.23). This classification is meant to span the path between the most basic TRLs of 'exploration' to the most advanced and closest to the market, further research or standardisation activities. Another very positive result has been the identification of at least 42 innovations that scored above 50 points in the Innovation Potential Index, making them ideal first candidates for follow-up actions for exploitation proposals.

Figure 1.23: Clustering of innovations based on maturity level, up to 2020



Since the pilot launch of the IR, the JU has collected valuable feedback to communicate to the European Commission (e.g. DG Research and Innovation, DG Communications Networks, Content and Technology) and has participated in the IR R&I meetings to support further improvement of the IR and explore how the information collected can be further utilised by other European Commission services that support the commercial exploitation of research results (HRB, HRP etc.) ([90]). The PO monitors any project activity within these initiatives to guide them and provide dedicated assistance to enable dissemination and, finally, utilisation of the key exploitable results (KERs).

D&E activities of the projects: During the last two days of the second European Hydrogen Week, the PO organised the 2021 programme review days (2–3 December 2021). The event is based on the annual data collection exercise organised every year to collect updated information and technological data about the projects that were ongoing during the reference period (2020). Alongside the TRUST platform to collect descriptive and operational data from the activities of the projects, the other pillar of the exercise is the EU survey questionnaire that the projects submit to provide other types of information that cannot be captured otherwise. Its purpose is to gather the necessary input to support the in-depth assessment of the progress realised by the FCH 2 JU (and Clean Hydrogen JU) programme, identify its successes and form recommendations for improvement.

According to the data provided by 85 active projects in 2020, regarding the D&E activities and the KERs:

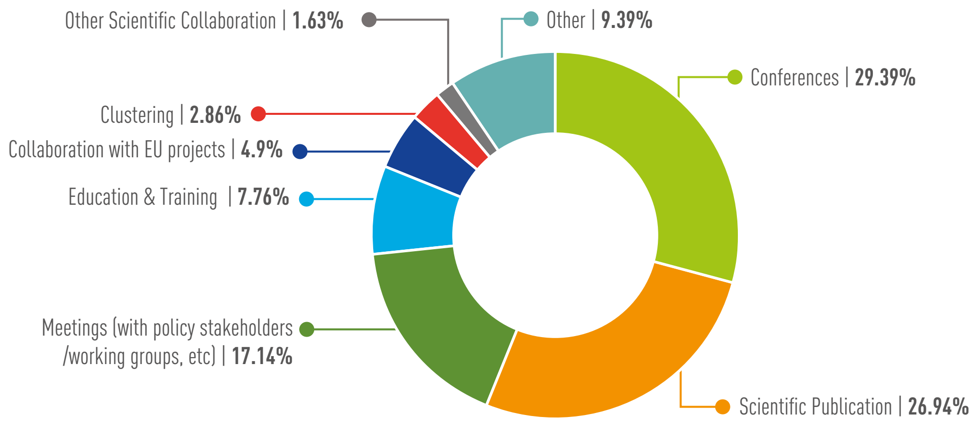
- 64 projects reported 245 dissemination activities in total;
- 43 projects reported 105 results in total;
- 33 projects reported 73 KERs in total.

Dissemination activities during 2020 appeared relatively less than in 2019. Although the portfolio of projects changes every year, as some projects are concluded whereas others start during the reference period, the dissemination activities are roughly estimated to have reduced by 35 %, probably affected by the pandemic situation and the consequent lockdowns during 2020.

Moreover, a total of 53 publications were reported and 2 patents were granted (under the projects DOLPHIN and NEWELY).

As for the type of the reported activities, almost 29 % were related to active participation in conferences, 27 % to scientific publications, 17 % to meetings with policy stakeholders and 8 % to education and training (Figure 1.24).

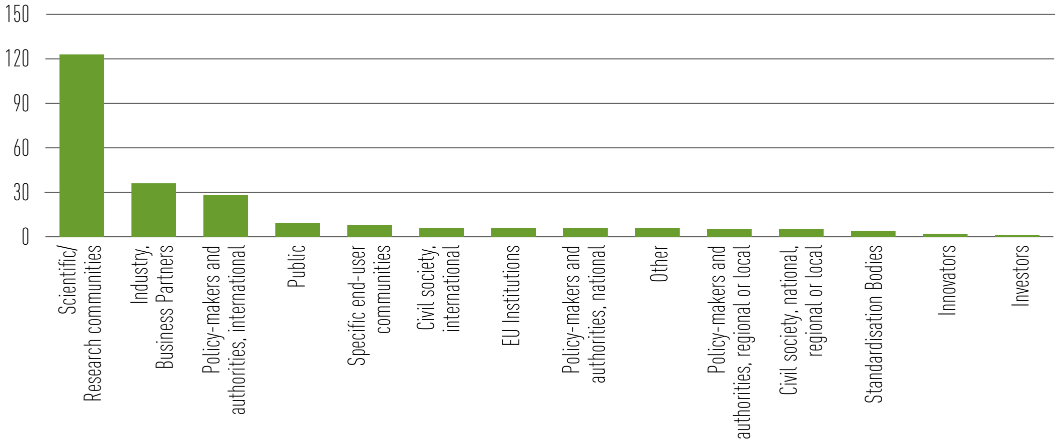
Figure 1.24: Types of dissemination activities performed by FCH 2 JU projects, 2020



Almost half of all the dissemination activities targeted the scientific and research communities, while another 15 % targeted in industry and/or business partners and 11 % in international policymakers and authorities (Figure 1.25).

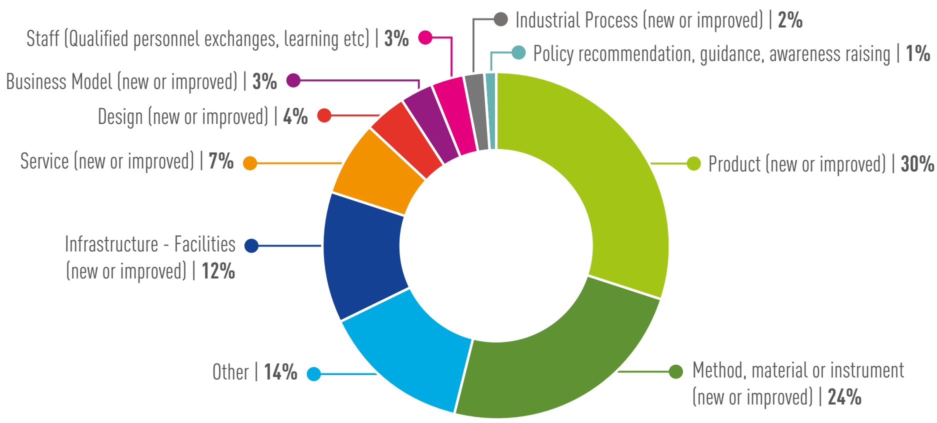
([90]) Furthermore, a new service, the Dealflow.eu, is available to support the innovations/innovators in further exploiting their results, especially in commercialising their innovations (Go-to-Market'), by facilitating access to clients and investors and providing high-end coaching services (venture building, preparation for fundraising, networking, pitching to possible investors etc.).

Figure 1.25: Number of dissemination activities performed by FCH 2 JU projects aimed at each target audience, 2020



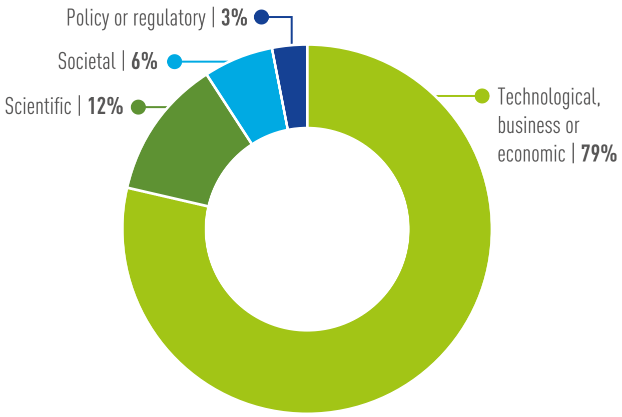
The projects also reported their main outputs and results, especially the key exploitable ones. In general, the types of all the reported results appear to be diverse: 30.5 % of them are related to a new or improved product, 23.8 % to a new or improved method, material or instrument, 12.4 % to new or improved infrastructure and facilities and 6.7 % to new or improved services, while a wide variety of different options (including 'other') were used for the rest (Figure 1.26).

Figure 1.26: Types of outcomes and results reported by the projects, 2020



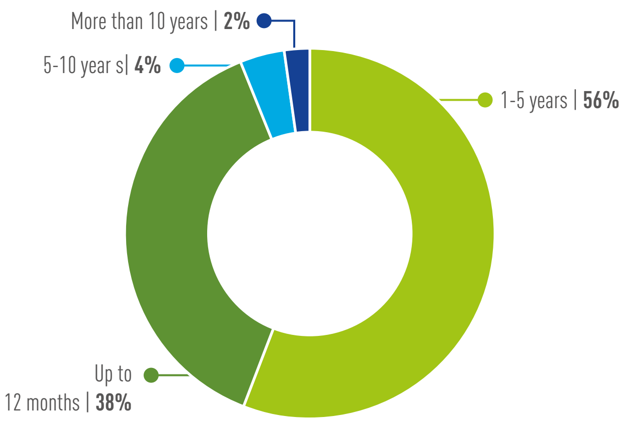
The projects flagged almost 70 % of all the reported results as KERs or key results. As regards the potential of the KERs, the vast majority (78.8 %) have been identified as having high technological, business or economic potential, which reflects the nature of the programme, while 12.1 % have scientific, 6.1 % societal and 3 % policy or regulatory potential.

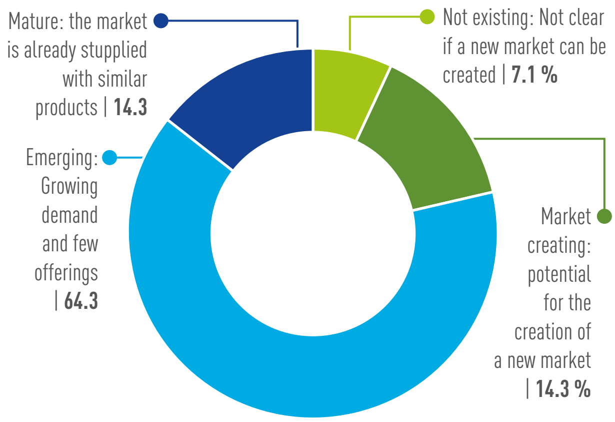
Figure 1.27: Potential of the KERs reported by the projects, 2020



The reported results are expected to affect the hydrogen and FC sector in the short to medium term (Figure 1.28). More than half of them (56 %) are expected to have an impact in 1–5 years, whereas 38 % seem to be already influencing the related fields, according to their owners (expected impact time up to 12 months). In terms of market maturity, most of the result cases are positioned in emerging markets, where there is growing demand but not many market players are positioned yet (64.3 %). Some results are positioned in mature markets (14.3 %), while for the rest there is a potential to create a market (14.3 %) or it is still uncertain whether a market can be created to incorporate them (7.1 %).

Figure 1.28: Expected impact time of the reported results and market maturity, 2020





The **exploitation activities** performed by the projects to support the uptake of the aforementioned results were quite diverse as well (Figure 1.29). Almost 20.5 % were related to intellectual property rights, 13.6 % to business model/plan presentation and similar percentages to meetings with user communities and potential investors. As regards the target audience of these activities (Figure 1.30), the vast majority of them (two thirds) were addressed to the industry and/or business partners, and much smaller percentages to the research communities (16 %) and the standardisation bodies (6 %).

Figure 1.29: Types of exploitation activities performed by JU projects, 2020

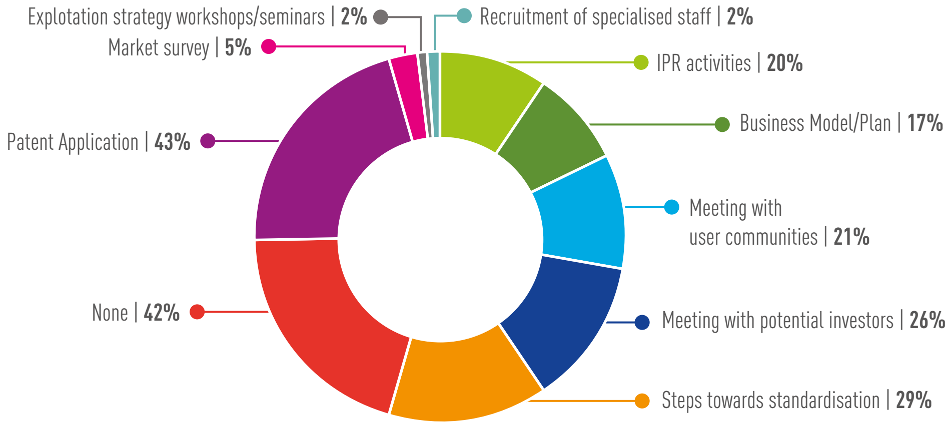
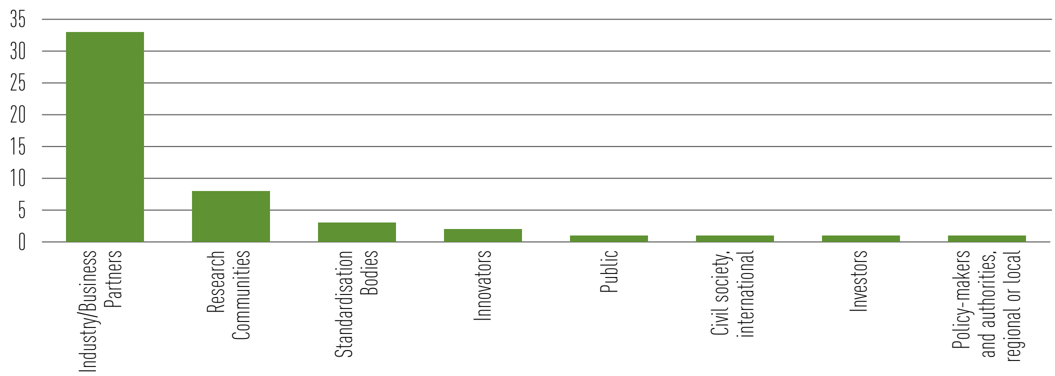


Figure 1.30: Target audiences of the exploitation activities performed by JU projects, 2020



1.6. Operational budget execution

The total budget available in 2020 (including internal assigned revenues) for OPEX reached EUR 10 227 166 in terms of commitment appropriations and EUR 49 676 325 in terms of payment appropriations. The commitment utilisation rate reached 98.3 % (94.9 % in 2020), which is the highest rate in the last 4 years, whereas the payment execution rate reached 88 % (96.9 % in 2020).

- **FP7 budget:** In 2021, three periodic reports were assessed (one interim and two final), with the total amount of payments reaching EUR 1.1 million. The budget execution (in terms of payment appropriations) reached 97.8 % (88.8 % in 2020).
- **H2020 budget:** In 2021, 62 reports were assessed (46 interim and 16 final payments). In addition, H2020 operational payment appropriations were used for two pre-financing payments (from the 2020 call), as well as for procurement activities, the work of JRC and the work of experts in the context of the EHSP. Budget execution in terms of payment appropriations reached 87.8 % (97.5 % in 2020). The reasons for the lower implementation rate are explained in Section 2.3.2. In terms of commitment appropriations, the execution rate reached 98.4 % (96.5 % in 2020).

For further details on the budget, see Section 2.3.

1.7. In-kind contributions

In-kind contributions in H2020

The FCH 2 JU legal framework for in-kind contributions [91] is defined in Council Regulation 559/2014 of 6 May 2014 establishing the FCH 2 JU, in which Article 4 provides that:

> *The Members of the FCH 2 Joint Undertaking other than the Union shall make or arrange for their constituent entities or their affiliated entities to make a total contribution of at least EUR 380 million over the period defined in Article 1.*

In 2021, FCH 2 JU members other than the EU were able to demonstrate an **overall figure exceeding EUR 1 000 million** of certified contributions from private members, greatly exceeding the minimum targets.

For a detailed calculation of the leverage effect formula, the following contributions made by JU members other than the EU and their constituent or affiliated entities have been considered:

- contributions to the **administrative costs** of the FCH 2 JU;
- co-financing required to carry out R&I actions supported by the FCH 2 JU (i.e. in-kind contributions in operational activities (**IKOP**) through **co-funding FCH 2 JU projects**);
- contributions towards additional activities (**IKAA**) by members other than the EU or their constituent or affiliated entities, as specified in an additional activities plan, which should represent contributions to the broader FCH Joint Technology Initiative and the sector as a whole.

LEVERAGE EFFECT FORMULA

Contributions of JU members other than the Union to administrative costs + Contributions of all private partners to FCH 2 JU actions + certified IKAA) / EU contribution

The amounts of each contribution, as at 31 December 2021, are detailed in Tables 1.1–1.5.

[91] This legal framework was complemented by methodologies for in-kind contributions in operational activities and for IKAA, agreed by the JU GB on 18 November 2015 and 9 December 2016, respectively. Ref. to: https://www.clean-hydrogen.europa.eu/about-us/key-documents/kind-additional-activities_en

Administrative costs

Table 1.1: Financial contributions of the members to FCH 2 JU administrative costs, 2014–2021 cash (million EUR)

YEAR	INDUSTRY GROUPING	RESEARCH GROUPING	Total
2014	0.26	0.04	**0.30**
2015	0.41	0.07	**0.48**
2016	0.40	0.07	**0.47**
2017	0.05	0.01	**0.06**
2018	2.01	0.33	**2.34**
2019	2.31	0.38	**2.68**
2020	2.05	0.33	**2.38**
2021	2.28	0.37	**2.65**
Total 2014–2021	**9.77**	**1.59**	**11.36**

The lower amounts of cash contributions until 2017 can be explained by the fact that the administrative costs were also funded by FP7 contributions.

In-kind contributions in operational activities

Table 1.2 provides an overview of private-sector co-financing in all FCH 2 JU projects signed up to 31 December 2021. The total amounts committed by FCH 2 JU members, by all private partners (members and non-members) and by the EU are broken down according to the call for each year.

When comparing total private contributions in projects with the total EU contribution, we can observe near parity, a ratio close to 1:1 (EUR 627 million of EU committed contribution vs EUR 553 million of private contributions).

Table 1.2: In-kind contributions and EU contributions for grants under calls, 2014–2020 (million EUR)

Year	Number of projects	Total EU contribution ([92]) (A)	Committed in-kind contributions from members (B)	Committed in-kind contributions from non-members (C)	Total committed private contributions (D = B + C)	Total committed EU + private contributions (E = A + D)
2014	15	80.09	32.82	14.40	47.22	127.31
2015	15	107.31	58.50	61.44	119.94	227.25
2016	19	87.98	6.44	81.33	87.77	175.76
2017	24	113.09	12.19	106.38	118.57	231.65
2018	19	71.61	14.26	38.47	52.73	124.33
2019	17	69.13	15.24	70.26	85.51	154.64
2020	25	97.84	18.80	22.71	41.52	139.35
TOTAL	**134**	**627.04**	**158.27**	**394.99**	**553.25**	**1,180.30**

Considering that funding rates in projects follow H2020 rules (i.e. up to 100 % of direct costs in research and innovation actions and in coordination and support actions, and up to 70 % in innovation actions), these private contributions are significantly higher than was initially foreseen. This is because most of the largest demonstration projects have effective funding rates lower than 70 % (of direct costs), as they are very close to the market.

In-kind contributions in additional activities

The underlying purpose of additional activities is to demonstrate private investments in the sector and ensure that a balanced contribution is made by both the private and public entities in the context of the partnership.

In 2021, members of Hydrogen Europe and of Hydrogen Europe Research, and their affiliate entities, jointly delivered a cumulative amount of EUR 1 039 million certified IKAA (for 2014–2020) (Table 1.3), which is more than three times the minimum requirement for IKAA of EUR 285 million, as defined in the FCH 2 JU Council regulation.

Table 1.3: IKAA for 2014–2020 as at 31 December 2021 (million EUR)

2014/2015	2016	2017	2018	2019	2020	TOTAL
217.56	164.65	107.34	177.45	209.55	162.45	1039.00

The values in Table 1.4 have been taken into account in order to calculate the portion of private investments in relation to public investment in the FCH 2 JU that combines an operational component with additional activities.

([92]) Calculated as follows: for closed projects, based on amount finally paid; for ongoing projects, based on the committed amount; for finished projects for which final payment is not made until 31 December 2021 but cost claim received, based on the amounts paid in previous periods + amount received but not yet validated.

Table 1.4: Values of leverage effect as at 31 December 2021 compared with the overall H2020 targets (million EUR)

Overall H2020 targets set in the Council regulation for FCH 2 JU		Members' contributions as at 31 December 2021 and certified as additional activities for 2014–2020		Overall private contributions as at 31 December 2021 and certified as additional activities for 2014–2020	
Total minimum contribution from members other than the EU	380	Cash and committed in-kind support in projects plus certified additional activities – MEMBERS	1 209	Cash and committed in-kind support in projects plus certified additional activities – MEMBERS and NON-MEMBERS	1 604
Total EU contribution	665	Committed EU contribution (2014–2020)	627	Committed EU contribution (2014–2020)	627
Target leverage effect over the whole H2020 programme	0.57	Leverage effect – members only as at 31 December 2021	1.93	Leverage effect – all private partners as at 31 December 2021	2.56

(A) Leverage effect, members only as at 31 December 2021 = (11.36 + 158.27 + 1 039/627.04) = 1 209/627 = 1.93

In other words, for every EUR 1 of EU contribution for all JU signed H2020 grant agreements up to 31 December 2021, members of Hydrogen Europe and Hydrogen Europe Research committed to spend EUR 1.93 either on JU projects or in certified additional activities.

The leverage effect of 1.93 considering only members of Hydrogen Europe Industry and Hydrogen Europe Research is already more than three times the target leverage effect as defined in the FCH 2 JU founding regulation (0.57).

(B) Leverage effect, all private partners as at 31 December 2021 = (11.36 + 553.25 + 1 039/627.04) = 1 604/627 = 2.56

This formula is fully aligned with the method used in the Staff Working Document (SWD) accompanying the Interim Evaluation of the PPPs ([93]).

In contrast to the previous formula (A), in this formula (B) **the leverage effect of 2.56 takes into consideration all private partners' contributions to FCH 2 JU actions**.

In other words, for EUR 1 of EU contribution for all JU signed H2020 grant agreements until 31 December 2021, the private partners committed to spend EUR 2.56 either on JU projects or in certified additional activities – which is more than 4 times the amount of leverage effect (0.57) expected at the beginning of the H2020 programme.

On the one hand, calculation of the leverage effect takes into account the operational component (private financial and in-kind contributions to projects for each euro committed by the European Commission) and, on the other hand, any additional leverage (private contributions to additional activities not directly linked to the project portfolio but contributing to the JU's overall objectives).

In 2021, the JU further confirmed and demonstrated to the Council and European Parliament that the overall commitment of the industry and research has significantly surpassed the minimum requirement of EUR 380 million for H2020.

The EUR 380 million threshold was set to be demonstrated by validated or certified values delivered by private partners only. In H2020, the majority of the IKOP amounts are certified and subsequently validated after the JU receives an external certificate on financial statements (CFS). According to H2020 rules, it is compulsory to provide CFSs only after the end of the action. Since in 2021 the vast majority of the JU actions were still ongoing and only a few CFS certificates were received, the validated amount of IKOP was EUR 38 million by end of 2021. Another reason for the huge difference between EUR 553 million (committed private

([93]) European Commission, *Commission Staff Working Document – Interim Evaluation of the Joint Undertakings operating under Horizon 2020*, SWD(2017) 338 final, Brussels, 6 October 2017, Table 12, p. 44.

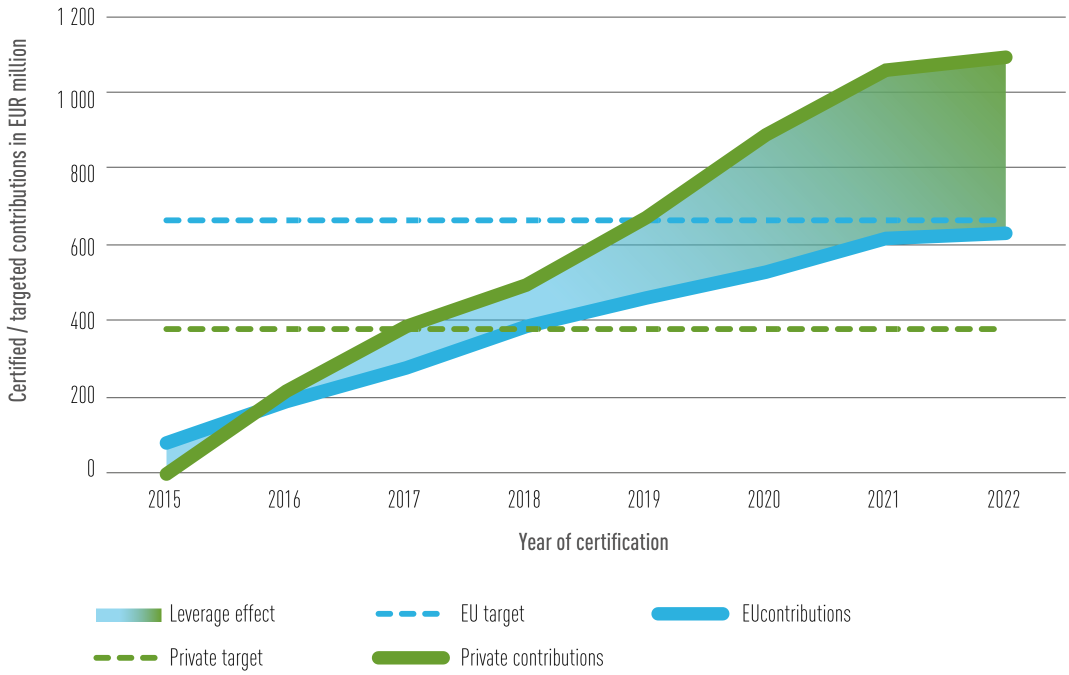
contribution) and certified IKOP (shown in the JU accounts) is that, for the accounts, only contributions coming from the members of Hydrogen Europe and Hydrogen Europe Research can be recognised. Contributions from non-members, even if they are realised, validated and certified, are not shown. We believe that this picture may not necessarily give a true and fair view of the overall investments, so the readers may wish to complement this information with committed figures as well.

Table 1.5 and Figure 1.31 provide an overview of members' contributions under the FCH 2 JU.

Table 1.5: Financial and certified in-kind contributions from private members as at 31 December 2021 (million EUR)

Cash contributions to FCH 2 JU administrative costs	
Industry	9.77
Research	1.59
TOTAL cash contribution	**11.36**
IKOP	
Certified IKOP as of 31 December 2020	11.92
Newly certified IKOP in 2021	26.72
Total certified IKOP as at 31 December 20212	**38.63**
IKAA	
Certified IKAA as at 31 December 2020	876.55
Newly certified IKAA in 2021	162.45
Total certified IKAA as at 31 December 2021	**1 039.00**
Total	**1 062.28**

Figure 1.31: EU and certified private contributions as at 31 December 2021 with outlook for 2022



In-kind contributions in operational activities

IKOP are costs incurred in implementing indirect actions minus the contribution of the JU and any other EU contribution to those costs (Statutes of the Council Regulation establishing FCH 2 JU, Article 13(3)(b)).

To be considered IKOP, these costs must be incurred by members of Hydrogen Europe or Hydrogen Europe Research or their affiliates participating in FCH 2 JU indirect actions.

The regulation establishing FCH 2 JU provides that IKOP should be valued according to members' usual accounting practices and applicable national and international accounting standards (Article 4(4)).

The regulation allows the members to base their declaration of IKOP on the basis of their 'total costs' (according to their usual accounting practices), which may be slightly higher than their 'eligible costs' (according to H2020 rules). On a proposal from the industry and research groupings, the GB decided to limit IKOP to eligible costs for cost-efficiency and simplification reasons.

As a result, the IKOP in H2020 projects for FCH 2 JU are limited to the amount of eligible costs as per H2020 rules, minus the EU contribution.

Calculation of the level of in-kind contributions is based on the methodology endorsed by the GB on 18 November 2015. *Ex ante* controls for the IKOP under H2020 follow the harmonised practice in line with the common strategy of the rest of the RTD family, with the aim of simplifying and easing the controls performed when the payment is approved.

Ex post certification of IKOP is provided by the *ex ante* CFS, which, in contrast to the FP7 programme, is applicable for the final project period only if the amount of FCH contribution to direct costs is higher than EUR 325 000.

Validation of the amount of IKOP is provided at Executive Director level, upon receipt of the CFS and/or based on the result of the *ex post* audits.

The amount of IKOP reflected in the JU accounts is based on all signed running projects as at 31 December 2021, considering mainly the estimated costs (mostly pro rata), as well as cost claims that had been received but not validated at the cut-off date.

As at 31 December 2021, the estimated in-kind contributions for the 134 projects signed for the H2020 programme (2014–2020 calls) were as shown in Table 6.

Table 1.6: Overview of IKOP (million EUR)

H2020 in 2020	Accumulated validated IKOP at 1.1.2021	Validated IKOP for 2021	IKOP received but not validated at 31.12.2021	IKOP estimate (pro rata) at 31.12.2021	IKOP estimate to be validated	Forecast of aggregate level of IKOP
Industry grouping	11.77	26.72	34.48	9.50	75.55	158.02
Research grouping	0.15	0.00	0.00	0.00	0.10	0.24
TOTAL	**11.92**	**26.72**	**34.48**	**9.50**	**75.65**	**158.27**

Most of the IKOPs were not certified, as this will happen later during the H2020 programme at the final payment of the projects when the CFSs are due.

In-kind contributions in additional activities

According to the FCH 2 JU regulation, additional activities are defined as activities carried out by members of Hydrogen Europe and Hydrogen Europe Research and their affiliates contributing to the FCH 2 JU programme's objectives but undertaken outside its work plan, which are not funded by the EU or the JU.

The regulation provides that determination of the costs taken into account for the valuation of the in-kind contributions must be in accordance with the usual cost accounting practices of the entities concerned, the applicable accounting standards of the country where the entity is established, and the applicable international accounting standards and international financial reporting standards (Article 4(4)).

The FCH 2 JU regulation establishes a minimum level of IKAA at EUR 285 million over the period defined in Article 1 of the regulation.

The planning, reporting and certification process of the additional activities in 2020 followed a formal FCH 2 JU IKAA methodology, describing a robust control process to ensure the planned, reported and certified IKAA figures are reasonable (the methodology was agreed by the JU GB on 9 December 2016).

Because of the high level of IKAA in previous years, in 2021 the private members certified the additional activities as part of the 2020 IKAA plan for the last time under H2020. There was no further IKAA plan for 2021 under H2020, as the private members had started their transition and were preparing to report in-kind contributions under the Horizon Europe programme.

1. **(Preliminary) reporting of the values of the IKAA contributions for 2020 by Hydrogen Europe and Hydrogen Europe Research members as at 31 January 2021**

According to the FCH 2 JU regulation, members of the FCH 2 JU other than the EU must report each year by 31 January to the FCH 2 JU GB on the value of the contributions in additional activities made in each of the previous financial years.

In accordance with the regulation, the 2020 IKAA preliminary report was submitted on 29 January 2021 to the JU GB for information. An estimated IKAA of EUR 218.52 million was reported as achieved compared with the initial 2020 IKAA plan of EUR 313.56 million adopted by the JU GB on 13 December 2019.

2. **IKAA certifications for 2020**

By June 2020, the members delivered certificates for the additional activities for a total amount of EUR 162.45 million.

To ensure strict continuity and compliance with the adopted plan, no new activities (for the 2020 reporting period) compared with the adopted 2020 IKAA plan were included in that report.

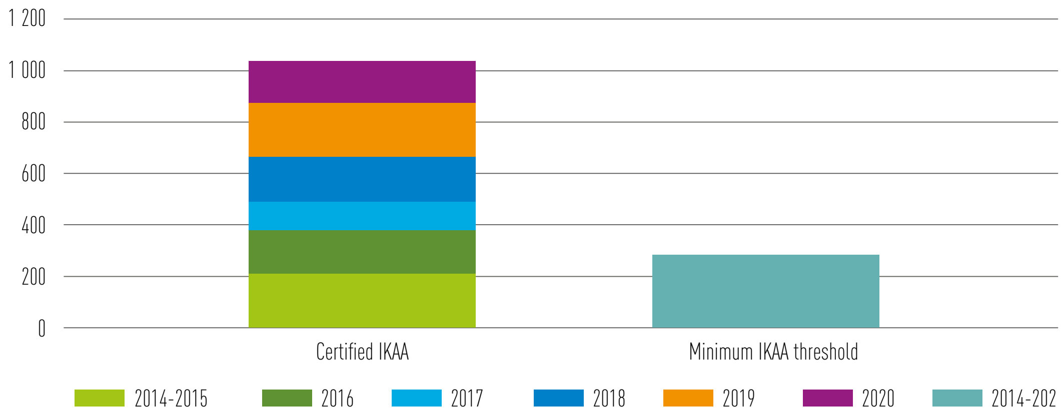
With newly certified activities for 2020, for an amount of EUR 162.45 million, the **total certified IKAA amount for 2014–2020 reached EUR 1 039.00 million**.

General overview of additional activities for H2020 as at 31 December 2021

This section provides an overview of the cumulative amount of additional activities:

- certified IKAA for 2014–2020 (based on the certificates received and validated at 31 December 2021, totalling EUR 1 039.00 million),
- minimum IKAA threshold for the H2020 programme of EUR 285 million envisaged in the FCH 2 JU Council regulation.

Figure 1.32: Certified and reported IKAA for 2014–2020



The JU believes that the scope and volume of investments reflected in the additional activities are a clear testimony to the members' strong commitment, the continued progress of these technologies towards the market and the strong leverage of JU investment. The JU believes that these investments in additional activities successfully demonstrated a robust contribution towards achieving joint objectives even beyond the FCH 2 JU regulation.

Seventh framework programme

The FCH JU founding regulation states that the FCH JU operational costs are to be covered through the financial contribution of the EU and through in-kind contributions from the legal entities participating in the activities.

Calculation of the level of in-kind contributions follows a methodology approved by the FCH JU GB on 10 February 2012. Verification of these costs includes (i) *ex ante* controls before validation of the cost claims submitted by the beneficiaries (based on desk review assessment by the PO and/or CFSs provided by independent auditors) and (ii) *ex post* audits after validation of the cost claims, carried out by independent auditors appointed by the JU, in line with the JU *ex post* audit strategy.

In addition, in accordance with the methodology, the aggregated level of in-kind contributions is assessed every year by an independent external auditor.

In February 2021, KPMG carried out the assessment and confirmed the amount of the aggregated level of in-kind contributions certified by the JU Executive Director (cut-off date 31 December 2020).

The full publishable report can be found on the Clean Hydrogen Partnership's website (https://www.clean-hydrogen.europa.eu/about-us/key-documents/annual-activity-reports_en).

Table 1.7 gives details of the aggregate level of in-kind contributions as at 31 December 2021.

Table 1.7: Aggregate level of in-kind contributions (in million EUR)

Grouping	Accumulated validated contributions at 1.1.2021	Validated contributions in 2021	Contributions received but not validated at 31.12.2021	Contribution estimate (pro rata) at 31.12.2021	Contribution estimate to be validated as from 1.1.2022	Forecast of aggregate level of in-kind contributions
Industry	292.86	2.00	0.00	1.71	9.02	305.58
Research	147.54	1.50	0.00	2.51	3.63	155.18
TOTAL	**440.39**	**3.50**	**0.00**	**4.22**	**12.65**	**460.76**

2. SUPPORT TO OPERATIONS

2.1. Communication activities

Communication activities focused in 2021 on two main areas, following the communication plan included in AWP 2021: continuing to promote the results of the FCH 2 JU and developing the communications framework for its successor. This last part included the development of a new brand and visual identity, of the new website (www.clean-hydrogen.europa.eu) and of a new newsletter. A communications campaign was launched around the new partnership, generating media coverage and awareness among various stakeholders.

2.1.1. Communication campaigns and media relations

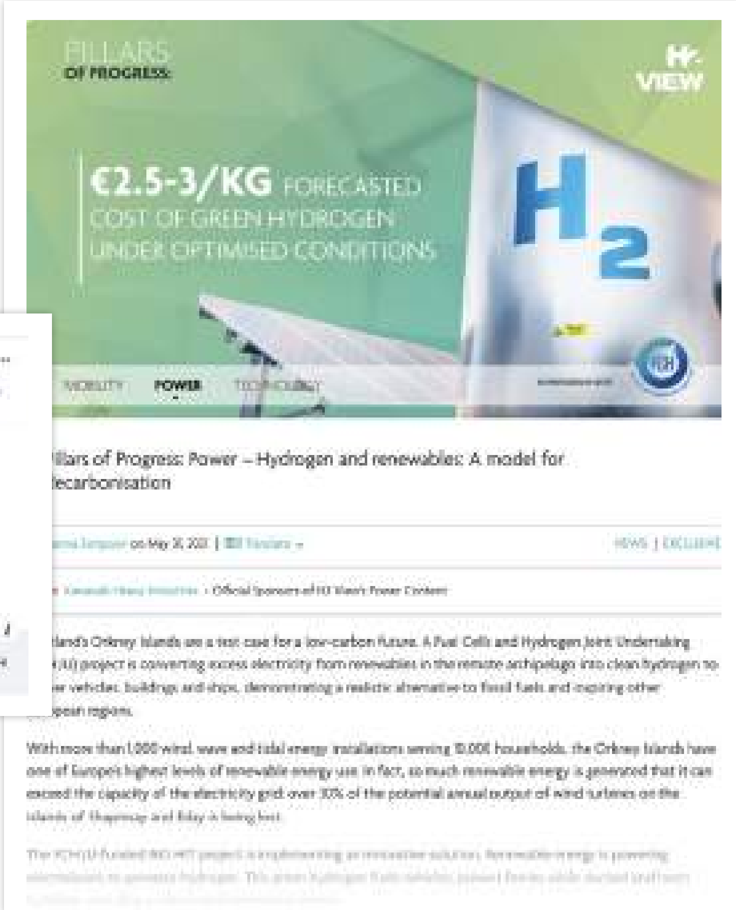
Throughout 2021, the FCH 2 JU partnered with several European media outlets to promote the results of its projects and to announce the launch of its successor, the Clean Hydrogen JU.

The FCH 2 JU had been supporting the hydrogen section in Euractiv's Energy & Environment hub since May 2020. It also supported the *hydrogène* and *Wasserstoff* sections on euractiv.fr and euractiv.de, respectively. The sections have included ongoing editorial coverage of relevant issues, based on direct contact with Euractiv journalists. The section also offered visibility to the JU with the inclusion of its logo and a video teaser. As of 12 January 2021, the section had generated 92 148 page views coming from 69 576 unique visitors.

In addition, the FCH 2 JU partnered with Politico Europe for the launch of the Clean Hydrogen JU, using a multiplatform approach – including a home page takeover and a Politico Studio editorial – to create a solid awareness campaign.

A series of five articles was published on the specialised website Science and Business, representing a network of universities, companies, and research and policy organisations. The themes were 'How Europe can stay at the heart of the hydrogen economy', 'Unleashing the potential of hydrogen for Europe's ports', 'Bringing hydrogen power to the steel industry', 'Awarding excellence in hydrogen technology' and 'How Europe can step-up shift to clean hydrogen power'.

The partnership with H2 View, an established platform to support and promote the growing hydrogen economy, continued to promote the JU projects and success stories within the 'Pillars of Progress' section and the monthly opinion columns from the JU Executive Director. The Pillars of Progress series continued receiving positive attention in 2021.



Another partnership, with *The Brussels Times*, allowed the JU to reach out to a large audience and obtain more than 1 900 000 views by publishing two promoted articles on the magazine's home page.

2.1.2. Delivering the new branding and visual identity

With the publication of Council Regulation (EU) 2021/2085 in the Official Journal, the Clean Hydrogen Partnership (legal name: Clean Hydrogen Joint Undertaking) is the universal successor of the FCH 2 JU and has taken over its legacy portfolio.

To ensure a smooth transition to its new name and keep connected with its extended audience, the Clean Hydrogen Partnership underwent a rebranding process. The results of the rebranding were a new logo, corporate visual identity and website.

It aligned its style with the visual identity guidelines of the European Commission, in particular the newly developed ones for partnerships. The aim was to create a compelling, modern visual identity that speaks to the overall brand promise, which is further used across all the JU's communication touch points: website, social media, print collateral, email signatures, business cards, e-newsletter, letterheads, presentations and branded products (vehicles, trucks, buses etc.).

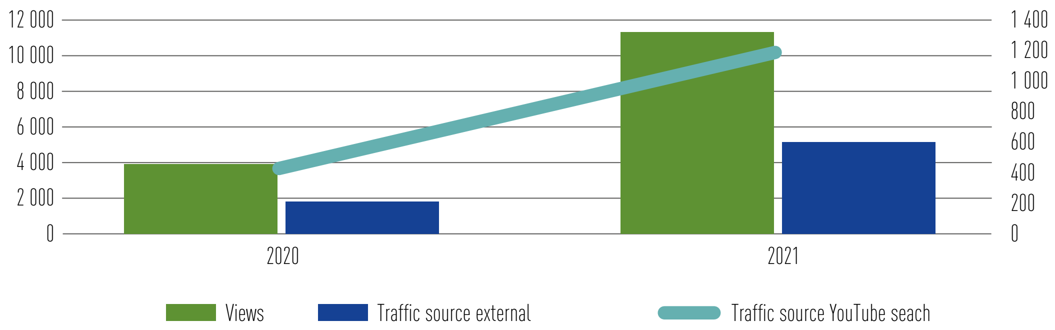
2.1.3. Website and social media

The Clean Hydrogen Partnership website (www.clean-hydrogen.europa.eu) was launched in December 2021, shortly after the Hydrogen Week and the entering into force of the new partnership. The website boasts a new structure and visual presentation, compatible with the Europa Web Publishing Platform (EWPP), on which it is hosted. Visitors can now browse through all the JU's initiatives, events, news and find out more about the new partnership. The FCH 2 JU website (https://www.fch.europa.eu) will still continue to exist until the end of the FCH 2 JU's legacy.

Social media developments 2020–2021

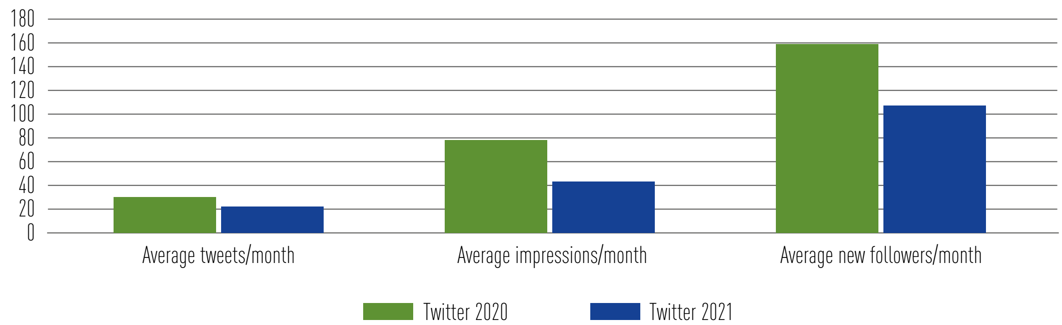
Growth on social media channels, in particular LinkedIn and YouTube, continued in 2021 in accordance with the new trends and the yearly media plan.

Figure 2.1: Growth on YouTube



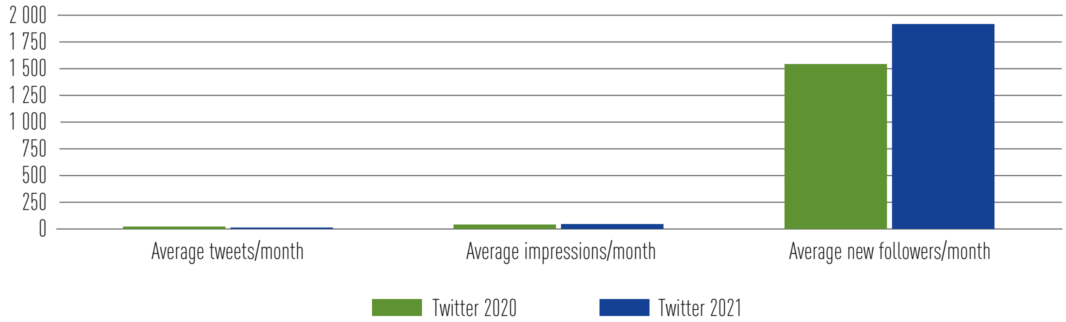
According to YouTube key performance metrics, the official channel of the JU recorded increased figures in 2021: the number of views tripled (from 3 912 in 2020 to 11 333 views in 2021). In addition, the channel became more sought-after in 2021: the YouTube search engine reported 1 188 queries mentioning the name of the JU, compared with 428 in 2020 (Figure 2.1).

Figure 2.2: Decline on Twitter



The summary of the official Twitter account and the breakdown of additional data indicated that, in 2021, the JU published fewer tweets per month (an average of 22) than in 2020 (an average of 30) (Figure 2.2). As a result, the average number of impressions [94] decreased by approximately 44 %.

Figure 2.3: Growth on LinkedIn



In contrast to Twitter, although the JU shared less content on LinkedIn in 2021, it attracted more traffic and more engagement from the online community (Figure 2.3). Although the impressions KPI remained constant over these 2 years, the reach [95] increased substantially from an average of 1 540 clicks per post in 2020 to 1 916 clicks per post in 2021.

Monthly newsletters were sent throughout 2021 to a database of more than 11 000 subscribers. In December 2021, following the transition to the new website and the new visual identity, a new newsletter was developed based on the Newsroom platform provided by DG Communications Networks, Content and Technology. The first issue of the Clean Hydrogen Partnership newsletter was sent out to a database comprising over 12 000 subscribers.

2.1.4. European Hydrogen Week

The second edition of the European Hydrogen Week brought together over 2 000 participants from the public and private sectors across Europe and beyond to review progress and look ahead to new opportunities for the production and use of hydrogen throughout the economy.

The event marked the public launch of the Clean Hydrogen Partnership as the successor of the FCH 2 JU, in the presence of the President of the European Commission, Ursula von der Leyen.

'This new Partnership builds on years of cooperation promoted by the Fuel Cell and Hydrogen Joint Undertaking. And many thanks for that. And it brings that model to the next level. It is a new big step

[94] Impressions are defined by the total number of times social media browsers have shown the content; impressions count exposure.
[95] Reach, as a performance indicator, refers to the number of users who choose to see the social media content and engage with it using 'likes', 'comments' or 'shares'.

forward to bring innovative technologies from the laboratory to the factory and, ultimately, to European businesses and consumers ... 'Clean hydrogen is the energy of the next generation', said President von der Leyen.

The event benefited from the participation of several high-level speakers from the European Commission as well other international organisations. Among these were Frans Timmermans, Executive Vice-President of the European Commission; the EU Commissioners for Energy, Kadri Simson, and for Transport, Adina Valean; Jean-Eric Paquet, Director General of DG Research and Innovation at the European Commission; and Fatih Birol, Executive Director of the International Energy Agency.

Participants discussed, among other topics, the actions needed for a large-scale roll-out of clean hydrogen, hydrogen's contribution to global climate mitigation actions, and the role of EU Member States in setting up synergies and working jointly at EU, national, regional and city levels.

Other topics included education and skills needed for the hydrogen economy, renewable hydrogen production, distribution and storage, and ports' roles as drivers and beneficiaries of hydrogen technologies.

A day was dedicated to discussions on the scientific priorities of the new Clean Hydrogen Partnership. All sectors, including the wider European scientific community, were invited to define the strategic scientific priorities of the hydrogen economy and ways to bridge the gaps between ready-to-market technology and large-scale uptake, while improving and diversifying the technological options.

The Hydrogen Week concluded with the FCH 2 JU programme review days, which presented the progress of projects and technological developments supported by the FCH 2 JU (more details in Section 1.2).

2.1.5. FCH JU Awards

The FCH 2 JU presented awards to its trailblazing clean hydrogen energy projects during the Hydrogen Week.

The JU acknowledged successful collaborations between research, industry and policymakers at its awards ceremony in Brussels on 29 November. The winning projects are delivering world-class solutions and accelerating the transition to a greener world. The JU introduced these awards in 2018 as an additional incentive for project beneficiaries to excel.

Best Innovation Award: Everywh2ere

Proving that hydrogen power development is not only for industrial users, the winning project, Everywh2ere, is a demonstration-to-market project that developed portable FC units, or generator sets. These can provide power to construction sites, music festivals and other temporary events in European cities, providing a solution to a real need. The generator sets feature PEM FCs and safe pressurised-hydrogen technology.

The innovation has helped to bring hydrogen FC technology closer to citizens, eliminating the noise and pollution of diesel generators. Receiving the award on behalf of the consortium, Rina's project manager, Stefano Barberis, said: 'Our project will increase social awareness of FCH technologies, which will be the backbone of future clean energy and a hydrogen-based EU society.'

Best Success Story Award: Towards a sustainable and circular hydrogen economy

This award goes to a group of projects that contributed to the circularity of the hydrogen sector. This year there were 13 finalists, with project achievements across the entire hydrogen value chain, ranging from hydrogen-powered aviation to hydrogen valleys.

Six projects contributed to the winning success story and each received the award: FC-HYGUIDE, SH2E, HYTECHCYCLING, BEST4HY, EGHOST and CertifHy.

The winning success story demonstrates that hydrogen power not only must deliver clean energy efficiently and cost-effectively but should also incorporate sustainability.

The industrial partners and researchers involved in this success story have developed or are developing guidelines on sourcing, dismantling and recycling materials in line with a circular, clean hydrogen economy.

FC-HYGUIDE developed guidance, training materials and courses on how to use LCAs. The SH2E project is building on this to include economic and social dimensions.

HYTECHCYCLING and BEST4HY focused on recycling and dismantling, recovery and reuse of resources such as platinum. Currently, EGHOST is developing environmentally friendly design criteria in technology development.

Finally, CertifHy created the first EU-wide GO scheme for green and low-carbon hydrogen. The project's current third phase includes building a market for GO trade and harmonisation across all Member States.

'Without the backing of the FCH JU since 2014, CertifHy could have never achieved the leading role we now have worldwide on certification schemes. We are honoured to get this award. It boosts our enthusiasm to continue the project,' said Wouter Vanhoudt, Director Europe and Asia at Hinicio, the coordinator of CertifHy.

Best Outreach Award: Refhyne

This award goes to a project for excellent public engagement and creative use of communication activities, to spread the word about the production of clean hydrogen. The 2021 winner is Clean Refinery Hydrogen for Europe (Refhyne).

The 5-year project began in 2018 and built a 10-MW PEM electrolysis plant, the largest in Europe, at the Shell Rhineland Refinery in Wesseling, near Cologne, Germany. This electrolyser for industrial applications started operation in July 2021 and can produce up to 4 tonnes of hydrogen a day when running at full power. It can also help balance the refinery's internal electricity grid, while selling primary control reserve service to the German transmission system operators. Plans are under way to expand the capacity of the electrolysis plant to 100 MW.

Anders Ødegård of SINTEF, Refhyne project coordinator, concluded: 'We are honoured to receive this award in recognition of our dissemination activities. We believe it is vital to share our experiences and learnings to accelerate the further scale-up of clean hydrogen production. On behalf of the entire Refhyne consortium, I want to thank the FCH JU for the support for our 10M-W PEM electrolyser project and for this distinct outreach award.'

FCH JU projects videos

On the occasion of the European Hydrogen Week, the JU produced three videos with a focus on three main topics: hydrogen for decarbonising industry (steel industry), hydrogen for transport and hydrogen Valleys. Several projects have been featured in each video, to showcase their activities through on-site interviews and presentations.

2.1.6. Events

FCH 2 JU Webinars

The JU organised a series of four webinars, covering a variety of topics. The online events have reached more than 2 300 participants in total.

Launch of Hydrogen Valleys Mission Innovation Platform

The launch event of the Hydrogen Valleys Mission Innovation Platform ([96]) took place on 19 January 2021 and included keynote speakers from the Mission Innovation innovation challenge 8 co-leads: Australia, the European Commission and Germany. The event featured presentations from the developers of the platform, Roland Berger and Inycom, which presented the platform's functionalities as well as key findings of the global analysis of Hydrogen Valleys.

The Mission Innovation Hydrogen Valley Platform (https://www.h2v.eu) was developed under the Mission Innovation (http://mission-innovation.net) innovation challenge 8 'Renewable and Clean Hydrogen' (http://mission-innovation.net/our-work/innovation-challenges/renewable-and-clean-hydrogen). The platform features comprehensive insights into the most advanced and ambitious hydrogen valleys around the globe.

Hydrogen certification

By showcasing the results from the CertifHy initiative supported by the JU, European policymakers, industry representatives and NGOs had the opportunity on 21 May 2021 to debate what is needed to harmonise hydrogen GO schemes around Europe and beyond ([97]).

Anion exchange membrane electrolysers

Still in the early development stage, AEMELs have the potential of combining the strengths of alkaline and PEM electrolysers. Since 2020, the JU has supported three cutting-edge projects in this research field: ANIONE, CHANNEL and NEWELY. The projects showcased their achievements and challenges in developing 2-kW prototypes of AEMELs ([98]). The presentations were followed by a discussion of the steps needed to upscale AEMELs, including EU support.

Project development assistance

The final report of the PDA facility and the major achievements of this initiative were presented on 19 October 2021, during an exclusive webinar with the participation of some of the regions involved and representatives of the European Commission and the European Investment Bank ([99]).

([96]) https://www.clean-hydrogen.europa.eu/get-involved/mission-innovation-hydrogen-valleys-platform_en

([97]) https://www.clean-hydrogen.europa.eu/media/news/webinar-hydrogen-certification-2021-05-04_en

([98]) https://www.clean-hydrogen.europa.eu/media/news/review-anion-exchange-membrane-electrolysers-webinar-2021-07-07_en

([99]) https://www.clean-hydrogen.europa.eu/media/events/webinar-results-fch-jus-project-development-assistance-pda-regions_en

Project events

GrInHy2.0 – Salzgitter

On 14 July, the JU's Executive Director, Bart Biebuyck, was a guest of the GrInHy2.0 project, to discuss the progress of the project and the operation of the world's most powerful high-temperature electrolyser [100].

Inauguration of Europe's largest proton exchange membrane electrolysis plant – Refhyne project

The Refhyne project is at the forefront of the effort to supply green hydrogen for Europe. Europe's largest PEM water electrolyser began operations at Shell's Energy and Chemicals Park in the Rhineland near Cologne, producing green hydrogen [101]. As part of the Refhyne European consortium and with EU funding through the JU, the fully operational plant is the first to use this technology at such a large scale in a refinery.

European Sustainable Energy Week 2022

The JU co-hosted three high-level European Sustainable Energy Week sessions on greening European industry, to showcase groundbreaking JU-funded projects and initiatives.

1. **Hydrogen and its potential to decarbonise industrial hubs through ports (14 October 2021)** [102]**:** This session brought together policymakers, industry representatives and regional authorities to talk about their experiences and share their visions of how ports can play a key role in moving towards a green hydrogen economy.
2. **Clean steel with hydrogen (18 October 2021)** [103]**:** Achieving climate neutrality in the next 30 years requires radical changes in the way steel is produced: a higher level of circular economy and the integration of renewable energy sources directly or indirectly through hydrogen. Participants discussed technology and policy issues related to the decarbonisation of the steel industry through hydrogen.
3. **The key role of European regions in kick-starting and advancing the clean hydrogen economy (26 October 2021)** [104]**:** The increasing importance of clean hydrogen in the energy mix provides opportunities and raises as many questions, if not more. The entire clean hydrogen value chain can support sustainable regional development, increase growth and provide long-term employment. The speakers and panellists shared with the audience their experience of and views on developing a hydrogen economy.

[100] https://www.green-industrial-hydrogen.com/news-detail/fch-ju-meets-grinhy20-in-salzgitter
[101] https://www.clean-hydrogen.europa.eu/media/news/inauguration-europes-largest-pem-electrolysis-plant-refhyne-project-2021-07-02-0_en
[102] https://eusew.eu/extended-programme-sessions/hydrogen-and-its-potential-decarbonize-industrial-hubs-through-ports
[103] https://eusew.eu/extended-programme-sessions/clean-steel-hydrogen
[104] https://eusew.eu/programme-sessions/key-role-european-regions-kick-starting-and-advancing-clean-hydrogen

Other events with JU participation

At the core of the European Green Deal lies the need to fight climate change. Hydrogen technologies are an important part of the overall solution for meeting the 2050 climate-neutrality goal of the European Green Deal. The involvement and support of the younger generation is essential in order to increase confidence in and acceptance of these new technologies.

On 13 October 2021, as part of the **EU Regions Week,** the JU took part in a workshop on 'Youth engagement for the European green deal and a carbon-neutral society with hydrogen' ([105]). It brought together local and regional authorities, industry and business sectors and young people to learn from each other and see the impact that young people can have and how they can influence the decision-making process.

The JU was part of the programme of the Science, Technology, Research and Innovation Day at the 26th Conference of the Parties (COP26), 1 November 2021. The session highlighted how R&I funding, corporate companies, start-ups and local authorities can work together to make the hydrogen transformation a reality.

In addition, the JU presented the new policy and finance models for hydrogen valleys at the **H2 Transition Forum in Glasgow** ([106]), which took place on 11 November 2021.

On 3–4 October 2021, the JU's Executive Director, Bart Biebuyck, participated in a high-level event at the Swedish pavilion of Expo Dubai 2021, which aimed to highlight the EU's excellence in R&I as a tool for climate neutrality and sustainability ([107]). The high-level event brought together policymakers and innovators from the EU and the rest of the world to present the new EU R&I programme (Horizon Europe) and the Mission Innovation initiative. It was also an occasion to showcase some of the JU's projects.

The JU also participated in two events organised jointly with the EU Council Presidencies of 2021:

- the **Conference on a Hydrogen Ecosystem for the North Adriatic** ([108]) on 24 November 2021 was part of the agenda of the Slovenian Presidency of the Council of the European Union, and a side event to the 15th Strategic Energy Technology Plan Conference in Bled;
- the high-level conference on **'Hydrogen in Society – Bridging the Gaps'** ([109]), organised in collaboration with the Portuguese Presidency of the Council of the European Union, took place on 7 April 2021.

([105]) https://eu.app.swapcard.com/event/eu-regions-week/planning/UGxhbm5pbmdfNjMxMzA3
([106]) https://events.climateaction.org/2021/sustainable-innovation-forum
([107]) https://eu-green-deal-2020-research.eugcc-cleanergy.net/About.html
([108]) https://setplan2021.eu/sideevents/fuel-cells-and-hydrogen-joint-undertaking-and-ecubes
([109]) https://www.2021portugal.eu/en/events/high-level-conference-on-hydrogen-hydrogen-in-society-bridging-the-gaps

2.2. Legal and financial framework

During 2021, the following procedure was drafted and adopted:

- Decision of the Governing Board of the Clean Hydrogen Joint Undertaking No CleanHydrogen-GB-2021–03 adopting the transfer of decisions of the Fuel Cells and Hydrogen 2 Joint Undertaking's Governing Board to Clean Hydrogen Joint Undertaking.

According to Article 174(12) of Regulation (EU) 2021/2085, in its first meeting, the GB of each JU must adopt a list of decisions adopted by the GB of the preceding JUs that will continue to apply to the JU concerned established by the regulation.

The above GB decision comprises in its annex the one previous decision that continues to apply:

- Decision of the Governing Board of the Clean Hydrogen Joint Undertaking No CleanHydrogen-GB-2021-02 adopting the rules of procedure of the Governing Board.

Data protection

As an EU body applying Regulation (EU) 2018/1725 [110], in the course of 2021, the JU continued its data protection activities as follows.

- It further implemented mitigating measures that resulted from the data protection impact assessment done in the previous year. As a part of the mitigating measures, the JU has adopted a manual for handling sensitive data in Microsoft tools. It is a practical guide to be followed each time the JU processes sensitive personal data, ensuring internal harmonised practices.

2.3. Budgetary and financial management

2.3.1. Budget

The JU budget comprises revenue and expenditure. On the expenditure side, the budget is divided into three titles:

- Title 1 covers staff expenditure, such as salaries, allowances and benefits, contributions, and taxes. In addition, it includes expenses for training, missions and medical services as well as the costs associated with the recruitment procedure and representation costs.
- Title 2 covers the costs associated with the functioning of the PO, such as renting premises, IT needs, expenses related to communications, experts' fees, other service contracts and various office supplies.
- Title 3 covers the operational activities for both the FP7 and H2020 programmes.

Compared with 2020, the 2021 appropriations decreased by 85 % in terms of commitments and by 46 % in terms of payments. The decrease in the 2021 budget was due to the lack of calls launched in 2021. In addition, no pre-financing was planned in 2021.

There were three budget amendments and three budget transfers in 2021. The first two amendments introduced unused administrative payment appropriations and unused operational commitment and payment appropriations, whereas the third one decreased FP7 and H2020 operational payment appropriations in the context of the global transfer of appropriations. An overview of the initial budget, the amendments and transfers is presented in Table 2.1.

[110] Regulation (EU) 2018/1725 of the European Parliament and of the Council of 23 October 2018 on the protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data, and repealing Regulation (EC) No 45/2001 and Decision No 1247/2002/EC, OJ L 295, 21 November 2018, p. 39.

Table 2.1: Budget changes

BUDGET 2021 (in EUR)	Voted budget		Amendments		Transfers		Assigned revenues	Final budget	
	CA	PA	CA	PA	CA	PA	CA + PA	CA	PA
Revenue									
EU operational FP7		1 150 639		– 810 598				0	340 041
EU administrative	2 649 250	2 649 250						2 649 250	2 649 250
Hydrogen Europe	2 278 355	2 278 355						2 278 355	2 278 355
Hydrogen Europe Research	370 895	370 895						370 895	370 895
EU operational H2020		60 815 319		– 16 500 000				0	44 315 319
Reactivations from previous years	1 493 500	2 777 987	7 041 287	1 471 501				8 534 787	4 249 488
JTI revenues							2 014 143	2 014 143	2 014 143
Total revenue	**6 792 000**	**70 042 445**	**7 041 287**	**– 15 839 097**	**0**	**0**	**2 014 143**	**15 847 430**	**56 217 491**
Expenditure									
Title 1	3 814 800	3 814 800		110 622	– 66 225	– 66 225	19 122	3 767 697	3 878 319
Title 2	1 777 200	1 777 200		810 281	66 225	66 225	9 141	1 852 566	2 662 848
Title 3 – FP7	0	1 368 001		– 260 000			7 774	7 774	1 115 775
Title 3 – H2020	1 200 000	63 082 444	7 041 287	– 16 500 000			1 978 106	10 219 393	48 560 550
Total expenditure	**6 792 000**	**70 042 445**	**7 041 287**	**– 15 839 097**	**0**	**0**	**2 014 143**	**15 847 430**	**56 217 491**

CA, commitment appropriations; PA, payment appropriations.

2.3.2. Budget execution

In 2021, the level of commitments showed the highest rate of execution in the last 4 years. The main driver was the high execution rate observed for administrative expenses, which constitutes a record in JU's history.

The payment execution rate decreased by 8 percentage points compared with 2020, affected by the rate of execution for H2020 payments (Figure 2.4).

Figure 2.4: Budget execution rates, 2018–2021

The execution rates for the operational budget reached 98 % and 88 % for commitments and payments, respectively, as shown in Figure 2.4.

The utilisation rates for administrative commitments and payments improved from 2020 to 93 % and 78 %, respectively.

Further details of budget execution follow.

Revenues

Table 2.2 shows JU revenue for 2021.

Table 2.2: Implementation of revenues (EUR)

Heading	Income appropriation (budgeted)	Cashed
Operational expenditure, Union	44 655 360	44 655 360
Administrative expenditure, Union	2 649 250	2 649 250
Administrative expenditure, Industry Grouping	2 278 355	2 278 355
Administrative expenditure, Research Grouping	370 895	370 895
Recoveries		2 015 423
Reactivation of appropriations	4 081 303	
TOTAL	**54 035 163**	**51 969 283**

The amount shown above as cashed refers to revenue cashed and recorded in the budget.

Expenditure

Table 2.3: Implementation of expenditure

Title Chapter Article Item	Heading	Commitment			Payment		
		Commitment appropriations (EUR)	Committed (EUR)	% execution	Payment appropriations (EUR)	Paid (EUR)	% execution
1 1	Staff in active employment	3 643 698	3 515 254	96.5	3 750 274	3 429 142	91.4
1 2	Expenditure related to recruitment	10 400	9 451	90.9	10 400	9 451	90.9
1 3	Missions and travel	58 398	11 000	18.8	58 398	5 826	10.0
1 4	Sociomedical infrastructure	50 200	33 992	67.7	53 196	27 750	52.2
1 5	Entertainment and representation expenses	5 000	2 124	42.5	6 050	3 175	52.5
Total Title 1	**Staff expenditure**	**3 767 697**	**3 571 822**	**94.8**	**3 878 319**	**3 475 344**	**89.6**
2 0	Investments in immovable property, rental of buildings and associated cost	357 872	353 580	98.8	363 922	350 651	96.4
2 1	Information technology	464 750	458 180	98.6	727 503	464 887	63.9
2 2	Movable property and associated costs	10 000	498	0.0	10 000	0	0.0
2 3	Current administrative expenditure	9 394	6 772	72.1	12 001	5 782	48.2
2 4	Correspondence, postage and telecommunications	13 000	10 961	84.3	29 359	10 765	36.7
2 5	Expenditure on formal and other meetings	46 600	0	0.0	46 600	0	0.0
2 6	Communication costs	660 051	608 276	92.2	1 057 716	537 226	50.8
2 7	Service contracts	167 000	156 453	93.7	287 572	160 626	55.9
2 8	Expert contracts and meetings	123 900	87 750	70.8	128 175	90 900	70.9
Total Title 2	**Infrastructure**	**1 852 566**	**1 682 471**	**90.8**	**2 662 848**	**1 620 836**	**60.9**
Total Title 1+2	**Administrative expenditure**	**5 620 263**	**5 254 293**	**93.5**	**6 541 166**	**5 096 181**	**77.9**
3 0 0 1	Implementing the research agenda of FCH JU: FP7	7 774	0	0.0	1 115 775	1 091 651	97.8
3 0 0 2	Implementing the research agenda of FCH JU: H2020	10 219 393	10 057 144	98.4	48 560 550	42 621 296	87.8
Total Title 3	**Operational expenditure**	**10 227 166**	**10 057 144**	**98.3**	**49 676 325**	**43 712 948**	**88.0**
Total budget implementation		**15 847 430**	**15 311 437**	**96.6**	**56 217 491**	**48 809 128**	**86.8**

Administrative expenditure

The JU's administrative budget execution improved to 93 % (86 % in 2020) in terms of commitment appropriations, recording the best performance in its history. This improvement is attributed to the improved planning for 2021 activities, taking into account all potential disruptions and limitations.

Unused appropriations coming from the 2021 budget together with appropriations becoming available in 2021 from decommitments of previous years totalled EUR 459 829 and will be reactivated either in the 2022 budget (through amendment) or in 2023's initial budget, depending on needs and in accordance with the JU's financial rules.

In terms of payment appropriations, the execution rate also improved to 78 % (from 73 % in 2020).

More specifically, Title 1 commitment and payment rates improved compared with 2020 (commitment 95 % in 2021 and 88 % in 2020; payment 90 % in 2021 and 85 % in 2020). Staff in active employment represented 57 % of the total administrative budget and showed a commitment rate of 96 %, showcasing very good planning. Mission budget execution improved to 19 % in 2021 (from 12 % in 2020) but remained below the levels of the pre-COVID-19 period.

Title 2 also improved in both commitment and payments rates compared with 2020 (commitment 91 % in 2021 and 82 % in 2020; payment 61 % in 2021 and 56 % in 2020).

Specifically, the budget lines for investments in immovable property, building rental and associated costs and in IT showed an almost perfect execution of 99 %, followed closely by service contracts (94 %) and communication costs (92 %). Unused commitment appropriations come mainly from communication costs (EUR 51 775), since the organisation of the annual European Hydrogen Week was less expensive than initially budgeted, and from expert contracts and meetings (EUR 36 150), because of changes in planned reviews, stemming from amendments of grants' reporting periods. In terms of payments, the improvement compared with 2020 came as a result of better planning for payments. It is expected that this rate will be further improved in 2022, as any potential reactivation of unused appropriations will come from IT (EUR 262 616, which represents a quarter of the unused payment appropriations in Title 2) and communication costs (EUR 520 490, which represents half of the unused payment appropriations in Title 2) since many contracts and agreements will be paid only in 2022.

Operational expenditure

As regards **FP7 operational costs**, the execution rate on the payment appropriations reached 98 % (from 89 % in 2020). It should be noted that only three FP7 payments were carried out in 2021.

In reference to **H2020 operational costs** (call, procurement activities, JRC and EHSP), the commitment execution rate improved slightly to 98 % in 2021 (97 % in 2020). In terms of payments, the implementation rate reached 88 %, lower than in 2020 (97 %).

Several delays in grants' progress and implementation were reported in 2021. These delays were mitigated with amendments that shifted planned payments from 2021 to 2022. Other delays resulted in claims much lower than initially estimated. In total, delays in project implementation accounted for an estimated deviation of EUR 22 400 000 from the initial forecast, representing a third of the initial budget for H2020 payments. Most of this deviation was promptly identified and corrected by returning EUR 16 500 000 to the Commission in the context of the global transfer of appropriations. The unused payment appropriations of EUR 5 939 254 came for two projects for which the claims were submitted after the abovementioned correction.

Overview of programme implementation

Tables 2.4 and 2.5 give an overview of FP7 and H2020 implementation.

Table 2.4: Implementation of FP7 programme (EUR)

Type	Execution until 31.12.2021	Subsequent years	Total
Commitments (operational costs)	425 813 121		425 813 121
Payments (operational costs)	422 506 398	3 039 328	425 545 726
Cumulative execution (operational costs)	**99.2 %**	**99.9 %**	**99.9 %**
Commitments (administrative costs)	30 658 610		30 658 610
Payments (administrative costs)	30 658 610		30 658 610
Cumulative execution (administrative costs)	**100.0 %**	**100.0 %**	**100.0 %**
Overall FP7 execution	**99.3 %**	**99.9 %**	**99.9 %**

As regards **operational costs,** the overall execution rate until 31 December 2021 reaches 99.2 %. In the summary table (Table 2.4), it should be noted that operational commitments relate to individual commitments for grants and studies. The amounts shown under 'Subsequent years' represent the remaining obligations under the last open grant agreement, for which the final payment is expected in 2023. The amount of EUR 267 395 will be decommitted in 2022. From the total 155 grant agreements signed, 1 project was cancelled, final payments were made for 153 projects and 1 project remains open. In addition, 12 operational studies were conducted.

Table 2.5: Implementation of H2020 programme (EUR)

Type	Execution until 31.12.2021	Subsequent years	Total
Commitments (operational costs)	649 248 096	1 474 819	650 722 914
Recoveries	– 4 722 914		– 4 722 914
Payments (operational costs)	532 962 122	113 037 878	646 000 000
Cumulative execution (operational costs)	**82.7 %**	**100.0 %**	**100.0 %**
Commitments (administrative costs)	21 464 518	16 535 482	38 000 000
Payments (administrative costs)	20 479 362	17 520 639	38 000 000
Cumulative execution (administrative costs)	**95.4 %**	**100.0 %**	**100.0 %**
Overall H2020 execution	**83.1 %**	**100.0 %**	**100.0 %**

Regarding H2020 operational costs, the amount committed at the end of 2020 refers to the 134 individual commitments for H2020 projects. In addition, it includes the committed amounts for 25 procurement activities and a global commitment for the outstanding procurement activities from the 2021 AWP. It also includes four annual commitments for the EHSP and six commitments for the JRC's annual work.

With regard to H2020 administrative costs, EUR 985 156 was committed in 2020 and 2021 but not paid (as services are ongoing and/or invoices pending).

Amendments signed in 2021

Besides assessing the periodic reports, the JU's financial management also includes the processing of project amendments. In 2021, the Executive Director signed 1 FP7 and 51 H2020 amendments.

2.3.3. Time to pay

Operational payments

In 2021, 3 FP7 and 62 H2020 reports (interim and final) were assessed (59 in 2020). The overall time to pay (TTP) for FP7 and H2020 combined improved further compared with 2020, from 67 to 64 days. The gross TTP (including any suspensions due to requests for clarifications and amendments) reached 100 days.

More detail follows.

Seventh framework programme

Three reports were assessed in 2021 (four in 2020), of which two were final and one interim.

The average TTP of these reports was 53 days (78 days in 2020). The gross TTP (80 days) significantly improved compared with 2020 (235 days).

H2020

In 2020, 46 interim and 16 final reports were assessed, with an average TTP of 65 days (66 in 2020). The gross TTP was 101 days (98 in 2020).

Administrative payments

The average TTP for administrative payments (invoices from suppliers of goods, service providers and cost claims from experts/staff) was 15.1 days (15.8 in 2020). The number of late payments (1 %) marked the best performance in the FCH 2 JU's records, further improving on the 2020 performance. Strong monitoring measures on the open invoices contributed to this record.

2.4. Procurement and contracts

The tender and contract management has been simplified as far as possible by following the interinstitutional procurement procedures launched by the European Commission and using the resulting multiannual framework contracts. The JU also cooperates with other JUs on tendering needs in order to minimise the administrative effort.

As in previous years, most of JU's contracting was carried out under existing multiannual framework contracts, except mainly for operational procurement activities (see procurement studies under Section 1.4 'Calls for tender'). In terms of volume, operational procurement activities, IT services and the organisation of the European Hydrogen Week for 2021 were the contracts with the highest value.

Launching and publishing a call for tender, and receiving and opening tenders have been simplified by using eTendering, eNotices and eSubmission modules. This last enables the automatic registration of tenders with the European Commission's document management IT system (ARES). The JU is using the latest version of eSubmission and thus the publication, submission and reception of offers and opening stages are now fully digital.

In addition, the JU made use of EU Sign, a software solution provided by DG Informatics, which allows a qualified electronic signature (QES) to be applied to documents. The PO now applies a QES on its contracts, which facilitates business processes by significantly reducing the time and cost of signing a contract in blue ink. In addition, QESs, if applied using EU Sign, are legally binding, as they are compliant with Regulation (EU) No 910/2014 (the eIDAS regulation) for electronic transactions within the EU's internal market and provides a higher level of technical security.

Table 2.6 gives an overview of the contracts awarded in 2021, including the procedure used in each case and the name(s) of the contractor(s).

Only those contracts with a value exceeding EUR 15 000 are listed. In cases of specific contracts implementing framework ones, the information is aggregated for each contractor under the same framework contract.

Table 2.6: Contracts (> EUR 15 000) awarded in 2021

Type of contract	Contract title	Contract reference	Selection procedure (if applicable for contract awards)	Name of contractor	Amount (EUR)
Specific contracts	*2 specific contracts under framework contract*	Specific contracts No 14 and No 15	Specific contract under framework	Realdolmen N.V.	649 308.53
Direct service contract	Study hydrogen in ports	FCH/OP/Contract 300	Open procedure	Deloitte Consulting & Advisory	518 000.00
Framework contract for services	e-HRS availability	FCH/Contract 282	Open procedure	Spilett New technologies GmbH	400 000.00
Specific contract	European Hydrogen Week 2021	FWC/PCO/Lot3–21/025	Specific contract under framework	VO Communications	308 896.88
Specific contracts	*7 specific contracts for use of interim services*	FCH JU 2021 P014, P051, P061, P013, P052, P07 and P019	Specific contract under framework	Randstad Belgium NV	233 900.29
Direct service contract	Study impact of deployment of BEV and FCEV infrastructure	FCH/OP/Contract 296	Open procedure	McKinsey Solutions	200 000.00
Specific contracts	*2 specific contracts under framework contract*	Specific contracts No 1 and No 2	Specific contract under framework	Spilett New Technologies GmbH	83 195.00
Specific contract	Media buying services	COMM-2019-OP-0029-Lot2 – FCH-2	Specific contract under framework	Consortium E2COMMs formed by European Service Network (leader) and Ecorys Europe	70 196.00
Specific contract	Development of new Visual Identity	AV0187-FCH JU	Specific contract under framework	European Service Network SA	59 603.69
Specific contract	Equipment and installation material for meeting room 4/25	Specific contract No 2	Specific contract under framework	Telmaco Société Anonyme Production & Trade of Electronic Products	46 666.48
Specific contract	Editorial, writing and proof-reading assignment 2021	FCH/Contract 227-4	Specific contract under framework	European Service Network SA	42 698.00
Specific contract	1 specific contract for use of interim services	FCH JU 2021 P053	Specific contract under framework	Start People N.V.	38 211.13
Direct service contract	Data protection services	FCH/Contract 294	Negotiated procedure	Lydian	35 000.00
Specific contract	Ongoing services Eurodomain 01.01.2022–31.12.2022	Testa-ng II SC76	Specific contract under framework	Deutsche Telekom Business Solutions GmbH	31 463.76
Specific contract	Microsoft annual fee for software licence renewal	Order Form No 07722-OF-4854	Specific contract under framework	Insight Technology Solutions Belgium Inc	17 744.24

2.5. Information technology and logistics

The year 2021 was driven by the new ways of working accelerated by the COVID-19 situation. It has accelerated the deployment of software-as-a-service solutions, starting with the implementation of the mitigation measures identified in the Microsoft Office 365 data protection impact assessment. The year was marked by the replacement of in-person meetings with virtual meetings and conferences. That process was reinforced by a unified communication project to replace standard telephone systems. The last quarter was marked by the organisation and success of the European Hydrogen Week as a hybrid virtual web conference; by the highest ever attendance of the programme review days, which were for the first time broadcast from the newly created studio of the JU; and by the transition to the new Clean Hydrogen JU.

Support to core business

As in previous years, FCH 2 JU staff were ensured adequate access to the complete set of European Commission applications for grant management. The roles of the Single Point of Contact for COMPASS and Local Authorisations Manager for the IT accounting system (Accrual Based Accounting, ABAC) were again useful to ensure the successful implementation of H2020's 2021 call. More important was the fact that the efficient remote support provided by the IT officer and the service desk took into account reduced presence in the office and increased use of hybrid modes of working as well as health and safety requirements.

The urgent deployment of the Teams voice project during the second quarter, due to the COVID-19 situation, greatly helped the JU to continue the usual business activities without interruption.

A close follow-up of the infrastructure-as-a-service solution and managed IT service contracts available to the JU has been performed. As indicators supporting the new ICF we can mention the following:

- the business continuity operations were in evidence throughout 2021;
- the quality and performance indicators of the managed IT services and the downtime of the key systems are reported on a quarterly basis in the inter-JU IT governance report;
- we have several sources of monitoring depending on the type of service: performance metrics of European Commission tools, the ScienceLogic portal for the IT infrastructure and end-user support, the Icinga portal for the infrastructure-as-a-service cloud services, and Splunk from the Computer Emergency Response Team for the EU Institutions, bodies and agencies for the log files and security analysis;
- the JU was not affected by security incidents arising from external cyberattacks.

Business support tools

The JU continued to adopt more common EU solutions for grants and procurement. Among them, the module eSubmission from the new e-procurement suite provided by DG Informatics was used, allowing a smoother process, simplified interactions and efficiency gains in the evaluation process. The legacy tool, historically named e-PRIOR, is gradually being replaced by the end-to-end business process support covered in the new Corporate eProcurement suite. The JU is already engaged in the adoption of the new Public Procurement Management Tool to support negotiated procedures for medium- and low-value contracts, and the Contract Management module, which will be the link with eSubmission for the automatic generation of contracts and electronic signatures.

The JU started the effective use of the European Commission application Système de gestion du personnel (Sysper) (for personnel management) in February and is now preparing the next module, Mission Processing System, as the IT application for the management of business travel approval workflows and the reimbursement of costs incurred by mission performers. The transition to the new Clean Hydrogen JU was also the occasion to automate processes further by synchronising the user profiles between ARES and Sysper, improving the data quality.

The JU website is hosted by DG Informatics under the Next-Europa services to ensure the stability and continuity of this essential tool for the external communication and visibility of the FCH programme. Setting up the new Clean Hydrogen Partnership website achieved the creation of a completely new website compliant with the EWPP norm, released exactly on time in November. The old website will be archived in 2022.

There were plenty of challenges in 2021, especially during the transition to the new Clean Hydrogen JU in November, which required dealing with all the implications of the renaming, change of logo, and associated changes in graphics, in all contexts, in due time without business interruption. One of the positive impacts was the progress achieved in moving from a simple QES to the official sealing certificate with the service EU Sign.

Internal support

The specific contract under the European Commission framework contract TESTA NG II for the provision of secured telecommunications was signed to enable the continuation of services for all JUs, the European Union Agency for Railways, the European Labour Authority and the Agency for Support for the Body of European Regulators for Electronic Communications. The technical choice to operate from a community cloud in Hamburg (operated by CANCOM) has proven very efficient and resilient, supporting without problems the massive use of teleworking during the lockdown.

The JU is engaged in the deployment of Office 365 as a software-as-a-service solution. The implementation of the mitigation measures after the data protection impact assessment performed by Deloitte in 2020 was completed by the data protection, IT officers, document management officers and human resources officers with some external consultancy. Teams with unified communications and collaboration features was already deployed in 2021, and SharePoint, OneDrive and Exchange Online – identified as priority assets – will be deployed during 2022.

The JU is the leading contracting authority for the framework contract for the managed IT services provided for the six JUs hosted in the White Atrium building. The specific contract for the associated services entered into force on 1 January 2022 after preparation and signature during the last quarter of 2021.

A contract for developing maintenance and support for the internally developed data collection platform TRUST is in place. The necessary technical and security improvements were delivered earlier in 2021, and the helpdesk and service requests are now used on an ad hoc basis to keep this application efficient.

To enhance the performance, usability and user interface of the applications, the Windows virtual private network (VPN) solution available with Windows 10 has also been deployed as an essential IT support for teleworking.

Given the increased use of teleworking, the JU has also put in place a failover solution for when a corporate device is damaged or missing. The private equipment using a virtual desktop solution was effective from August. The next step is the more modern mobile device management as a temporary environment using Office 365 tools, which was under evaluation in 2021 and is to be released early in 2022.

The JU started the effective use of the Systal tool for recruitment in June. The tool is shared by five JUs. A service level agreement was signed with the former Bio-Based Industries JU (now CBE JU), which leads the project. As Systal is configured now, all JUs can participate in shared recruitment with the advantage of using the same functionalities. It also supports the establishment of a future common back office with the migration of users to a new entity, but that was out of scope of the initial project and could lead to additional customisation in a subsequent phase.

Logistics

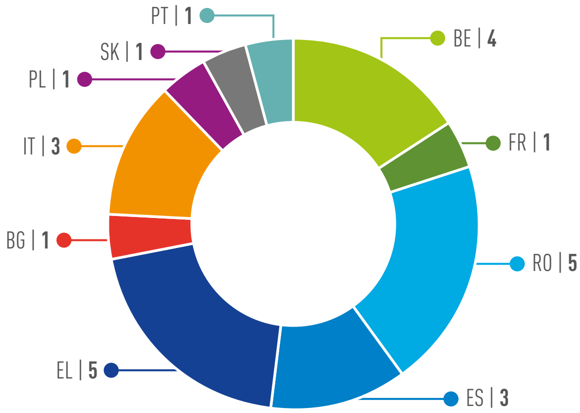
In addition, logistical support has been provided in the context of general administration. This encompasses the management of supply and maintenance of equipment, namely stationery, goods and services for administration, and includes the monitoring of services provided in particular through the Office des Infrastructures de Bruxelles, the Translation Centre and the Publications Office.

As in 2020 the use of web conferences as a communication method increased greatly, with events in hybrid or complete virtual mode. We observed again a shift in costs from business travel to telecommunications. Taking this into account, a special achievement was the implementation of new equipment for videoconferencing in a flexible audiovisual studio where this new kind of events can be organised. It proved to be capable of producing a livestreamed event during the programme review days in November.

2.6. Human resources

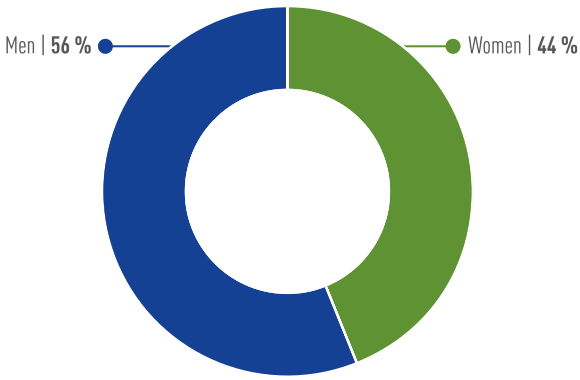
By the end of 2021, the JU PO had a total of 25 statutory staff (23 temporary agents and 2 contract agents) and 2 seconded national experts from 10 countries (Figure 2.5).

Figure 2.5: JU staff by nationalities, as at 31 December 2021



There is a good gender balance at JU (Figure 2.6): One third of managers are female and 2/3 are male.

Figure 2.6: JU staff gender balance



The COVID-19 situation continued throughout the year with short periods of return to the office on a voluntary basis. In October 2021 the JU was able to organise a half-day outdoor team-building event. The JU followed closely the guidelines of the Commission as set by the Belgian government in the situation of the pandemic.

During the pandemic the JU continued to have online meetings with the whole office. They were set every 2 weeks on Thursday morning to maintain the motivation and well-being of staff members.

As a follow-up of the resilience training organised for six JUs in 2020, three workgroups were created in 2021 to discuss and develop guidelines on the following topics:

- effective use of tools and the right to disconnect
- well-being during telework / managing teams remotely
- integration, support and learning.

The three working groups produced a document on best practices for hybrid working. It was an inter-JU effort, with a good mix of staff levels and members of different JUs.

The JU had organised a staff survey in 2020. To follow up on the results it had a workshop on goals, roles, interaction rules and procedures with a human resources specialist. In 2021, three WGs were created for the following topics:

- WG1: vision and mission of the next JU (September 2021)
- WG2: define responsibilities, roles and objectives to be reflected in the revised job descriptions (June 2021)
- WG3: implementing the new ways of working (beginning after the European Commission published the new guidelines).

The three WGs finalised the work, and the end results were shared with management.

At the same time as the WGs were established, the JU also looked for a volunteer to be its 'social chair'. Two people volunteered, and they tried to interact with staff while creating group challenges.

Recruitment

The post of Head of Administration and Finance was advertised on 7 May 2021 with a deadline for applications of 13 June 2021. The selection was completed on 10 September. The starting date for the head of unit was 1 January 2022.

On 28 June the JU advertised a vacancy for a grade 5 administrator (AD 5) position. The deadline for applications was 19 September 2021. This publication was to create a reserve list to recruit one additional project officer and one to replace a project officer who left in 2021.

On 15 September 2021 we published a post for a grade 3 assistant (AST 3) legal assistant. The deadline was set for 30 November 2021 and was extended until 31 December 2021. The deadline was extended because the two units involved in the selection procedure needed to focus on preparing all the relevant documents for the change of identity and name of the JU. It was decided that it would be better to have the Legal Officer as a member of the selection team, since the legal assistant would be working directly with her. This selection procedure will start in 2022.

To provide support to the PO, in projects, in communication and knowledge management and to cover for the maternity leave of the Legal Officer, short-term contracts for interim services were used in 2021.

Learning and development

In 2021, joint IT sessions were organised together with the other JUs with the main purpose of preparing for the switch to Office 365, SharePoint and OneDrive. There were also interesting sessions on cybersecurity for the JUs. Furthermore, the PO had organised a session for the whole organisation on fraud awareness and prevention, presented by the European Anti-Fraud Office (OLAF), and one on Horizon Europe rules, presented by the CIC. A specialised session on 'Accounting training on equipment treatment and R & D' was organised for the financial and project officers. During the pandemic, staff members took time to participate in online training to expand their knowledge related to their jobs. Participation in training was highly encouraged to keep staff motivated and connected with others during the lockdown.

Digitalisation of human resources

In February 2021 the JU onboarded Sysper. Throughout the year new modules were added. The use of Mission Processing System and the feature for the staff evaluations and promotions are expected.

Workshops were organised to introduce the new recruitment tool, Systal. This tool was rolled out to the JU in November 2021 and the next recruitment will be done using this system.

Other human resources-related activities

The 2021 appraisal and reclassification exercise was carried out and the decision on staff reclassified (four temporary agents) was adopted, with reclassifications taking effect retroactively on 1 January 2021.

The JU participated in the meetings organised by the European Union Network of Agencies, which continued the 'new ways of working' meetings giving updates on the different situations in the Member States regarding COVID-19. It also attended Learning Network meetings, to be informed of the different developments in EU Learn and LinkedIn Learning.

3. GOVERNANCE

3.1. Governing Board

Fuel Cells and Hydrogen 2 Joint Undertaking

The JU GB comprised three members from the European Commission representing the EU, six representatives from Hydrogen Europe and one from Hydrogen Europe Research.

The GB chair was René Schutte, Director of HyNorth. The vice-chair was Rosalinde van der Vlies, Director of Clean Planet at DG Research and Innovation.

In July 2021, three representatives from Hydrogen Europe left and were replaced by: Patrick Huber (H2 Energy), Melissa Verykios (Helbio), Glenn Llewellyn (Airbus).

During the year, the JU GB held three meetings, on 24 March, 18 June and 10 November.

Because of the COVID-19 situation, all meetings were virtual.

All the meetings focused on strategic issues and discussions on the progress of the programme and, included updates from the members on policy developments and preparations for Horizon Europe.

- The first meeting, in March, was mainly dedicated to discussions regarding the 2021–2027 SRIA (formerly MAWP), the 2021 and 2022 AWPs, and strategic priorities, as well as the 2020 AAR and the implementation of the JRC's rolling annual plan for 2020.
- The June meeting included an update on progress in the 2021–2027 SRIA, the 2021 and 2022 AWPs, and the preparation of the second European Hydrogen Week.
- In November, the main topics included the latest developments on the set-up of the Clean Hydrogen Partnership and its synergies, the state of play of the 2021–2027 SRIA and the2022 FCH 2 JU AWP, but also the status of the new 2022 JU call.

The GB also adopted major decisions by written procedure, including:

- FCH-GB-2021-01 Approval of 26 February 2021 of amendment No 1 to the FCH 2 JU AWP and Budget for 2021;
- FCH-GB-2021-02 Approval of 07 April 2021 of independent assessment of aggregate level of IK (FP7) at 31.12.2020;
- FCH-GB-2021-03 Approval of 15 June 2021 of the minutes of GB meeting of 24 March 2021;
- FCH-GB-2021-04 Approval of 31 May 2021 of amendment No 2 to the FCH 2 JU AWP and Budget for 2021;
- FCH-GB-2021-05 Assessment and approval of 15 June 2021 of the FCH 2 JU AAR 2020;
- FCH-GB-2021-06 Approval of 30 June 2021 of the FCH 2 JU final accounts for 2020;
- FCH-GB-2021-07 Approval of 30 September 2021 of the minutes of GB meeting of 18 June 2021;
- FCH-GB-2021-08 Approval of 29 November 2021 of the FCH 2 JU AWP and Budget for 2022;
- FCH-GB-2021-09 Approval of 29 November 2021 of amendment No 3 to the FCH 2 JU AWP and Budget for 2021.

More information on the role and composition of the FCH 2 JU GB is available on the JU's website (http://www.fch.europa.eu/page/governing-board).

Clean Hydrogen Joint Undertaking

The Clean Hydrogen JU had its first GB meeting on 17 December2021.

It was dedicated to the main important decisions, such as:

- CleanHydrogen-GB-2021-01 Approval of 17 December 2021 of the Minutes of the FCH JU GB meeting of 10 November 2021
- CleanHydrogen-GB-2021-02 Rules of procedures of the Governing Board
- CleanHydrogen-GB-2021-03 Omnibus
- CleanHydrogen-GB-2021-04 Specific criteria and selection process for the composition of the Stakeholders Group.

In addition, the chair and vice-chair were elected (René Schutte and Rosalinde van der Vlies, respectively).

More information on the role and composition of the GB is available on the Clean Hydrogen Partnership's website (https://www.clean-hydrogen.europa.eu/about-us/organisation/governing-board_en).

3.2. Executive Director

According to Article 19 of the Council regulation establishing Clean Hydrogen JU, the Executive Director is the legal representative and the chief executive responsible for the day-to-day management of the JU, in accordance with the decisions of the GB.

Bart Biebuyck was appointed as Executive Director by the JU GB and took up his duties on 16 May 2016. In 2019, his contract was extended until May 2023.

3.3. States Representatives Group

During 2021, the States Representatives Group (SRG) met on 5 March, 27 May and 19 October. Among other things, its activities focused on monitoring JU's achievements and results and on preparations for a future partnership, including the following:

- At the June meeting, the main topics included an update on the Single Basic Act establishing partnerships under Horizon Europe and in particular the Clean Hydrogen Partnership, and coordination mechanisms with other partnerships; an update on the status of the 2021–2027 SRIA (formerly MAWP); and presentations on the Clean Hydrogen Alliance's status and on the results of the study on FC hydrogen trucks.
- During the May meeting, the SRG members were updated on the status of the 2021–2027 SRIA and 2021–2022 AWP, and on the Single Basic Act establishing partnerships under Horizon Europe and in particular the Clean Hydrogen Partnership, including coordination mechanisms with other partnerships and synergies; DG Energy presented the Hydrogen Energy Network.
- At the November meeting, the PO presented the status of the 2022 SRIA and AWP, and the status of tenders/studies with a view to potential synergies/collaboration with Member States (including alignment of R&I activities). The European Commission updated the SRG members on the Single Basic Act establishing partnerships under Horizon Europe and in particular the Clean Hydrogen Partnership, and on coordination with other partnerships (including the Clean Energy Transition Partnership) and synergies with other initiatives such as the European Union Agency for Railways.

As per Article 20(7) of the Council Regulation, the SRG members were consulted and provided positive opinion on the current AAR.

3.4. Scientific Committee

The Scientific Committee was an advisory body to the GB under FCH 2 JU and comprised a maximum of nine members reflecting a balanced representation of globally renowned expertise from academia, industry and regulatory bodies. Its role was to provide advice on scientific priorities to be addressed in the AWPs, and on scientific achievements described in the annual activity reports. The committee was consulted on the latter.

3.5. Stakeholder Forum

The Stakeholder Forum was one of the FCH 2 JU's key governance bodies, which ensures the transparency and openness of the FCH 2 JU programme to all stakeholders, including the public. It also provides opportunities to enhance the FCH 2 JU's communication activities, as the forum brings together a large number of policymakers and EU stakeholders.

The Stakeholder Forum was integrated in the European Hydrogen Week. The event was held on 29 November 2021, in a hybrid format, with the participation of high-level speakers from the European Commission as well as from the industry and research sectors. The Clean Hydrogen Partnership was launched during the forum, in the presence of the European Commission's President, Ursula von der Leyen.

Clean hydrogen power is indispensable to Europe's competitiveness and for limiting global warming to 1.5 °C. Europe is leading the global hydrogen energy revolution and needs to ensure it maintains its competitive advantage by integrating systems, developing skills, scaling up projects and removing policy hurdles, said representatives of the European Commission and of industry, speaking at the event.

'This is the time to invest in Europe's leadership on hydrogen, for our own sake and for the world's sake,' President von der Leyen said in her opening speech. The EU had started investing in new generation electrolysers before the rest of the world, making it the global leader in patents and publications on this technology, she highlighted.

The need for cooperation, for connecting the various stakeholders and sectors, was a recurring theme of the event, as was urgency of turning plans into reality. Decisions on large investments must be synchronised and multiple projects linked to create a snowball effect and build a viable market.

'The synergies and joint agenda have been well identified politically. Now it needs to happen. You can count on Commission services to support this agenda,' said Jean-Eric Paquet, Director-General of DG Research and Innovation.

For more information on the European Hydrogen Week, please see Section 2.1.4.

3.6. Preparation of Stakeholders Group

At its first meeting, on 17 December 2021, the GB of the Clean Hydrogen JU approved the specific criteria and selection process for the composition of the Stakeholders Group. The Stakeholders Group is an official advisory body, to be consulted on various cross-cutting issues or specific questions. It will provide input on the strategic and the technological priorities to be addressed by the JU as laid down in the SRIA; provide suggestions to enable concrete synergies to take place between the JU and the adjacent sectors or any sector with which synergies are deemed of added value; and provide input to the JU's Stakeholder forum and to the EU Hydrogen Forum of the European Clean Hydrogen Alliance. The Stakeholders Group will be regularly informed of the activities of the JU and will be invited to provide comments on the JU's planned initiatives.

An open call for expressions of interest in membership of the Stakeholders Group was launched on the same day and remained open for a month. Following the call, more than 60 applications were received, which shows a high level of interest in the activities of the JU. On 2 February 2022, the GB selected and appointed the 13 members of the Stakeholders Group, consisting of representatives of most sectors along the hydrogen value chain across the Union, including the representatives of other relevant European partnerships, of the European Hydrogen Valleys Interregional Partnership and of the scientific community ([111]). The Stakeholders Group will meet at least twice a year, and the first meeting of its newly appointed members was convened on 9 February 2022. Considering the continuous need to ensure full sector coverage, as well as geographical and gender balance, the composition of the Stakeholders Group will be reassessed in 2023.

([111]) https://www.clean-hydrogen.europa.eu/about-us/organisation/stakeholders-group_en

4. INTERNAL CONTROL FRAMEWORK

4.1. Financial procedures

The financial procedures guide JU operations and set out how it uses and manages its funds and resources. Effective implementation of COMPASS workflows adds efficiency in managing grants. Publication of calls for tenders, managing the calls (in particular soliciting questions and publishing answers), submission of offers and opening of tenders are based on IT solutions that significantly reduce the resources expended. The financial circuits were updated in September 2021 following the departure of the head of unit for finance and administration, who also acted as financial verifying agent.

4.2. *Ex ante* controls on operational expenditure

Ex ante controls are essential to prevent errors and avoid the need for *ex post* corrective action. In 2021, the JU continued to apply the provisions of Article 74 of the financial regulation and Article 21 of the JU financial rules: 'each operation shall be subject at least to an *ex ante* control relating to the operational and financial aspects of the operation, on the basis of a multiannual control strategy which takes risk into account'.

Therefore, the main objective of *ex ante* controls is to ascertain that the principles of sound financial management have been applied.

The JU has developed and continues to apply well-developed procedures defining the controls to be performed by project and finance officers for every financial claim, invoice, commitment, payment and recovery order, taking into account risk-based and cost-effectiveness considerations.

For operational expenditure, the processing and recording of transactions in ABAC are performed using the corporate H2020 IT tools (System for Grant Management (SyGMa) and COMPASS) for H2020 grants and experts, which ensures a high degree of automation, and the controls are embedded in each workflow.

Ex ante control activities in 2021 included:

- assessment of 65 periodic reports [112];
- participation of project and finance officers in H2020 project kick-off meetings in order to clearly communicate the financial reporting requirements [113];
- targeted webinars focused on the specificities of each project;
- drawing up a list of selected beneficiaries (mostly SMEs and newcomers), based on a detailed analysis of the most common audit findings and financial claims, and sending a financial questionnaire to them with the purpose of enhancing FCH beneficiaries' knowledge and strengthening their sound financial management and understanding of the H2020 rules;
- as a follow-up on the answers to the questionnaires (following H2020 guidance on risk), targeted bilateral financial webinars with the purpose of enhancing knowledge of FCH beneficiaries and strengthening their sound financial management and understanding of the H2020 rules, with individual follow-ups;
- reinforced monitoring and targeted checks during *ex ante* controls for interim and final payments, in accordance with the H2020 *ex ante* control strategy, as published by the Common Support Centre Steering Board on 18 December 2020.

[112] In total, 62 reports for H2020 and an additional 3 reports for FP7 were assessed.

[113] Due to COVID-19 restrictions, the meetings were organized online.

In addition, the JU actively contributed to the development of the Horizon Europe control strategy (*ex ante*, audit and fraud prevention) by participating in the dedicated WGs set up by the CIC and providing input. The work started in 2020 and continued in 2021.

As a result of persistent systemic errors in declared personnel costs, particularly those of SMEs and new beneficiaries (which are more error-prone than other beneficiaries), the JU had already strengthened its internal controls in 2020 to address the increased risk regarding SMEs and new beneficiaries.

In 2020, a pilot project was launched to reinforce risk-based *ex ante* controls among top JU beneficiaries. It was specifically dedicated to newcomers and SMEs. The first results were available in 2021 and showed reduced error rates (see Table 4.1).

Table 4.1: Quantitative impact of *ex ante* webinars project in 2020 and 2021 – reduced error rates

Period	Years in which *ex post* audits were launched	Error rate of representative audits (of SMEs and newcomers) closed by 31 December 2021 (%)
Before *ex ante* webinars	2017–2019	– 2.35
After introduction of *ex ante* webinars	2020–2021	– 0.74
TOTAL	**2017–2021**	**– 1.99**

The benefits of the reinforced *ex ante* controls included the following, among others:

- quantitative benefits:
  - reduced error rates and reduced amount of ineligible costs,
  - timely corrections of the potential errors *ex ante* – for example, average duration of the entire exercise from the moment of identification of the risky beneficiary until the closure of a follow-up action was 6 months, in comparison with 24–36 months for a risk-based audit (from the moment of identification until the letter of conclusion);
- qualitative benefits:
  - preventive measure with a long-term effect,
  - learning for both grant officers and beneficiaries,
  - reinforced teamwork and cooperation among officers with technical and financial knowledge.

Thanks to positive results in terms of reduced error rates, and encouraging feedback received from the beneficiaries on this initiative, the JU will continue with the reinforced risk-based controls in 2022, with aid of the reinforced monitoring tool available in the corporate COMPASS/SyGMa system for H2020 grants management.

Cost of controls

The recently re-adopted [114] financial rules of the JU envisaged that the annual activity report should indicate the efficiency and effectiveness of the internal control systems, including an **overall assessment of the costs and benefits of controls**.

The **principle of efficiency** concerns the best relationship between resources employed and results achieved. The **principle of effectiveness** concerns the attainment of the specific objectives set and the achievement of the intended results.

Efficiency and effectiveness

To demonstrate effective and efficient use of resources in order to achieve application of sound financial management in all ongoing projects as at 31 December 2021, the relationship between the cost of *ex ante* controls and the operational expenditure in 2021 as shown in Table 4.2 was considered.

[114] Decision reference CleanHydrogen-GB-2021-03 of the Governing Board of the Clean Hydrogen Joint Undertaking of 17/12/2021 adopting the transfer of decisions of the Fuel Cells and Hydrogen 2 Joint Undertaking's Governing Board to Clean Hydrogen Joint Undertaking.

Table 4.2: Proportional cost of controls as at 31 December 2021

Efficiency and effectiveness of controls as at December 2021	Operational expenditure/ running grants	Resources used on *ex ante* and *ex post* controls – estimated	Average proportion
Operational expenditure for 2021 (EUR)	95 868 825	1 020 500 ([115])	1.06 %
Number of running grants	82	6.5 FTEs	1 FTE per 12.6 grant agreements

The cost of controls represents 1.06 % of the JU operational expenditure in 2021 and can be quantified as EUR 12 445 per running grant agreement ([116]).

As an additional measure of effectiveness, we consider that the residual error rate shows a stable trend over the years, well below 2 %. In 2021 we were also able to demonstrate a significant decrease in the error rate for SMEs and newcomers after the introduction of the targeted risk-based *ex ante* webinars in 2020.

Costs and benefits

In the cost–benefit analysis, the JU considered the cost of controls employed *ex ante* and *ex post* in comparison with the amount of recoveries and ineligible costs detected either *ex ante* or *ex post*.

The ratio of the average cost to the average benefit for one running project in 2021 is 1:13 and this is mainly due to the relatively high level of rejected costs.

Table 4.3: Costs and benefits of controls as at 31 December 2021 (EUR)

BENEFITS and COSTS of CONTROLS as at 31 December 2021	Cost or benefit in EUR	Average cost or benefit of control per running grant (82 running grants)
Costs of ex ante and ex post controls in 2021 – estimated	1 020 500	12 445
Ex ante rejections (benefits)	12 087 692	
Recoveries and ex post audit adjustments in 2021	1 029 921	159 971

Tables 4.2 and 4.3 demonstrate measurable benefits of the efficient and effective use of resources in the JU to reduce error rates ensure that principles of sound financial management are well understood and followed by the JU beneficiaries. In the long-term perspective, we believe that other benefits of a preventive nature that are not directly measurable will materialise in future.

([115]) Average cost per temporary agent used for legislative financial sheets as announced by DG Budget in November 2021 is EUR 157 000 a year.
([116]) All validated costs in 2021 for running projects as at 31 December 2021 for all running programmes (both FP7 and H2020) were considered.

4.3. *Ex post* control of operational expenditure and error rates identified

The main objectives of the *ex post* controls are to ensure that legality, regularity and sound financial management (economy, efficiency and effectiveness) have been respected and to provide the basis for corrective and recovery activities, if necessary.

Horizon 2020 programme – ex post controls, audit strategy and cooperation with the Common Implementation Centre

Ex -post controls of operational expenditure for H2020 are designed and implemented in line with the H2020 *ex post* audit strategy ([117]). For H2020, the CIC (formerly known as the Common Support Centre) developed this audit strategy in cooperation with all of its clients (i.e. the entities that implement the H2020 budget: European Commission services, executive agencies and JUs).

Unit RTD.H.2 of the CIC, the Common Audit Service (CAS), ensures harmonised implementation of the H2020 *ex post* audit strategy for the EU's R&I expenditure, serving all 20 H2020 stakeholders. The CAS uses the IT tool AUDEX for audit process management. Its mission is to deliver a corporate approach to the audit cycle: audit selection, planning, application of rules, relations with beneficiaries and management information on the audit process.

The main objective of the audit strategy is to provide the individual authorising officers with the necessary elements of assurance in a timely manner, thereby allowing them to report on the budget expenditure for which they are responsible. *Ex post* controls on operational expenditure contribute in particular to:

- assessing the legality and regularity of expenditure on a multiannual basis;
- providing an indication of the effectiveness of the related *ex ante* controls;
- providing the basis for corrective and recovery mechanisms, if necessary.

The JU is effectively integrated in this control chain: it participates in defining the audit process and in monitoring its implementation in close cooperation with the CAS and its clients. The main objectives of this cooperation are to align operations and exploit synergies in the common audit effort. The efficiency gains will reduce audit costs and the administrative burden on auditees, always in line with the specific objectives explained above for *ex post* controls.

The implementation of all *ex post* audit results remains the responsibility of the JU.

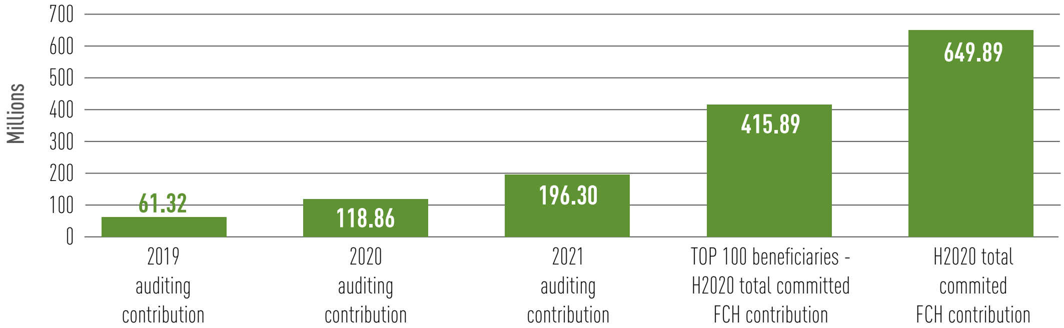
The JU also ensures the implementation of the research community's common anti-fraud strategy. The main actions derived from the strategy include the organisation of awareness-raising sessions within the JU and cooperation with OLAF (in the case of risk-based audits conducted by the CAS or outsourced contractors). Implementation of the action plan derived from the strategy is monitored by the Fraud and Irregularity Committee (see also Section 4.6).

In 2021, the following main achievements were attained.

- The JU and CAS cooperated on selecting **28 new corrective and representative H2020 *ex post* audits** for execution in 2022 with results (letter of conclusion sent) expected by 31 December 2022, focusing primarily on the top 100 beneficiaries.
- By continuous application of the JUs' sampling methodology (endorsed by the CIC Executive Committee on 19 July 2019), the JU reached **a significant cumulative audit coverage** (see Figure 4.1) of the overall H2020 expenditures, forming a strong basis for the declaration of assurance in 2021.
- It closed the 43 representative audits by 31 December 2021 (**reaching approximately half of the overall H2020 target for representative *ex post* audits**).
- The JU participated in the extension of the audit findings exercise, common to all H2020 stakeholders, enabling further cleaning of the representative error rate down **to – 1.73** % **of the residual error rate**.

([117]) Ref. Ares(2016)981660 – 25/02/2016, endorsed by the CSC Steering Board.

Figure 4.1: Cumulative audit coverage of FCH 2 JU contribution, closed audits only, in comparison with committed JU contribution for top 100 beneficiaries and entire FCH 2 JU programme, 2019–2021



Horizon 2020 *ex post* audit methodology and error rates – corporate approach

The common representative sample (CRaS) provides an estimate, through a representative sample of cost claims across the R&I family, of the **overall level of error** in the research framework programmes, across all services involved in its management. All of these grants follow the same homogeneous overall control system set out in this report.

The H2020 *ex post* audit strategy builds upon different layers of audits:

- a corporate layer consisting of a CRaS ([118]) complemented by risk-based samples,
- an additional sample for entities with specific GAs or a separate discharge procedure and Article 10 audits at the demand of the JUs.

In H2020, all 22 implementing entities were expected to follow the same homogeneous overall *ex ante* control system.

The H2020 audit campaign started in 2016. At that stage, four CRaSs with a total of 629 expected results were selected. By the end of 2021, cost claims amounting to EUR 31.8 billion had been submitted to the services by the beneficiaries.

The error rates at 31 December 2021 were:

- representative detected error rate 2.29 % ([119]);
- cumulative residual error rate for the R&I family DGs 1.60 % (1.67 % for DG Research and Innovation ([120])).

Horizon 2020 *ex post* audit methodology and error rates – joint undertaking's approach

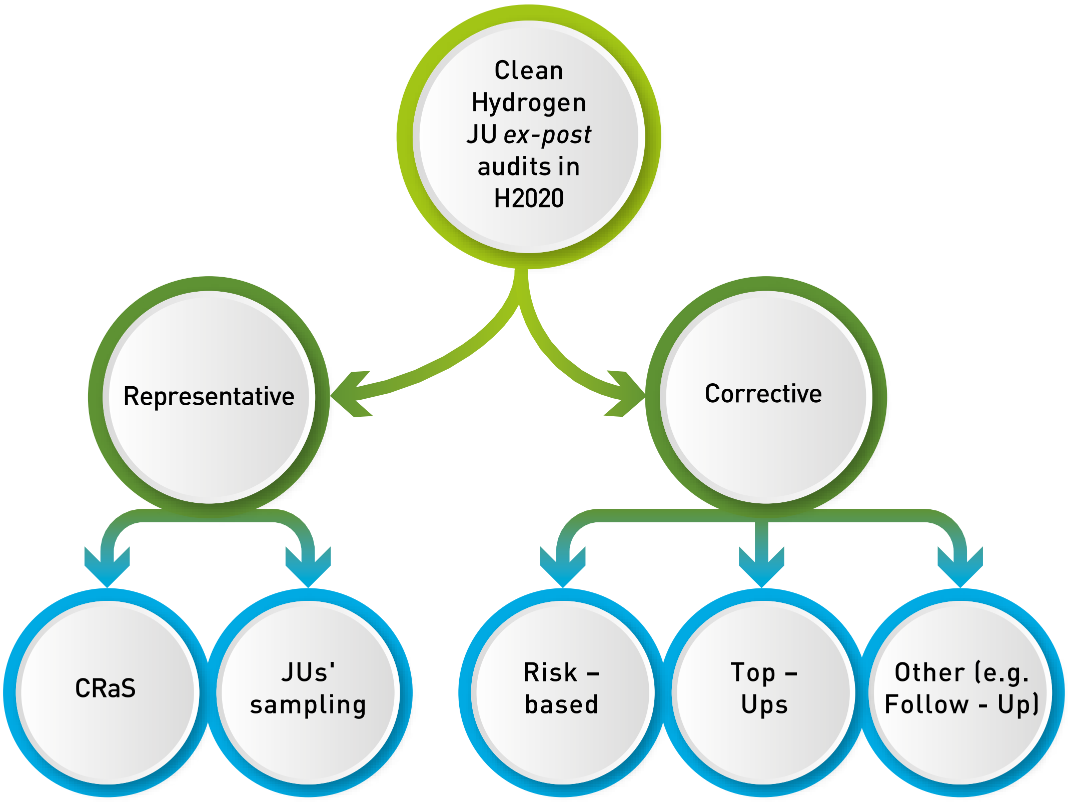
For classification, reporting and error rate calculation purposes, the JU distinguishes between representative and corrective audits (Figure 4.2). Corrective audits are defined as all audits that were not selected by statistically representative sampling.

([118]) Taken twice a year for 162 participations; monetary unit sampling is applied; population is determined by the costs declared and paid by the beneficiaries through financial statements which form the basis for calculating the EU contribution.

([119]) Based on the 418 representative results out of the 629 expected in the four CRaSs.

([120]) It should be noted that in 2021 most H2020 grants managed by DG Research and Innovation were transferred to executive agencies. Hence, this figure is based only on the actions that remained with DG Research and Innovation at the end of 2021.

Figure 4.2: H2020 *ex post* audit strategy at the JU – classification of the *ex post* audits



Given the relatively small size of the FCH 2 JU budget (overall European Commission contribution of EUR 665 million: 1 %) compared with the overall H2020 target budget (EUR 63 584 million ([121]): 100 %), the number of participations selected for *ex post* audit by the CAS through the CRaS is very limited.

This observation was confirmed by the fact that in the four rounds of CRaS (629 participations) there were only three JU participations directly hit by the monetary unit sampling. The items hit by CRaS are considered representative for calculation of the JU-specific error rates.

By 31 December 2021 there were two results available and incorporated into the JU-specific error rate calculation.

In addition to CRaS samples and in line with Annex 1 to the H2020 *ex post* audit strategy, the JU planned for additional audit sampling (i.e. the JU's specific sample) in order to ensure sufficient *ex post* audit coverage and enable a representative error rate of JU expenditure to be calculated over time. This is necessary to provide reasonable assurance to the JU Executive Director in view of his declaration of assurance and the separate discharge procedure for the JU.

By 31 December 2021, the JU had selected 153 participations for *ex post* audits (compared with the estimated target of 295 participations audited for the whole H2020 programme).

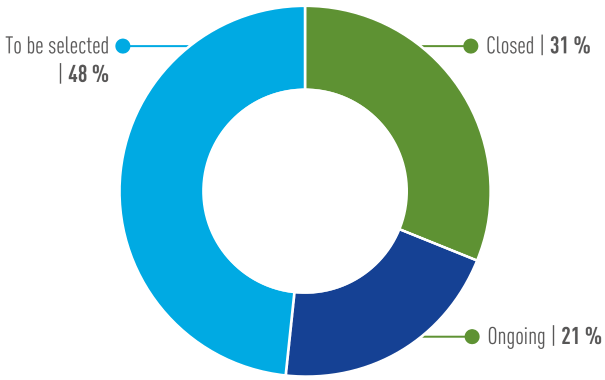
As observed in Table 4.4 and Figure 4.3, the JU is approximately in the middle of the H2020 campaign, reflecting a progressive validation of the H2020 expenditures in the ongoing actions.

Table 4.4: *Ex post* audits, completeness status at 31 December 2021

H2020 audits with JU participations	Number of participations			
	Closed	Ongoing	To be selected	H2020 overall target
Total up to 31 December 2021	92	61	142	295

([121]) H2020 operational budget of EUR 70 280 million less EUR 6 696 million related to the European Institute of Innovation & Technology financial instruments and others.

Figure 4.3: JU H2020 *ex post* audits, completeness status



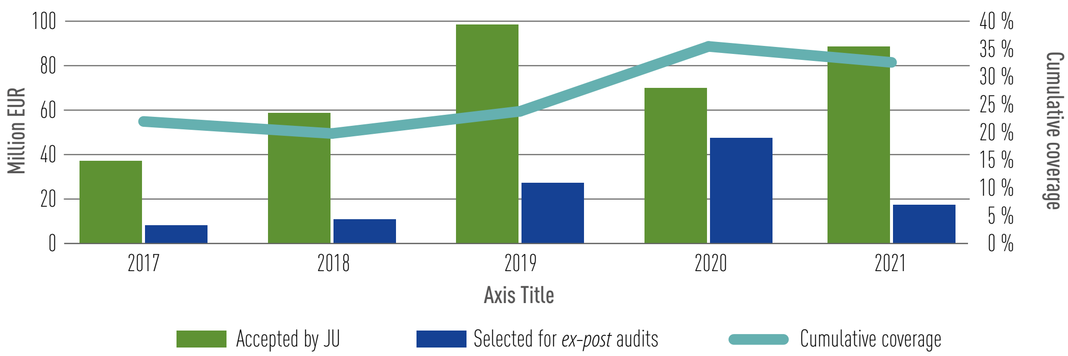
In 2021, the JU validated cost claims totalled EUR 159.78 million (EUR 88.14 million in 2020), of which EUR 88.62 million represented the EU contribution (EUR 70.03 million in 2020).

Of this EUR 88.62 million, throughout the year the JU selected corrective and representative audits to target overall audit coverage of around 20 % of H2020 expenditure (Table 4.5 and Figure 4.4).

Table 4.5: *Ex post* audits, direct audit coverage at 31 December 2021

Year	Accepted by the JU (million EUR)	Selected for ex post audits (million EUR)	Cumulative coverage (%)	Audits closed (million EUR)	Cumulative coverage (%)
2017	37.09	8.14	21.96	8.14	21.96
2018	58.65	10.80	19.79	10.80	19.79
2019	98.53	27.27	23.79	27.27	23.79
2020	70.03	47.50	35.46	9.09	20.92
2021	88.62	17.38	32.59	0.00	15.67
Total up to 31 December 2021	**352.91**	**111.09**	**31.48**	**55.30**	**15.67**

Figure 4.4: Coverage of JU contribution by H2020 *ex post* audits selected



Representative audits were selected following the JUs' common sampling methodology. This methodology was built on the principles of stratified random sampling (which is similar to the method used by the FCH JU in FP7) with the following objectives:

- efficient use of resources
- focusing on large-value cost claims
- providing an overview of the full range of projects and beneficiaries in the JU programme
- ensuring representativeness of the results, as per the International Standards on Auditing.

Risk-based audits in 2021 were selected by applying an analytical approach of reviewing the inherent risk and exposure profiles of JU beneficiaries (first step). In the second step, the selected beneficiaries were assessed internally by the project and financial officers to validate a rationale and specific risks involved in projects signed with those beneficiaries.

As a result of this approach, nine beneficiaries were selected for the risk-based audits, following a discussion with the operational services.

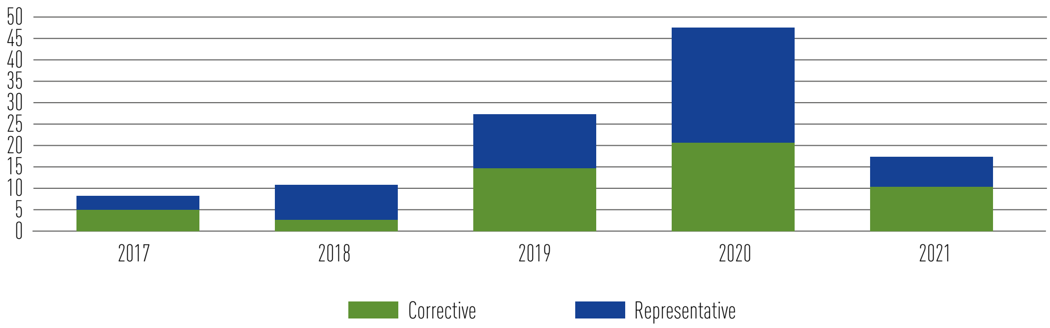
For efficiency purposes, all available cost claims validated by the JU until the audit was launched, if available, were added to the selection.

Distribution of the coverage of the two main audit streams is captured in Table 4.6 and Figure 4.5.

Table 4.6: Classification of participations selected for *ex post* audits at 31 December 2021 (million EUR)

Year	Corrective	Representative	Total
2017	4.98	3.16	**8.14**
2018	2.59	8.22	**10.80**
2019	14.66	12.61	**27.27**
2020	20.68	26.81	**47.50**
2021	10.30	7.08	**17.38**
Total up to 31 December 2021	**53.21**	**57.88**	**111.09**

Figure 4.5: Audited JU contribution up to 31 December 2021 covered by *ex post* controls (million EUR)



JU-specific error rates for H2020

For the calculation of the JU's representative error rate, only results coming from the items directly hit either by JU sampling or by monetary unit sampling of the CRaS are taken into consideration.

Results of 43 representative items were used to calculate **an indicative cumulative representative error rate on H2020 expenditure specific to the JU, as at 31 December 2021**:

- representative error rate on JU contribution – 3.84 %
- residual error rate on JU contribution – 1.73 %.

Seventh framework programme

The JU *ex post* controls of FP7 grants included financial audits carried out by external audit firms.

In 2021 no new audits were launched on FP7 projects. The last batch of FP7 audits launched in November 2019 was completed and finalised in 2020, with ongoing implementation in 2021.

Ex post audits – coverage

Table 4.7 gives an overview of the number of *ex post* audits and their audit coverage.

Table 4.7: Number of audits and audit coverage, cumulative

Batch	Year	To be launched	Ongoing	Finalised	TOTAL	Of which	
						Representative	Risk-based
1 to 12	2011–2019	0	0	145	145	120	25
Total (audits)		**0**	**0**	**145**	**145**	**120**	**25**
Total (cost claims)					**574**		
Total costs accepted by FCH JU (cumulative) (EUR) **(A)**					852 333 828		
Total costs of audits launched (cumulative) (EUR) **(B)**					189 657 854		
Total costs of audits finalised (cumulative) (EUR) **(C)**					189 657 854		
Direct audit coverage of total audits (%) **(B/A)**					22		
Direct audit coverage of finalised audits (%) **(C/A)**					22		
Total FCH JU beneficiaries **(D)**					561		
FCH JU beneficiaries audited **(E)**					142		
Audit coverage (number of beneficiaries) of total audits (%) **(E/D)**					25		

In conclusion, for the whole FP7, 145 *ex post* audits were launched, of which 120 were representative and 25 risk-based, covering in total EUR 189.66 million of accepted costs declared by the beneficiaries, with an average of EUR 1.31 million of accepted costs per individual audit.

This resulted in direct audit coverage of 25 %, from all validated costs claims by the FCH 2 JU for all 155 projects totalling EUR 852.33 million since the beginning of FP7 (as at 31 December 2021).

Ex post audits – error rates

The error rates resulting from the 145 finalised audits are as follows:

- representative error rate on the FCH contribution – 1.97 %
- residual error rate on the FCH contribution – 1.11 %.

Implementation of audit results

The JU has implemented the necessary controls and monitoring mechanisms to ensure that all errors detected in favour of the JU are corrected in due course (either through a recovery order or by offsetting a future payment).

Since the last FP7 audits were finalised at the end of 2020, implementation of the audit results was still ongoing in 2021 in line with the implementation rules and legal deadlines for FP7.

As at 31 December 2021, the JU had cumulatively implemented positive adjustments on its contribution amounting to EUR 2.24 million, stemming from the results of 145 FP7 *ex post* audits.

Implementation of extrapolation / extension of audit findings

Extension of the audit findings (formerly known as extrapolation) is the process whereby systematic errors detected in audited cost claims are extrapolated to all other non-audited JU claims from the same audited beneficiary. The timely implementation of extension of audit findings relies on beneficiaries preparing and submitting revised cost claims from which the effect of any systematic errors detected in audits has been eradicated.

The overall situation on the implementation of the extension of audit findings in the FP7 programme, is as follows:

- of 145 finalised FP7 audits, 44 (81 projects) led to extrapolation (30 %) – in other words, 1 out of 3 audits included findings of a potentially systemic nature;
- as part of the FP7 audit engagements with the external audit firms, all the cost claims potentially affected by the extrapolation were assessed by the audit firm and the results were presented to the JU for implementation.

European Court of Auditors audits

In 2020, the European Court of Auditors (ECA) started to perform additional systems testing at each JU.

This additional testing, based on a monetary unit sample of 30 transactions, should provide the additional assurance required to assess the implementation of H2020 and FP7 projects, and ensure the quality of the audit opinion, in line with auditing standards. In view of the COVID-19 situation, and to ensure the efficient use of audit resources, the ECA has requested that the necessary supporting documents be provided by the JU or final beneficiary, to perform desk reviews rather than on-site visits.

In respect of the individual discharge for each of the JUs, ECA will continue to provide each JU with a separate audit opinion.

The opinion on the legality and regularity of underlying transactions will be assessed separately taking into account the following elements:

- the JU's individual error rate from the *ex post* audits;
- the common error rate based on the results of the ECA's substantive testing;
- the error rate related to the transactions of a specific JU within the ECA's substantive testing; and
- the correctness of the calculation of the residual error rate reported by the JUs, based on the *ex post* audit results for their grant payments.

In 2021 and early in 2022, the ECA selected and reviewed 4 transactions (out of 30) from JU participations validated in 2021.

COVID-19 considerations in Horizon 2020 *ex post* audits

As a result of the COVID-19 pandemic crisis and related travel limitations during 2020 and in 2021, the CAS – in line with the instructions of the Commission – had to postpone on-site visits until further notice. To minimise the impact of COVID-19 on the implementation of the audit campaign, the CAS converted traditional in-house audit assignments into desk reviews, in line with international best practice and auditing standards. Regarding outsourced audits, the CAS instructed the audit firms to perform as many audit tests as possible remotely and then complement those with on-site audit visits once travel restrictions were eased.

4.4. Audit of the European Court of Auditors

In 2021, the JU:

- continued its cooperation with an independent auditor to audit JU accounts, as required by the JU financial rules;
- provided support for the ECA auditors in the framework of their audit on the 2020 accounts;
- liaised with ECA in their review of 4 transactions selected for the on-the-spot checks with the JU beneficiaries;
- followed up and implemented the recommendations made in the ECA's reports on the JU's 2020 annual accounts;
- assisted the ECA in its preliminary review of the accounts and legality and regularity checks conducted in connection with the 2021 annual account;
- assisted the ECA in its newly announced cross-cutting audit on the Commission's staff planning for JUs under the new programme Horizon Europe and the consequences and risks for the JU, which was launched in December 2021.

4.5. Internal audit

The internal audit is carried out in accordance with Article 20 of the JU's financial rules.

In 2021, the IAS accepted an action plan developed by the JU to address two important recommendations stemming from the IAS audit on H2020 grant implementation in the FCH 2 JU and concluded that the action plan is adequate to mitigate the risks identified.

In 2021, in line with the agreed action plan, the JU formalised the current monitoring practices regarding risks and complexity of the grant agreements and developed internal guidance for monitoring D&E of the H2020 project results – mostly referring to the D&E monitoring after the end of the project's lifetime.

The JU shared general observations and recommendations (including the recommendations raised by the IAS) concerning the implementation of the D&E plan in a letter to the director of the CIC, to which it also received a reply.

By the end of 2021, the JU considered all action plans fully implemented.

4.6. Risk management and conflict of interest

Risk management

During the annual risk assessment workshop, held in October 2021, the JU team focused on critical risks affecting the achievement of the JU's objectives and on action plans that had been identified in the previous year, and assessed their adequacy and relevance to 2021 and – for the activities of the H2020 programme that would continue the following year- 2022.

Moreover, in preparing for the transition to the Clean Hydrogen Partnership/JU, other transitional risks had already been identified. Early in 2022, an additional risk assessment exercise was conducted in order to prepare new input into an updated version of the 2022 AWP, including objectives and activities under the new partnership.

The full list of important risks and related action plans identified can be found in the 2022 AWP.

A complete risk matrix (including lower-priority risks) is regularly assessed and discussed by the management, as part of an ongoing risk assessment process, to reflect on any changes in the organisation's internal and external environment. This exercise, part of the internal control system, is designed to capture, in a timely way, any new and emerging risks that could potentially influence the achievement of the JU's objectives, as well as to provide timely reflection on the rating and relevance of the existing risks, to ensure that appropriate actions and mitigating measures are put in place.

The revision of the entire risk matrix is planned for Q2 of 2022, during which the newly emerged situation of the Ukrainian war and its impact on the JU's work plan and its activities will also be considered.

Managing potential conflict of interest

The PO has developed a comprehensive set of rules and procedures that are effectively implemented across its entire governance structure, as follows:

- when joining the PO team, each staff member agrees to the application of the staff regulation and signs a declaration of honour on the management of conflicts of interest;
- with the Executive Director's decision of 27 September 2019, the JU applies by analogy, *mutatis mutandis*, the 'Code of good administrative behaviour for staff of the European Commission in their relations with the public';
- conflict of interest procedures were in place for the members of both the FCH 2 JU GB and the advisory bodies, and were renewed in December 2021 in the scope of newly adopted rules of procedures of the GB for the Clean Hydrogen JU;
- specific measures have been implemented for the prevention and management of conflicts of interest of experts in charge of the evaluation of grant applications and of the review of projects and tenders.

In addition, the JU implements the common research anti-fraud strategy. In March 2019, the CIC adopted the revised strategy and the associated action plan. The implementation of the action plan is monitored through regular meetings of the Fraud and Irregularity Committee, in which the JU participates.

Furthermore, for areas of expenditure other than grants, the JU applies *mutatis mutandis*, by analogy, the anti-fraud strategy of DG Research and Innovation. This is relevant in particular to expert management, procurement and internal fraud, and the risk analysis leads to the conclusion that the residual risks (after mitigating actions) are low.

4.7. Compliance and effectiveness of internal control

The JU ICF is designed to provide reasonable assurance regarding the achievement of the following five objectives:

- effectiveness, efficiency and economy of operations,
- reliability of reporting,
- safeguarding of assets and information,
- prevention, detection, correction and follow-up of fraud and irregularities,
- adequate management of the risks relating to the legality and regularity of the underlying transactions.

In line with the objectives and priorities described in the 2021 AWP, the robustness of the internal control system was monitored throughout the year. Internal control matters, such as *ex ante* and *ex post* controls, segregation of duties, documented processes and procedures, and sound financial management, were discussed at least on a weekly basis during unit meetings and on an ad hoc basis when preparing new processes or revising existing operating processes. Risks identified through the annual risk assessment exercise (see Sections 1.1 and 4.6), which might pose a threat to achieving the JU's mission and objectives, were also systematically assessed and managed through appropriate controlling and mitigating actions. Throughout the year, particular efforts were made to monitor the KPIs, which led to further improvement in financial management as indicated by the TTP.

Register of exceptions, analysis of internal control weakness or control failures recorded during 2021

The PO keeps a register of all exceptions and non-compliance events; reports are entered into the register through a dedicated procedure and using predefined templates. The central register is reviewed regularly by the head of finance and administration, the IAS and, in the course of the declaration of assurance procedure, by the ECA. The reasons for the events reported in 2021 have been analysed by JU management in order to further strengthen the internal control system and ensure compliance with rules and procedures. Related risks and financial impacts have been assessed and monitored when material corrective measures were introduced (e.g. internal instructions). Other deviations considered of limited relevance after management assessment were controlled and documented in appropriate notes to the file.

Reliability of financial reporting and accounting

In addition, DG Budget carried out its annual evaluation of the JU's local financial system by reviewing the information on changes in the local systems and/or in the control environment. The DG Budget team also verified a sample of transactions for the operations authorised by the JU during the 2020 financial year. The evaluation did not identify any weaknesses in the internal control systems that would materially affect the accuracy, completeness and timeliness of the information required to draft the annual accounts and produce reliable reporting.

The self-assessment of the effectiveness of the ICF in 2021 was based on:

- an objective examination of reports and assessments carried out by the management and by internal (IAS) and external auditors (independent auditors of the annual accounts, and the ECA),
- the management's overview of progress made on the implementation of the corresponding action plans.

The latter was implemented in the following ways in 2021.

- Training and awareness sessions on cybersecurity, phishing, etc. continued. The IT systems were continuously updated.
- Mitigating measures against the COVID-19 pandemic were implemented, including vaccinations, limits on the percentage of staff physically present in the office, increased use of teleworking and adopting new ways of hybrid working.

Assessment of the functioning of the internal control system

In conclusion, it can be confirmed that the JU is in compliance with all the principles, the controls in place are working as intended, and the internal control system is providing an effective framework for managing any risks to the JU's ability to achieve its objectives.

5. MANAGEMENT assurance

5.1. Assessment of the annual activity report by the Governing Board

This section will be provided separately.

5.2. Elements supporting assurance

Reasonable assurance is the personal judgement of the JU's Executive Director – as the JU's authorising officer at the date of signature of this annual activity report – based on all the information at his disposal.

The main elements supporting the assurance are the JU's management assessment of the robustness of the JU's ICF, the results of audits from the ECA and the IAS, the reporting from the internal control and audit manager, and the reporting from the heads of unit.

No significant weaknesses were identified or reported under Section 2 ('Support to operations') and Section 4 ('Internal control framework'). Furthermore, based on their review, the heads of unit consider that, given the scope of the statement of assurance and taking into account the controls and monitoring system in place, there are no weaknesses that could call into question the reasonable assurance as to the use of resources for their intended purpose, in accordance with the principles of sound financial management, and the fact that the implemented control procedures provide the necessary guarantees of the legality and regularity of the underlying transactions.

5.3. Reservations

Horizon 2020 programme

The indicative representative error rate resulting from the 43 representative audits finalised is 3.84 % [122] (2020: 2.16 %) at JU contribution level.

The residual error rate (i.e. error remaining in the population after corrections and recoveries) calculated at this point is 1.73 % (2020: -1.34 %) at JU contribution level. This rate should develop as more audits are closed and more corrections and recoveries undertaken.

Taking the following into consideration, no reservation is necessary:

- the residual error rates, currently below 2 %
- the adequate audit coverage, comprising a representative number of finalised audits
- the experience gained by JU staff in the *ex ante* validation of cost claims
- the JU's strong and further reinforced risk-based *ex ante* controls (financial webinars, etc.).

In the opinion of the Executive Director, considering the aspects above and with the information available at this stage, it is possible to state with reasonable assurance that by the end of the programme the residual error rate will be below the materiality threshold (i.e. 2 %) established in Annex 9 below ('Materiality criteria').

[122] There was one specific outlier case, the impact of which has been absorbed and cleaned in the subsequent residual error rate calculation.

Seventh framework programme

The representative error rate resulting from the 145 representative audits finalised is stable 1.97 % (2020: 1.97 %) at JU contribution level.

The residual error rate (i.e. error remaining in the population after corrections and recoveries) is 1.11 % (2020: 1.01 %) at JU contribution level. This rate is final as all FP7 audits were closed.

JU actions towards an acceptable level of residual error rate:

The declaration of assurance in 2020 did not include a reservation, which is also the case in 2021. This is the result of the JU's firm commitment to maintain a robust internal control system in which *ex post* audits play a significant role. The residual error rate is a key indicator of the legality and regularity of the JU's transactions.

The JU actions include a combination of preventive, detective and corrective measures, and they are closely monitored. The measures/actions are as follows.

- Organisation of financial webinars to explain key aspects of the financial provisions of the H2020 model grant agreement and of financial reporting, with a focus on specificities and business models pertinent to the JU and aiming to prevent errors. Since 2016, for all new signed grants, specific targeted financial webinars have been organised within the first year following the start of the action, which are available to all members of the consortia (see also Section 4.2).
- Greater involvement by the financial officers during grant agreement preparations and in project kick-off meetings in order to check the financial aspects and clarify financial reporting requirements.
- Ad hoc financial webinars for individual projects, depending on the complexity of the project and needs of the beneficiaries.
- Since 2020, bilateral targeted webinars with beneficiaries selected based on risk assessment.
- *Ex ante* controls consistent with the guidelines on *ex ante* controls in H2020, adopted by the CIC, which are predominantly risk-based and/or justified by deviations from the budget.
- *Ex post* audits. As indicated in the sections on H2020 *ex post* audits above, the JU will ensure that, in line with Annex 1 to the H2020 audit strategy, the audit effort is sufficient to allow for adequate coverage and the calculation of a representative error rate on JU expenditure.
- Participation by the financial officers in the *ex post* audits as observers, to further improve the system of *ex ante* controls.

The JU has a clear control strategy, which is multiannual in nature and combines *ex ante* and *ex post* controls while taking cost-efficiency into consideration. Since this strategy has proved its effectiveness from an assurance point of view, the JU is fully committed to continuing its work along the same control principles and to further improving it in the upcoming Horizon Europe framework programme.

5.4. Overall conclusion

The purpose of this section is to provide an overall conclusion on the declaration of assurance as a whole (Section 6).

It is important to note that only material weaknesses/risks lead to any reservation concerning the assurances in Section 6. The concept of materiality provides the Executive Director with the basis for assessing the importance of the weaknesses/risks identified. Deciding whether something is material involves making a judgement in both qualitative and quantitative terms (see details of the materiality criteria in Annex 9).

Based on the information provided in the sections above, the following conclusions can be drawn.

- Concerning the JU's policy activities, no qualification needs to be made. Likewise, there is no reservation in the procedures relating to the selection of contractors and beneficiaries for JU grant agreements and their underlying financial operations (legal and financial commitments). This is also the case for JU's payments relating to administrative expenditure and procurement, as well as for pre-financing payments in the case of grants.
- The amounts with a greater risk of being affected by errors are the expenditures incurred against cost statements. Based on the analysis of error rates and the effectiveness of the preventive, detective and corrective actions presented in Section 5.3, no reservation is necessary in this area either.

In conclusion, the JU's management has reasonable assurance that, overall, suitable controls are in place and are working as intended, risks are being properly monitored and mitigated, and necessary improvements noted by the auditors (i.e. the IAS and the ECA) are being implemented. Therefore, the Executive Director, in his capacity as authorising officer, has signed the declaration of assurance presented in Section 6.

5.5. Statement on management reporting

For the Manager in charge of risk management and internal control:

I declare that in accordance with the JU Governing Board decision No FCH-GB-2018-12 on Revision of FCH 2 JU internal control framework, I have reported my advice and recommendations on the overall state of internal control in the JU to the Executive Director.

I hereby certify that the information provided in the present Annual Activity Report and in its annexes is, to the best of my knowledge, accurate and complete.

Brussels, 20 May 2022

signed

Philippe Binet, Head of Finance and Administration

For the Manager taking responsibility for the completeness and reliability of management reporting on results and on the achievement of objectives:

I hereby certify that the information provided in the present Annual Activity Report and in its annexes is, to the best of my knowledge, accurate and complete.

Brussels, 20 May 2022

signed

Mirela Atanasiu, Head of Unit Operations and Communications

6. DECLARATION OF ASSURANCE

I, the undersigned, Bart Biebuyck

Executive Director of the Clean Hydrogen JU

In my capacity as authorising officer

Declare that the information contained in this report gives a true and fair view [123].

State that I have reasonable assurance that the resources assigned to the activities described in this report have been used for their intended purpose and in accordance with the principles of sound financial management, and that the control procedures put in place give the necessary guarantees concerning the legality and regularity of the underlying transactions.

This reasonable assurance is based on my own judgement and on the information at my disposal, such as the results of the self-assessment, ex-post controls, the work of the internal control and audit manager, the observations of the Internal Audit Service and the lessons learnt from the reports of the Court of Auditors for years prior to the year of this declaration.

Confirm that I am not aware of anything not reported here which could harm the interests of the Joint Undertaking.

Brussels, 20 May 2022

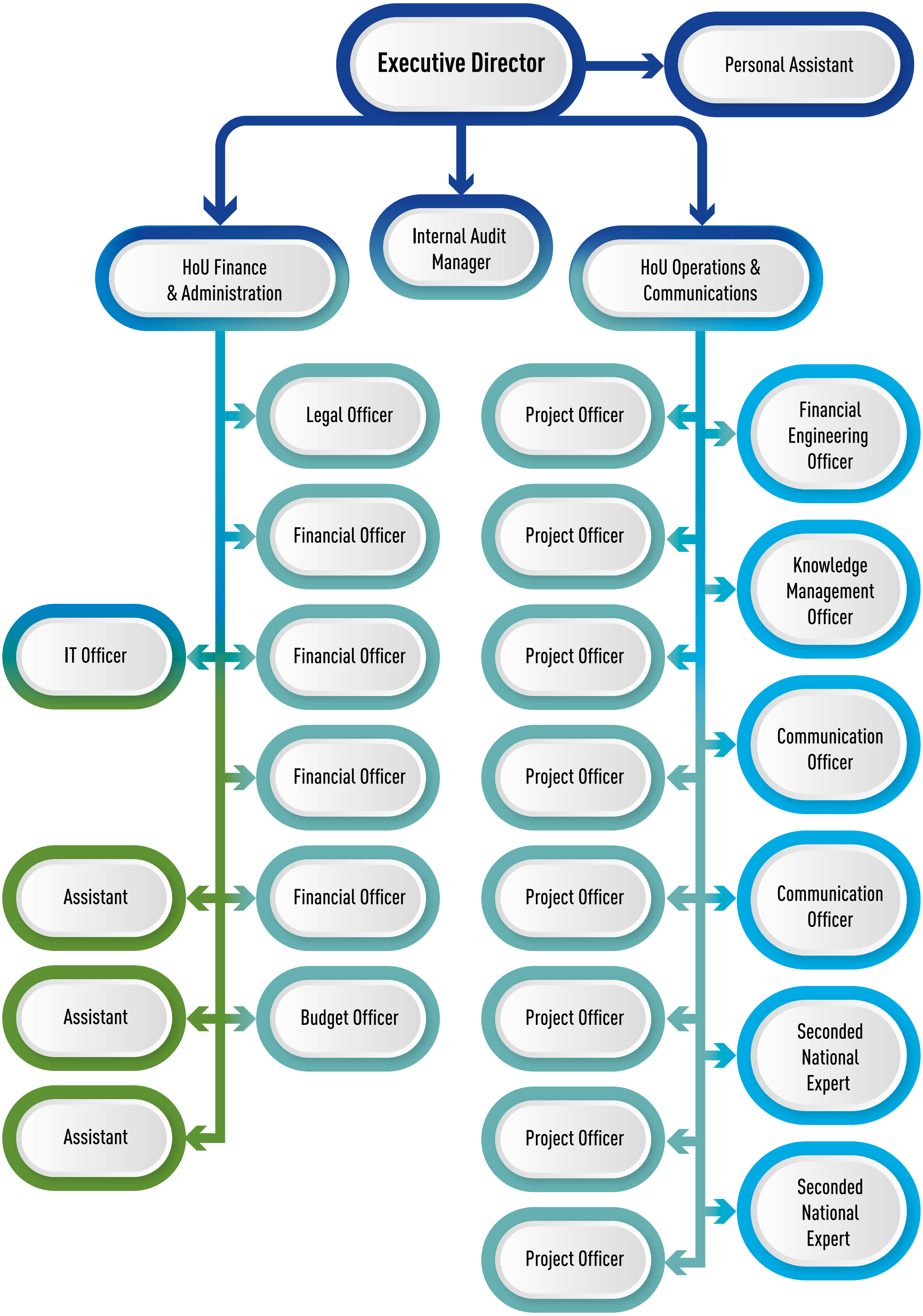
signed

Bart Biebuyck

[123]True and fair in this context means a reliable, complete and correct view on the state of affairs in the Joint Undertaking.

7. ANNEXES

Annex 1 – Organisational chart



Annex 2 – Staff Establishment Plan

The JU had 23 temporary agents, 2 contract agents and 2 SNEs on 31/12/2021.

The 2020-2021 staff establishment plan is shown below:

GRADE	2020 BUDGET	2020 FILLED	2021 BUDGET	2021 FILLED
AD 16				
AD 15				
AD 14	1	1	1	1
AD 13				
AD 12			2	1
AD 11	2	2		
AD 10				
AD 9	4	4	5	4
AD 8	4	4	3	1
AD 7	1	1	2	2
AD 6	3	3	2	5
AD 5				
Total AD	**15**	**15**	**15**	**14**
AST 11				
AST 10				
AST 9	1	1	1	1
AST 8	1	1	1	1
AST 7	1	1	1	1
AST 6	1	1	1	
AST 5	1	1	2	1
AST 4	4	4	3	5
Total AST	**9**	**9**	**9**	**9**
Function Group IV	1	1	1	1
Function Group III	1	1	1	1
Function Group II	1	1	1	
Total contract agents	**3**	**3**	**3**	**2**
Total Seconded National Experts	**2**	**2**	**2**	**2**

Annex 3 – Publications from projects

Publications related to H2020 projects. Information extracted from CORDA for the years 2020 and after, that were not already included in AAR2020. For previous years, please refer to our past Annual Activity Report publications.

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
ANIONE	CONFERENCE_ PROCEEDING	Green hydrogen production by innovative membrane electrolysis technologies			Antonino Salvatore Aricò, Stefania Siracusano, Sabrina Campagna Zignani, Alessandra Carbone	Electrolysers, Fuel Cells & H2 Processing, Proceedings of EFCF 2021 Conference,	EFCF-2021_PoC_ Proceedings_A-Sessions_ ConfVersion_s	European Fuel Cell Forum AG	Luzern-Adligenswil / Switzerland	2021	123-127	No	Yes	www.Zenodo.org
CHANNEL	PEER_ REVIEWED_ ARTICLE	Tuning Ni–MoO2 Catalyst–Ionomer and Electrolyte Interaction for Water Electrolysers with Anion Exchange Membranes	10.1021/ acsaem.0c03072	25740962	Alaa Y. Faid, Alejandro Oyarce Barnett, Frode Seland, Svein Sunde	ACS Applied Energy Materials	4/4	ACS Publications American Chemical Society	Washington, USA	2021	3327-3340	Yes	No	
ComSos	PEER_ REVIEWED_ ARTICLE	Fuel cell cogeneration for building sector: European status		1307-3729	Marta Gandiglio, Domenico Ferrero, Andrea Lanzini, Massimo Santarelli	REHVA Journal (REHVA is the Federation of European Heating, Ventilation and Air Conditioning)	01/2020 (Volume: 57 Issue: 1 February 2020)	Publisher TEKNİK SEKTÖR YAYINCILIĞI A.Ş	Barbaros Mahallesi, Uğur Sk. No: 2/2 Üsküdar/ İstanbul, Turkey	2020	Pages 21-25	No	No	
ComSos	PEER_ REVIEWED_ ARTICLE	Installation of fuel cell-based cogeneration systems in the commercial and retail sector: Assessment in the framework of the COMSOS project	10.1016/j. enconman. 2021.114202	01968904	F. Accurso, M. Gandiglio, M. Santarelli, J Buunk, T. Hakala, J. Kiviaho, S. Modena, M. Münch, E. Varkaraki	Energy Conversion and Management	239	Pergamon Press Ltd.	United Kingdom	2021	114202	Yes	No	http://hdl.handle.net/11583/2899252
COSMHYC XL	ARTICLE	Hydrogen Compression with Metal Hydrides - Novel compression concept for hydrogen refueling stations based on metal hydrides		2367-3931	Jan Zerhusen	H2international - The e-journal on hydrogen and fuel cells	04	Hydrogeit Verlag	Oberkraemer, Germany	2021	34-36	No	No	
CRESCENDO	PEER_ REVIEWED_ ARTICLE	A comparative perspective of electrochemical and photochemical approaches for catalytic H2O2 production	10.1039/ d0cs00458h	03060012	Yanyan Sun, Lei Han, Peter Strasser	Chemical Society Reviews	49/18	Royal Society of Chemistry	United Kingdom	2020	6605-6631	No	No	https://zenodo.org/deposit/5607364
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Advancements in cathode catalyst and cathode layer design for proton exchange membrane fuel cells	10.1038/s41467-021-25911-x	20411723	Yanyan Sun, Shlomi Polani, Fang Luo, Sebastian Ott, Peter Strasser, Fabio Dionigi	Nature Communications	12/1	Nature Publishing Group	United Kingdom	2021		No	No	https://zenodo.org/record/5643621

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Deactivation, reactivation and super-activation of Fe-N/C oxygen reduction electrocatalysts: Gas sorption, physical and electrochemical investigation using NO and O2	10.1016/j. apcatb.2021.120169	09263373	Paul Boldrin, Daniel Malko, Asad Mehmood, Ulrike I. Kramm, Stephan Wagner, Stephen Paul, Natascha Weidler, Anthony Kucernak	Applied Catalysis B: Environmental	292	Elsevier BV	Netherlands	2021	120169	No	Yes	https://spiral.imperial.ac.uk/handle/10044/1/87903
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Effects of the induced micro- and meso-porosity on the single site density and turn over frequency of Fe-N-C carbon electrodes for the oxygen reduction reaction	10.1016/j. apcatb.2021.120068	09263373	Marco Mazzucato, Giorgia Daniel, Asad Mehmood, Tomasz Kosmala, Gaetano Granozzi, Anthony Kucernak, Christian Durante	Applied Catalysis B: Environmental	291	Elsevier BV	Netherlands	2021	120068	No	No	https://zenodo.org/record/5607330
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Establishing reactivity descriptors for platinum group metal (PGM)-free Fe–N–C catalysts for PEM fuel cells	10.1039/ d0ee01013h	17545692	Mathias Primbs, Yanyan Sun, Aaron Roy, Daniel Malko, Asad Mehmood, Moulay-Tahar Sougrati, Pierre-Yves Blanchard, Gaetano Granozzi, Tomasz Kosmala, Giorgia Daniel, Plamen Atanassov, Jonathan Sharman, Christian Durante, Anthony Kucernak, Deborah Jones, Frédéric Jaouen, Peter Strasser	Energy & Environmental Science	13/8	Royal Society of Chemistry	United Kingdom	2020	2480-2500	No	No	https://hal.archives-ouvertes.fr/hal-03024561
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Highly Graphitised Fe-N-C Electrocatalysts Prepared from Chitosan Hydrogel Frameworks	10.3390/ catal11030390	20734344	Giorgia Daniel, Tomasz Kosmala, Federico Brombin, Marco Mazzucato, Alessandro Facchin, Maria Chiara Dalconi, Denis Badocco, Paolo Pastore, Gaetano Granozzi, Christian Durante	Catalysts	11/3	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2021	390	No	No	https://zenodo.org/record/5607307
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Identification of durable and non-durable FeNx sites in Fe–N–C materials for proton exchange membrane fuel cells	10.1038/s41929-020-00545-2	25201158	Jingkun Li, Moulay Tahar Sougrati, Andrea Zitolo, James M. Ablett, Ismail Can Oğuz, Tzonka Mineva, Ivana Matanovic, Plamen Atanassov, Ying Huang, Iryna Zenyuk, Andrea Di Cicco, Kavita Kumar, Laetitia Dubau, Frédéric Maillard, Goran Dražić, Frédéric Jaouen	Nature Catalysis	4/1	Springer Nature	United Kingdom	2021	10-19	No	Yes	https://hal.archives-ouvertes.fr/hal-02931434
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Impact of ionomer structuration on the performance of bio-inspired noble-metal-free fuel cell anodes	10.1016/j. checat.2021.01.001	26671093	Nathan Coutard, Bertrand Reuillard, Tran Ngoc Huan, Fabrice Valentino, Reuben T. Jane, Solène Gentil, Eugen S. Andreiadis, Alan Le Goff, Tristan Asset, Frédéric Maillard, Bruno Jousselme, Adina Morozan, Sandrine Lyonnard, Vincent Artero, Pascale Chenevier	Chem Catalysis	1/1	Elsevier	The Netherlands	2021	88-105	No	No	https://hal-cnrs.archives-ouvertes.fr/hal-03126604
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Noncovalent Integration of a Bioinspired Ni Catalyst to Graphene Acid for Reversible Electrocatalytic Hydrogen Oxidation	10.1021/ acsami.9b18922	19448244	Bertrand Reuillard, Matías Blanco, Laura Calvillo, Nathan Coutard, Ahmed Ghedjatti, Pascale Chenevier, Stefano Agnoli, Michal Otyepka, Gaetano Granozzi, Vincent Artero	ACS Applied Materials & Interfaces	12/5	American Chemical Society	United States	2020	5805-5811	No	No	https://hal.archives-ouvertes.fr/hal-02468287

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Stable, Active, and Methanol-Tolerant PGM-Free Surfaces in an Acidic Medium: Electron Tunneling at Play in Pt/FeNC Hybrid Catalysts for Direct Methanol Fuel Cell Cathodes	10.1021/ acscatal.0c01288	21555435	Tomasz Kosmala, Nicolas Bibent, Moulay Tahar Sougrati, Goran Dražić, Stefano Agnoli, Frédéric Jaouen, Gaetano Granozzi	ACS Catalysis	10/14	American Chemical Society	United States	2020	7475-7485	No	No	https://hal.umontpellier.fr/hal-02918327
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Sulfur Doping versus Hierarchical Pore Structure: The Dominating Effect on the Fe–N–C Site Density, Activity, and Selectivity in Oxygen Reduction Reaction Electrocatalysis	10.1021/ acsami.1c09659	19448244	Giorgia Daniel, Marco Mazzucato, Riccardo Brandiele, Laura De Lazzari, Denis Badocco, Paolo Pastore, Tomasz Kosmala, Gaetano Granozzi, Christian Durante	ACS Applied Materials & Interfaces	13/36	American Chemical Society	United States	2021	42693-42705	No	No	https://zenodo.org/record/5607252
CRESCENDO	PEER_ REVIEWED_ ARTICLE	Upcycling of polyurethane into iron-nitrogen-carbon electrocatalysts active for oxygen reduction reaction	10.1016/j.electacta. 2020.137200	00134686	Giorgia Daniel, Tomasz Kosmala, Maria Chiara Dalconi, Luca Nodari, Denis Badocco, Paolo Pastore, Alessandra Lorenzetti, Gaetano Granozzi, Christian Durante	Electrochimica Acta	362	Pergamon Press Ltd.	United Kingdom	2020	137200	No	No	https://doi.org/10.5281/zenodo.5607358
DEMOSOFC	PEER_ REVIEWED_ ARTICLE	Pathways to commercialisation of biogas fuelled solid oxide fuel cells in European wastewater treatment plants	10.1016/j.apenergy. 2020.116127	03062619	Gbemi Oluleye, Marta Gandiglio, Massimo Santarelli, Adam Hawkes	Applied Energy	282	Pergamon Press Ltd.	United Kingdom	2021	116127	No	Yes	
eGHOST	CONFERENCE_ PROCEEDING	Social Life Cycle Assessment of a Proton Exchange Membrane Fuel Cell stack	10.1051/e3sconf/ 202233409001		Eleonora Bargiacchi, Felipe Campos-Carriedo, Diego Iribarren and Javier Dufour	EFC21 - European Fuel Cells and Hydrogen Piero Lunghi Conference	Volumen 334	EDP Sciences	E3S Web of Conferences 334, 09001 (2022)	2022		No	Yes	https://www.e3s-conferences.org/ articles/e3sconf/abs/2022/01/e3sconf_ efc2022_09001/e3sconf_efc2022_09001. html
EMPOWER	PEER_ REVIEWED_ ARTICLE	Hydrogen production via aqueous-phase reforming for high-temperature proton exchange membrane fuel cells - a review	10.12688/ openreseurope. 13812.1	27325121	Paranjeet Lakhtaria, Paulo Ribeirinha, Werneri Huhtinen, Saara Viik, José Sousa, Adélio Mendes	Open Research Europe	1	European Commission	https://open-research-europe.ec.europa.eu/ articles/1-81/v1	2021	81	Yes	Yes	https://doi.org/10.12688/ openreseurope.13812.1
EMPOWER	THESIS_ DISSERTATION	Development and characterisation of an aqueous phase methanol reformer for a fuel cell system			Huhtinen, Werneri			Aalto University	Espoo, Finland	2021		No	Yes	
EMPOWER	THESIS_ DISSERTATION	Development and characterisation of a thermoelectric generator for a fuel cell system			Hospu, Jeremias			Aalto University	Espoo, Finland	2021		No	Yes	
FCHgo	PEER_ REVIEWED_ ARTICLE	FCHgo: Fuel Cells Hydrogen educational model for schools, an imaginative approach to hydrogen and fuel cell technology for young students and their teachers	10.1088/1742-6596/1929/ 1/012019	17426588	E Dumont, H U Fuchs, F Corni, A Contini, T Altiero, M Romagnoli, G P Karwasz	Journal of Physics: Conference Series	1929/1	Institute of Physics	United Kingdom	2021	012019	No	No	https://drive.google.com/file/d/1N2lP_fN-9VxVARyC9U4dDbN3149owsYn/ view?usp=sharing
FLAGSHIPS	CONFERENCE_ PROCEEDING	FLAGSHIPS: Deploying Two Hydrogen Vessels in Europe – Design Phase	10.5957/smc-2021-028		Jyrki Mikkola, Alexandre Bellot, Arber Haxhiu, Maria Luisa Angrisani, Victor Laravoire, Hilde-Kristin Sæter, Pavel Berg			OnePetro	Providence, Rhode Island, USA	2021		No	No	https://onepetro.org/SNAMESMC/ proceedings-abstract/SMC21/2-SMC21/ D021S002R002/470680

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FLAGSHIPS	PEER_ REVIEWED_ ARTICLE	Electric Power Integration Schemes of the Hybrid Fuel Cells and Batteries-Fed Marine Vessels – An Overview	10.1109/ tte.2021.3126100	2332-7782	Arber Haxhiu, Ahmed Abdelhakim, Sami Kanerva and Jostein Bogen	IEEE Transactions on Transportation Electrification		IEEE	electronic	2021		Yes	No	https://ieeexplore.ieee.org/ document/9606740
FLHYSAFE	CONFERENCE_ PROCEEDING	A Novel Re-configurable LLC Converter for Electric Aircraft	10.1109/ecce-asia49820. 2021.9479165		Sumantra Bhattacharya; Caroline Willich; Pia Hoenicke; Josef Kallo	2021 IEEE 12th Energy Conversion Congress & Exposition - Asia (ECCE-Asia)		IEEE	Singapore	2021		No	Yes	https://ieeexplore.ieee.org/ document/9479165
FLHYSAFE	CONFERENCE_ PROCEEDING	A seamless Functional Hazard Analysis for a fuel cell system supported by Spreadsheets	10.3850/978-981-18-2016-8_114-cd	978-981-18-2016-8	Axel BERRES, Tim BITTNER	Proceedings of the 31st European Safety and Reliability Conference		Research Publishing	Singapore	2021		No	No	https://rpsonline.com.sg/ proceedings/9789811820168/pdf/114.pdf
FLHYSAFE	PEER_ REVIEWED_ ARTICLE	Proposal of a New Technique to Obtain Some Fuel Cell Internal Parameters Using Polarisation Curve Tests and EIS Results	10.3390/ en14217161	19961073	Guillermo Gómez, Pilar Argumosa, Adrian Correro, Jesús Maellas	Energies	14/21	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2021	7161	No	No	https://www.mdpi.com/1996-1073/14/21/7161/htm
GAIA	PEER_ REVIEWED_ ARTICLE	Advancements in cathode catalyst and cathode layer design for proton exchange membrane fuel cells	10.1038/s41467-021-25911-x	20411723	Yanyan Sun, Shlomi Polani, Fang Luo, Sebastian Ott, Peter Strasser, Fabio Dionigi	Nature Communications	12/1	Nature Publishing Group	United Kingdom	2021		No	No	https://zenodo.org/record/5643621
GAIA	PEER_ REVIEWED_ ARTICLE	Design and Validation of a Fluidised Bed Catalyst Reduction Reactor for the Synthesis of Well-Dispersed Nanoparticle Ensembles	10.1149/1945-7111/ aba4eb	19457111	Elisabeth Hornberger, Henrike Schmies, Benjamin Paul, Stefanie Kühl, Peter Strasser	Journal of The Electrochemical Society	167/11	The Electrochemical Society	USA	2020	114509	No	Yes	https://iopscience.iop.org/ article/10.1149/1945-7111/aba4eb
GAIA	PEER_ REVIEWED_ ARTICLE	Enhancing the activity and stability of carbon-supported platinum–gadolinium nanoalloys towards the oxygen reduction reaction	10.1039/ d1na00740h	25160230	C. A. Campos-Roldán, F. Pailloux, P.-Y. Blanchard, D. J. Jones, J. Rozière, S. Cavaliere	Nanoscale Advances	4	Royal society of chemistry	United Kingdom	2021	26-29	No	No	https://hal.archives-ouvertes.fr/hal-03432743/
GAIA	PEER_ REVIEWED_ ARTICLE	Rational Design of Carbon-Supported Platinum–Gadolinium Nanoalloys for Oxygen Reduction Reaction	10.1021/ acscatal.1c02449	21555435	Carlos A. Campos-Roldán, Frédéric Pailloux, Pierre-Yves Blanchard, Deborah J. Jones, Jacques Rozière, Sara Cavaliere	ACS Catalysis	11/21	American Chemical Society	United States	2021	13519-13529	No	Yes	https://hal.archives-ouvertes.fr/hal-03424386/
GAIA	PEER_ REVIEWED_ ARTICLE	Seed-Mediated Synthesis and Catalytic ORR Reactivity of Facet-Stable, Monodisperse Platinum Nano-Octahedra	10.1021/ acsaem.1c01696	25740962	Elisabeth Hornberger, Valentina Mastronardi, Rosaria Brescia, Pier Paolo Pompa, Malte Klingenhof, Fabio Dionigi, Mauro Moglianetti, Peter Strasser	ACS Applied Energy Materials	4/9	American Chemical Society	USA	2021	9542-9552	No	Yes	
HIGGS	CONFERENCE_ PROCEEDING	Hydrogen In Gas GridS: a systematic validation approach at various admixture levels into high-pressure grids			Agustin Pascual Aranda			Gasnam	https:// greengasmobilitysummit. com/edicionesanteriores/ ggms2020/	2020		No	No	

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HIGGS	CONFERENCE_ PROCEEDING	Injection of hydrogen in high-pressure gas grids: technical, regulatory and legal aspects			Javier Sánchez-Laínez, Rodrigo Pérez, Alberto Cerezo, Virginia Madina, Michael Walter, Vanesa Gil1			WHTC 2021	Montreal (Canada)	2021		No	No	
HIGGS	CONFERENCE_ PROCEEDING	Presentation of project HIGGS			Vanesa Gil	EU Green Week		ERIG	Virtual	2021		No	No	
HIGGS	CONFERENCE_ PROCEEDING	Presentation of project HIGGS			Vanesa Gil	European Hydrogen Forum 2021		European Clean Hydrogen Alliance	Belguium	2020		No	No	
HIGGS	OTHER	Presentation of HIGGS project			Vanesa Gil	Prime movers' group on Gas Quality and H2 handling Sub-Group 2) #2 meeting		ENTSOG	Belgium	2021		No	No	
HyCARE	OTHER	Characterisation of powder and pellets	10.5281/ zenodo.4638519		Dematteis, Erika Michela; Cuevas, Fermin; Latroche, Michel			Zenodo	Zenodo	2021		No	No	https://zenodo.org/record/4638519
HyCARE	OTHER	Data Management Plan M6	10.5281/ zenodo.3824773		Sabina Fiorot		1	Zenodo	Zenodo	2020		No	No	https://zenodo.org/record/3824773
HyCARE	OTHER	Design of hydrogen-heat-storage module	10.5281/ zenodo.4639812		Capurso, Giovanni		1	Zenodo	Zenodo	2020		No	No	https://zenodo.org/record/4639812
HyCARE	OTHER	Optimised alloy composition	10.5281/ zenodo.3712826		Erika Michela Dematteis; Fermin Cuevas; Michel Latroche		1	Zenodo	Zenodo	2020		No	No	https://dx.doi.org/10.5281/zenodo.3712826
HyCARE	OTHER	Processing parameters	10.5281/ zenodo.3712858		Dematteis, Erika Michela; Cuevas, Fermin; Latroche, Michel			Zenodo	Zenodo	2020		No	No	https://zenodo.org/record/3712858
HyCARE	OTHER	Selected alloy characterisation	10.5281/ zenodo.3712849		Dematteis, Erika Michela; Cuevas, Fermin; Latroche, Michel		1	Zenodo	Zenodo	2020		No	No	https://dx.doi.org/10.5281/zenodo.3712849
HyCARE	PEER_ REVIEWED_ ARTICLE	Fundamental hydrogen storage properties of TiFe-alloy with partial substitution of Fe by Ti and Mn	10.1016/j. jallcom.2021. 159925	0925-8388	Erika Michela Dematteis; David Michael Dreistadt; Giovanni Capurso; Julian Jepsen; Julian Jepsen; Fermin Cuevas; Michel Latroche	Journal of Alloys and Compounds	8	Elsevier BV	Netherlands	2021	159925	No	Yes	https://hal.archives-ouvertes.fr/hal-03211535
HyCARE	PEER_ REVIEWED_ ARTICLE	Metal (boro-) hydrides for high energy density storage and relevant emerging technologies	10.1016/j.ijhydene. 2020.08.119	0360-3199	L. J. Bannenberg; Michael Heere; Michael Heere; H. Benzidi; Jorge Montero; Erika Michela Dematteis; Erika Michela Dematteis; Suwarno Suwarno; Tomasz Jaroń; M. Winny; P. A. Orłowski; Wojciech Wegner; Agnieszka Starobrat; Karol J. Fijalkowski; Wojciech Grochala; Zhao Qian; J.-P. Bonnet; Ioana Nuta; Wiebke Lohstroh; Claudia Zlotea; Omar Mounkachi; Fermin Cuevas; C. Chatillon; Michel Latroche; Maxim	International Journal of Hydrogen Energy	7	Pergamon Press Ltd.	United Kingdom	2020		No	Yes	https://hal.archives-ouvertes.fr/hal-02954746

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
HyCARE	PEER_ REVIEWED_ ARTICLE	Solid-State Hydrogen Storage Systems and the Relevance of a Gender Perspective	10.3390/ en14196158	1996-1073	Erika Michela Dematteis; Jussara Barale; Marta Corno; Alessandro Sciullo; Marcello Baricco; Paola Rizzi	Energies		Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2021		No	No	https://www.mdpi.com/1996-1073/14/19/6158
HyCARE	PEER_ REVIEWED_ ARTICLE	Substitutional effects in TiFe for hydrogen storage: a comprehensive review	10.1039/ d1ma00101a	2633-5409	Erika Michela Dematteis; Erika Michela Dematteis; Nicola Berti; Fermin Cuevas; Michel Latroche; Marcello Baricco	Materials Advances	2	Royal Society of Chemistry	Cambridge, United Kingdom	2021	2524	No	No	https://hal.archives-ouvertes.fr/hal-03190450
HyResponder	PEER_ REVIEWED_ ARTICLE	Hydrogen Jet Fire from a Thermally Activated Pressure Relief Device (TPRD) from Onboard Storage in a Naturally Ventilated Covered Car Park	10.3390/ hydrogen2030018	26734141	Harem Hussein, Síle Brennan, Vladimir Molkov	Hydrogen	2/3	MDPI	Online	2021	343-361	No	No	
HyStorIES	ARTICLE	Wodór jako paliwo przysz³oœci. Wyzwania dla polskiej geologii		0033-2151	Radoslaw Tarkowski	Przegl¹d Geologiczny Journal	vol. 69, nr 4, 2021	Panstwowy Instytut Geologiczny	Poland	2021		No	No	https://www.pgi.gov.pl/dokumenty-pig-pib-all/publikacje-2/przeglad-geologiczny/2021-2/4-kwiecien-1/8374-wodor-jako-paliwo-przyszlosci-wyzwania-dla-polskiej-geologii/file.html
HyStorIES	CONFERENCE_ PROCEEDING	Four Ways to Store Large Quantities of Hydrogen	10.2118/208178-ms	978-1-61399-834-2	Louis Londe	Paper presented at the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE	November 2021.	OnePetro	online	2021		No	Yes	https://hystories.eu/wp-content/uploads/2022/01/Unformated-Londe_H2_ADIPEC_SPE-208178-MS.pdf
ID-FAST	PEER_ REVIEWED_ ARTICLE	Advancement of Segmented Cell Technology in Low Temperature Hydrogen Technologies	10.3390/ en13092301	19961073	Indro Biswas, Daniel G. Sánchez, Mathias Schulze, Jens Mitzel, Benjamin Kimmel, Aldo Saul Gago, Pawel Gazdzicki, K. Andreas Friedrich	Energies	13/9	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2020	2301	No	No	https://www.mdpi.com/1996-1073/13/9/2301
ID-FAST	PEER_ REVIEWED_ ARTICLE	Mitigated Start-Up of PEMFC in Real Automotive Conditions: Local Experimental Investigation and Development of a New Accelerated Stress Test Protocol	10.1149/1945-7111/ abf77b	00134651	Andrea Bisello, Elena Colombo, Andrea Baricci, Claudio Rabissi, Laure Guetaz, Pawel Gazdzicki, Andrea Casalegno	Journal of The Electrochemical Society	168/5	Electrochemical Society, Inc.	United States	2021	054501	No	No	http://hdl.handle.net/11311/1177724
ID-FAST	PEER_ REVIEWED_ ARTICLE	Mitigating PEMFC Degradation During Start-Up: Locally Resolved Experimental Analysis and Transient Physical Modelling	10.1149/1945-7111/ abf4eb	00134651	Elena Colombo, Andrea Bisello, Andrea Casalegno, Andrea Baricci	Journal of The Electrochemical Society	168/5	Electrochemical Society, Inc.	United States	2021	054508	No	No	http://hdl.handle.net/11311/1177796
ID-FAST	PEER_ REVIEWED_ ARTICLE	The Challenges in Reliable Determination of Degradation Rates and Lifetime in Polymer Electrolyte Membrane Fuel Cells	10.1016/j. coelec.2021.100863	24519103	Qian Zhang, Corinna Harms, Jens Mitzel, Pawel Gazdzicki, K. Andreas Friedrich	Current Opinion in Electrochemistry		Elseiver	online	2021		No	No	https://elib.dlr.de/144829/
LOWCOST-IC	PEER_ REVIEWED_ ARTICLE	Fast and stable approximation of laminar and turbulent flows in channels by Darcy's Law	10.1016/j. aej.2020.12.033	1110-0168	Omid Babaie Rizvandi, Xing-Yuan Miao, Henrik Lund Frandsen	Alexandria Engineering Journal	Vol. 60	Alexandria University	Egypt	2021	2155-2165	No	No	https://orbit.dtu.dk/en/publications/fast-and-stable-approximation-of-laminar-and-turbulent-flows-in-c

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
LOWCOST-IC	PEER_ REVIEWED_ ARTICLE	High toughness well conducting contact layers for solid oxide cell stacks by reactive oxidative bonding	10.1016/j. jeurceramsoc. 2020.11.021	0955-2219	Ilaria Ritucci, Belma Talic, Ragnar Kiebach, Henrik Lund Frandsen	Journal of the European Ceramic Society	Vol. 41	Elsevier BV	Netherlands	2021	2699-2708	No	No	https://orbit.dtu.dk/en/publications/high-toughness-well-conducting-contact-layers-for-solid-oxide-cel
LOWCOST-IC	PEER_ REVIEWED_ ARTICLE	Modelling of local mechanical failures in solid oxide cell stacks	10.1016/j.apenergy. 2021.116901	0306-2619	Xing-Yuan Miao, Omid Babaie Rizvandi, Maria Navasa, Henrik Lund Frandsen	Applied Energy	Vol. 293	Pergamon Press Ltd.	United Kingdom	2021	116901	No	No	https://orbit.dtu.dk/en/publications/modelling-of-local-mechanical-failures-in-solid-oxide-cell-stacks
LOWCOST-IC	PEER_ REVIEWED_ ARTICLE	Self-healing properties of Ce/ Co-coated stainless steel under simulated intermediate temperature solid oxide fuel cell conditions	10.1016/j.surfcoat. 2021.127894	0257-8972	Claudia Goebel, Vijayshankar Asokan, Sarah Khieu, Jan-Erik Svensson, Jan Froitzheim	Surface and Coatings Technology	Vol. 428	Elsevier BV	Netherlands	2021	127894	No	No	https://research.chalmers.se/en/publication/527227
MAMA-MEA	PEER_ REVIEWED_ ARTICLE	An experimental approach to evaluate drying kinetics and foam formation in inks for inkjet printing of fuel-cell layers		0894-1777	P.E. Santangelo, M. Romagnoli, M. Puglia	Experimental Thermal and Fluid Science		Elsevier BV	Netherlands	2021		No	No	
MAMA-MEA	PEER_ REVIEWED_ ARTICLE	Smart catalyst deposition by 3D printing for Polymer Electrolyte Membrane Fuel Cell manufacturing	10.1016/j. renene.2020.08.064	09601481	Maria Cannio, Stefania Righi, Paolo E. Santangelo, Marcello Romagnoli, Rolando Pedicini, Alessandra Carbone, Irene Gatto	Renewable Energy	163	Pergamon Press Ltd.	United Kingdom	2021	414-422	No	No	
NEWELY	PEER_ REVIEWED_ ARTICLE	From polybenzimidazoles to polybenzimidazoliums and polybenzimidazolides	10.1039/d0ta01788d	20507488	David Aili, Jingshuai Yang, Katja Jankova, Dirk Henkensmeier, Qingfeng Li	Journal of Materials Chemistry A	8/26	Royal Society of Chemistry	United Kingdom	2020	12854-12886	No	Yes	https://zenodo.org/record/5031357
NewSOC	PEER_ REVIEWED_ ARTICLE	3D printing the next generation of enhanced solid oxide fuel and electrolysis cells	10.1039/d0ta02803g	20507488	Arianna Pesce, Aitor Hornés, Marc Núñez, Alex Morata, Marc Torrell, Albert Tarancón	Journal of Materials Chemistry A	8/33	Royal Society of Chemistry	United Kingdom	2020	16926-16932	No	No	
NewSOC	PEER_ REVIEWED_ ARTICLE	An Elementary Kinetic Model for the LSCF and LSCF-CGO Electrodes of Solid Oxide Cells: Impact of Operating Conditions and Degradation on the Electrode Response	10.1149/1945-7111/ abf40a	00134651	E. Effori, J. Laurencin, E. Da Rosa Silva, M. Hubert, T. David, M. Petitjean, G. Geneste, L. Dessemond, E. Siebert	Journal of The Electrochemical Society	168/4	Electrochemical Society, Inc.	United States	2021	044520	Yes	Yes	https://hal.archives-ouvertes.fr/hal-03205084
NewSOC	PEER_ REVIEWED_ ARTICLE	Effect of the PH2O/PCO2 and PH2 on the intrinsic electro-catalytic interactions and the CO production pathway on Ni/GDC during solid oxide H2O/CO2 co-electrolysis	10.1016/j. jcat.2021.09.024	00219517	E. Ioannidou, M. Chavani, S.G. Neophytides, D.K. Niakolas	Journal of Catalysis	404	Academic Press	United States	2021	174-186	No	No	http://hdl.handle.net/10889/15309
NewSOC	PEER_ REVIEWED_ ARTICLE	Electrical characterisation of glass-ceramic sealant-metallic interconnect joined samples under solid oxide electrolysis cell conditions; influence on the microstructure and composition at the different polarised interfaces	10.1016/j.ceramint. 2020.11.176	02728842	Hassan Javed, Kai Herbrig, Antonio Gianfranco Sabato, Domenico Ferrero, Massimo Santarelli, Christian Walter, Federico Smeacetto	Ceramics International	47/6	Pergamon Press Ltd.	United Kingdom	2021	8184-8190	Yes	No	

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NewSOC	PEER_ REVIEWED_ ARTICLE	Electrode kinetics of porous Ni-3YSZ cermet operated in fuel cell and electrolysis modes for solid oxide cell application	10.1016/j.electacta. 2021.138765	00134686	Federico Monaco, Elisa Effori, Maxime Hubert, Elisabeth Siebert, Gregory Geneste, Bertrand Morel, Elisabeth Djurado, Dario Montinaro, Jérôme Laurencin	Electrochimica Acta	389	Pergamon Press Ltd.	United Kingdom	2021	138765	Yes	Yes	https://hal.archives-ouvertes.fr/hal-03267352
PECSYS	PEER_ REVIEWED_ ARTICLE	Host, Suppressor, and Promoter—The Roles of Ni and Fe on Oxygen Evolution Reaction Activity and Stability of NiFe Alloy Thin Films in Alkaline Media	10.1021/ acscatal.1c01190	21555435	Fuxi Bao, Erno Kemppainen, Iris Dorbandt, Fanxing Xi, Radu Bors, Natalia Maticiuc, Robert Wenisch, Rory Bagacki, Christian Schary, Ursula Michalczik, Peter Bogdanoff, Iver Lauermann, Roel van de Krol, Rutger Schlatmann, Sonya Calnan	ACS Catalysis	11/16	American Chemical Society	United States	2021	10537-10552	No	Yes	https://pubs.acs.org/doi/10.1021/ acscatal.1c01190
PEGASUS	PEER_ REVIEWED_ ARTICLE	Fe doped porous triazine as efficient electrocatalysts for the oxygen reduction reaction in acid electrolyte	10.1016/j. apcatb.2019.118507	09263373	Álvaro García, María Retuerto, Carlota Dominguez, Laura Pascual, Pilar Ferrer, Diego Gianolio, Aida Serrano, Pia Aßmann, Daniel G. Sanchez, Miguel A. Peña, Sergio Rojas	Applied Catalysis B: Environmental	264	Elsevier BV	Netherlands	2020	118507	No	No	https://digital.csic.es/ handle/10261/211725?mode=full
PEGASUS	PEER_ REVIEWED_ ARTICLE	Impact of the Cathode Layer Printing Process on the Performance of MEA Integrating PGM Free Catalyst	10.3390/ catal11060669	20734344	Pierre Toudret, Jean-François Blachot, Marie Heitzmann, Pierre-André Jacques	Catalysts	11/6	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	2021	669	No	No	
PRETZEL	PEER_ REVIEWED_ ARTICLE	Electrochemical Evaluation of Niobium Corrosion Resistance in Simulated Anodic PEM Electrolyser Environment	10.20964/ 2020.11.47	14523981	Andrea Kellenberger	International Journal of Electrochemical Science	15	Electrochemical Science Group, University of Belgrade	Serbia	2020	10664-10673	No	Yes	
PRETZEL	PEER_ REVIEWED_ ARTICLE	Porous Transport Layers for Proton Exchange Membrane Electrolysis Under Extreme Conditions of Current Density, Temperature, and Pressure	10.1002/ aenm.202100630	16146832	Svenja Stiber, Harald Balzer, Astrid Wierhake, Florian Josef Wirkert, Jeffrey Roth, Ulrich Rost, Michael Brodmann, Jason Keonhag Lee, Aimy Bazylak, Wendelin Waiblinger, Aldo Sau Gago, Kaspar Andreas Friedrich	Advanced Energy Materials	11/33	Wiley-VCH Verlag	Germany	2021	2100630	Yes	Yes	
REFLEX	ARTICLE	Development of an efficient rSOC based renewable energy storage system	10.1149/ 10301.0337ecst	19385862	1. Julie Mougin, Geraud Cubizolles, Anne Hauch, Jari Pennanen, Joaquin Alvarez, Sergii Pylypko, Marc Potron, Bastien Marquillier, Stephane Hody, Gianna Cesareo, Sabina Fiorot, Guillermo Perez	ECS Transactions	103 (1), 2021	Electrochemical Society, Inc.	United States	2021	337-350	No	No	
REFLEX	ARTICLE	Load Cycling Tests of Reversible Solid Oxide Cells – Effects of Current Density, Steam Content and Utilisation	10.1149/ 10301.0437ecst	19385862	Anne Hauch, S. Pylypko, Geraud Cubizolles and J. Mougin	ECS Transations	103 (1), 2021	Electrochemical Society, Inc.	United States	2021	437-450	No	No	
REFLEX	ARTICLE	Stack Optimisation and Testing for its Integration in a rSOC-Based Renewable Energy Storage System	10.1149/ 10301.0351ecst	19385862	G. Cubizolles, J. Mougin, S. Di Iorio, P.Hanoux and S. Pylypko	ECS Transations	103 (1), 2021	Electrochemical Society, Inc.	United States	2021	351-361	No	No	

Project Acronym	CR Publ Type	CR Publ Title	CR Publ DOI	CR Publ ISSN	CR Publ Authors	CR Publ Journal Title	CR Publ Journal Nbr	CR Publ Publisher	CR Publ Published Place	CR Publ Published Year	CR Publ Relevant Pages	CR Publ Is Joint Public/ Private?	CR Publ In Green O-A ?	CR Publ Repository URL
REMOTE	ARTICLE	REMOTE: Green hydrogen to support renewable energy storage in remote communities		2516-3817	Massimo Santarelli	Open Access Government	October 2021	Adjacent Digital Politics Ltd	United Kingdom	2021		No	No	
REMOTE	PEER_ REVIEWED_ ARTICLE	An MILP approach for the optimal design of renewable battery-hydrogen energy systems for off-grid insular communities	10.1016/j. enconman. 2021.114564	0196-8904	Paolo Marocco, Domenico Ferrero, Emanuele Martelli, Massimo Santarelli, Andrea Lanzini	Energy Conversion and Management	Volume 245, 1 October 2021, 114564	Pergamon Press Ltd.	United Kingdom	2021		No	No	http://hdl.handle.net/11583/2917770
REMOTE	PEER_ REVIEWED_ ARTICLE	A study of the techno-economic feasibility of H2-based energy storage systems in remote areas	10.1016/j. enconman. 2020.112768	01968904	P. Marocco, D. Ferrero, M. Gandiglio, M.M. Ortiz, K. Sundseth, A. Lanzini, M. Santarelli	Energy Conversion and Management	211	Pergamon Press Ltd.	United Kingdom	2020	112768	No	Yes	https://api.elsevier.com/content/article/PII:S019689042030306X?httpAccept=text/xml
REMOTE	PEER_ REVIEWED_ ARTICLE	Energy management strategies based on hybrid automata for islanded microgrids with renewable sources, batteries and hydrogen	10.1016/j.rser. 2020.110118	13640321	A. Kafetzis, C. Ziogou, K.D. Panopoulos, S. Papadopoulou, P. Seferlis, S. Voutetakis	Renewable and Sustainable Energy Reviews	134	Elsevier BV	Netherlands	2020	110118	No	No	https://api.elsevier.com/content/article/PII:S1364032120304093?httpAccept=text/xml
REMOTE	PEER_ REVIEWED_ ARTICLE	Optimal design of stand-alone solutions based on RES + hydrogen storage feeding off-grid communities	10.1016/j. enconman.2 021.114147	01968904	Paolo Marocco, Domenico Ferrero, Andrea Lanzini, Massimo Santarelli	Energy Conversion and Management	238	Pergamon Press Ltd.	United Kingdom	2021	114147	No	No	http://hdl.handle.net/11583/2917772
REMOTE	PEER_ REVIEWED_ ARTICLE	The role of hydrogen in the optimal design of off-grid hybrid renewable energy systems	10.1016/j. est.2021.103893	2352-152X	Paolo Marocco, Domenico Ferrero, Andrea Lanzini, Massimo Santarelli	Journal of Energy Storage	Volume 46, February 2022, 103893	Elsevier BV	Netherlands	2022		No	No	
TAHYA	PEER_ REVIEWED_ ARTICLE	Composite storage systems for compressed hydrogen - systematic improvement of regulations for more attractive storage units	10.1016/j.ijhydene. 2018.04.068	03603199	G.W. Mair, B. Becker, S. John, E. Duffner	International Journal of Hydrogen Energy	45/25	Pergamon Press Ltd.	United Kingdom	2020	13672-13679	No	Yes	
TAHYA	PEER_ REVIEWED_ ARTICLE	Safety criteria for the transport of hydrogen in permanently mounted composite pressure vessels	10.1016/j.ijhydene. 2020.07.268	03603199	G.W. Mair, S. Thomas, B. Schalau, B. Wang	International Journal of Hydrogen Energy	46/23	Pergamon Press Ltd.	United Kingdom	2021	12577-12593	No	Yes	
TeacHy	CONFERENCE_ PROCEEDING	An MSc Course in FCH Technologies			Robert Steinberger-Wilckens, Aravind Purushothaman Vellayani, Massimo Santarelli, Yegor Brodnikovskyi, Lars N. Cleeman, Karel Bouzek, Jan Van herle, Jean-Luc Delplancke, Ioan Iordache, Florence Druart, Vladimir Molkov, Olaf Jedicke	Proceedings of the 15th European Fuel Cell Forum	bi-annual	EFCF	Lucerne	2021	A1505	No	Yes	
VIRTUAL-FCS	PEER_ REVIEWED_ ARTICLE	Hybrid fuel cell system degradation modeling methods: A comprehensive review	10.1016/j.jpowsour. 2021.230071	03787753	L. Vichard, N. Yousfi Steiner, N. Zerhouni, D. Hissel	Journal of Power Sources	506	Elsevier BV	Netherlands	2021	230071	Yes	Yes	

Annex 4 - Patents from projects

(A) Information extracted from CORDA for H2020

PROJECT NUMBER	PROJECT ACRONYM	PATENT APPLICATION TITLE	PATENT APPL. NAME	PATENT APPL. DATE	PATENT AWARDED
671473	D2Service	Heat Exchanger and Method for Manufacturing a Heat Exchanger Core with Manifold	Bosal Emission Control Systems Nv	19/04/2018	YES
671403	INNO-SOFC	Protection arrangement and method of solid oxide cells	Elcogen Oy	14/03/2018	NO
671403	INNO-SOFC	Sealing Arrangement and Method of Solid Oxide Cell Stacks	Elcogen Oy	17/07/2014	YES
700101	Giantleap	Inrichting voor het koppelen van een trekkend voertuig met een te trekken voertuig	VDL Enabling Transport Solutions BV	06/02/2018	YES
700667	SOSLeM	Method for Determining an Operating State of an Electrochemical System	AVL List GmbH	07/12/2018	YES
700667	SOSLeM	Recursive, Time-Series-Based Method for Determining the State of an Electrochemical Reactor	AVL List GmbH	27/11/2018	YES
779644	TAHYA	Composite Pressure Vessel with Reinforced Inner Liner and Process for the Production Thereof	Optimum CPV	26/06/2019	YES
779644	TAHYA	Composite Pressure Vessel with Boss Connector	Optimum CPV	26/06/2019	YES
779644	TAHYA	Tank Liner Having Two Cylindrical Sections	Optimum CPV	26/06/2019	YES

(B) Additional information to CORDA, coming directly from the projects (for H2020)

PROJECT NUMBER	PROJECT ACRONYM	PATENT APPLICATION TITLE	PATENT APPL. NAME	PATENT APPL. DATE	PATENT AWARDED
700355	HyGrid	Carbon molecular sieve membrane and its use in separation processes	TUE Tecnalia	2019	YES
700355	HyGrid	Method for low hydrogen content separation from a natural gas mixture	TUE Tecnalia	12/2018	YES
621181	FERRET	Advanced double skin membranes for membrane reactors	TUE Tecnalia	2017	YES
700266	Cell3Ditor	Method and device for Manufacturing of Ceramic or Metallic Pieces by Additive Manufacturing	3DCERAM	20/06/2018	NO
700266	Cell3Ditor	Method and device for manufacturing at least one piece of at least ceramic and/or metallic material by additive manufacturing	3DCERAM	20/06/2018	NO
700266	Cell3Ditor	Method of manufacturing pieces by the technique of additive manufacturing by pasty process with an improved supply of paste and manufacturing machine for implementing the method	3DCERAM	20/06/2018	NO
700266	Cell3Ditor	Electrochemical cell device for use in a SOFC and/or a SOEC and methods for operating a SOFC or a SOEC by using thereof	3DCERAM	20/06/2018	NO
826204	DOLPHIN	Procédé de fabrication d'un guide d'écoulement pour réacteur électrochimique	CEA	2019	YES
875118	NEWELY	Composite ion-exchange membrane, method for preparing the same, and use thereof	KIST	11/06/2020	YES
875118	NEWELY	Polymer grafted with cationic groups as side chain, preparation method thereof, and anion exchange membrane made of the same	KIST, Technion	27/01/2021	NO
735918	INSIGHT	Stack monitoring by means of stack segments			NO
735918	INSIGHT	Monitoring by periodic non-sinusoidal excitation, multi frequency based metric approach			NO
735918	INLINE	Kalibrierverfahren für einen Projektor	Profactor Gmbh	07/05/2019	YES

Annex 5 - Scoreboard of H2020 common KPIs [124]

	H2020 KPI NUMBER	KPI	TYPE OF DATA REQUIRED	RESULTS H2020 UP TO 31 DECEMBER 2021 (CALLS 2014-2020)
INDUSTRIAL LEADERSHIP	12	SME - Share of participating SMEs introducing innovations new to the company or the market (covering the period of the project plus three years)	Number of SMEs that have introduced innovations	*96*
	13	SME - Growth and job creation in participating SMEs	Turnover of company, number of employees	Turnover of SMEs at most recent reporting: *EUR 1 261 mil* No. of employees in SMEs at most recent reporting: *12 791*
SOCIETAL CHALLENGES	14	Publications in peer-reviewed high-impact journals	Publications from relevant funded projects (DOI: digital object identifiers); journal impact benchmark (ranking) data to be collected by commercially available bibliometric databases	*377 publications* in peer-reviewed high-impact journals
	15	Patent applications and patents awarded in the area of the JTI	Patent application number	*14* patents awarded and *8* patent pending applications (aligned with ANNEX 4)
	16	Number of prototypes testing activities and clinical trials	Reports on prototypes, and testing activities, clinical trials	Nr of prototypes: 469 [125] Nr of testing activities: 672 Nr of clinical trials: 0
	17	Number of joint public-private publications in projects	Properly flagged publications data (DOI) from relevant funded projects	91 Joint Public/Private
	18 [126]	New products, processes and methods launched on the market	Project count and drop-down list enabling choice of the type of processes, products and methods	Nr of projects with: New products: 65 New processes: 36 New methods: 25

[124] Based on Annex II to Council Decision 2013/743/EU.
[125] MAMA-MEA and THyGA account together for 275 and 376 of the above numbers respectively.
[126] This indicator is not legally compulsory but covers several additional specific indicators requested for more societal challenges by the services in charge.

	H2020 KPI NUMBER	KPI	TYPE OF DATA REQUIRED	RESULTS H2020 UP TO 31 DECEMBER 2021 (CALLS 2014-2020)
EVALUATION	NA	Time to inform (TTI) all applicants of the outcome of the evaluation of their application from the final date for submission of completed proposals	Number and % of information letters sent to applicants within target Average TTI (calendar days) Maximum TTI (calendar days)	135 information letters with an average of 107 days (100 % within target)
	NA	Redress after evaluations	Number of redresses requested	13
GRANTS	N/A	Time to Grant (TTG) measured (average) from call deadline to signature of grants	Number and % of grants signed within target Average TTG in calendar days Maximum TTG in calendar days	Average TTG: 243 days Maximum TTG: 589 days
GRANTS	NA	Time to grant (TTG) measured (average) from call deadline to signature of grants	Number and % of grants signed within target	134 GA signed (81 % within target)
PAYMENTS	N/A	Time to Pay (TTP) (% made on time) • pre-financing • interim payment • final payment	Average TTG in calendar days	Average TTG: 243 days
HR	N/A	Vacancy rate (%)	Maximum TTG in calendar days	Maximum TTG: 589 days
JU EFFICIENCY	NA	Time to sign (TTS) grant agreements from the date of informing successful applicants (information letters)	Number and % of grants signed within target	134 GA signed
	N/A	Administrative budget: Number and % of total of late payments	Average TTS in calendar days	Average TTS: 130 days

Annex 6 – Indicators for monitoring cross-cutting issues [127]

<table>
<tr><th>NUMBER</th><th>DEFINITION/ RESPONDING TO QUESTION</th><th>TYPE OF DATA REQUIRED</th><th>AAR 2021 (CALLS 2014-2020) [128]</th></tr>
<tr><td>2.1</td><td>Total number of participations by EU-27 Member States
+ the UK</td><td>Nationality of H2020 applicants and beneficiaries (number)</td><td>EU-27 + UK
<table>
<tr><td>Application Participations
3197</td><td>Application Participants
1329</td></tr>
<tr><td>Grant Participations
1370</td><td>Grant Participants
698</td></tr>
</table></td></tr>
<tr><td>2.2</td><td>Total amount of EU financial contribution by EU-27 Member State + the UK
(EUR million)</td><td>Nationality of H2020 beneficiaries and corresponding EU financial contribution</td><td>In EUR million per country (total EUR 585.99 million):
<table>
<tr><td>AT</td><td>24.72</td><td>ES</td><td>39.10</td><td>LV</td><td>0.66</td></tr>
<tr><td>BE</td><td>23.23</td><td>FI</td><td>18.81</td><td>MT</td><td>0.03</td></tr>
<tr><td>BG</td><td>0.39</td><td>FR</td><td>85.90</td><td>NL</td><td>53.79</td></tr>
<tr><td>CY</td><td>0.17</td><td>HR</td><td>0.73</td><td>PL</td><td>1.07</td></tr>
<tr><td>CZ</td><td>1.46</td><td>HU</td><td>0.02</td><td>PT</td><td>0.76</td></tr>
<tr><td>DE</td><td>155.32</td><td>IE</td><td>0.28</td><td>RO</td><td>0.26</td></tr>
<tr><td>DK</td><td>24.05</td><td>IT</td><td>54.40</td><td>SE</td><td>9.60</td></tr>
<tr><td>EE</td><td>0.61</td><td>LT</td><td>0.13</td><td>SI</td><td>4.31</td></tr>
<tr><td>EL</td><td>6.15</td><td>LU</td><td>1.64</td><td>UK</td><td>78.39</td></tr>
</table></td></tr>
<tr><td>N/A</td><td>Total number of participations by Associated Countries</td><td>Nationality of H2020 applicants and beneficiaries (number)</td><td>Associated Countries
<table>
<tr><td>Application Participations
353</td><td>Application Participants
150</td></tr>
<tr><td>Grant Participations
153</td><td>Grant Participants
80</td></tr>
</table></td></tr>
<tr><td>N/A</td><td>Total amount of EU financial contribution by Associated Country (EUR million)</td><td>Nationality of H2020 beneficiaries and corresponding EU financial contribution</td><td>In EUR million per country (total EUR 46.63 million):
<table>
<tr><td>CH</td><td>12.62</td></tr>
<tr><td>IL</td><td>0.24</td></tr>
<tr><td>IS</td><td>1.07</td></tr>
<tr><td>NO</td><td>31.81</td></tr>
<tr><td>TR</td><td>0.85</td></tr>
<tr><td>UA</td><td>0.06</td></tr>
</table></td></tr>
<tr><td>3.1</td><td>Share of EU financial contribution going to SMEs (Enabling and industrial tech and Part III of H2020)</td><td>Number of H2020 beneficiaries flagged as SMEs
% of EU contribution going to beneficiaries flagged as SMEs</td><td>SME beneficiaries
<table>
<tr><td>Grants participations</td><td>Grant participants</td><td>Funding</td></tr>
<tr><td>353
(23 %)</td><td>166
(21 %)</td><td>EUR 179.8 mil.
(32 %)</td></tr>
</table></td></tr>
<tr><td>6.1</td><td>Percentage of women participants in H2020 projects</td><td>Gender of participants in H2020 projects</td><td>According to continuous reporting:
25.94 %</td></tr>
</table>

[127] Based on Annex III to Council Decision 2013/743/EU; source: CORDA, unless specified otherwise.
[128] The figures concern 133 projects, not including ELECTROOU which was terminated early.

NUMBER	DEFINITION/ RESPONDING TO QUESTION	TYPE OF DATA REQUIRED	AAR 2021 (CALLS 2014-2020) ([128])
6.2	Percentage of women project coordinators in H2020	Gender of MSC fellows, ERC principal investigators and scientific coordinators in other H2020 activities	39/133 (29.3 %)
6.3	Percentage of women in EC advisory groups, expert groups, evaluation panels, individual experts, etc.	Gender of members of advisory groups, panels, etc.	Scientific Com: 3/9 (33.3 %) SRG: 9/42 (21.4 %) Evaluators: N/A (no evaluations in 2021)
7.1	Share of third-country participants in H2020	Nationality of H2020 beneficiaries	**Third Countries** Grants participations: 14 Grant participants: 12 EU Funding: EUR 0.26 mil.
7.2	Percentage of EU financial contribution attributed to third-country participants	Nationality of H2020 beneficiaries and corresponding EU financial contribution	0.04 %
9.1	Share of projects and EU financial contribution allocated to IAs	Number of IA proposals and projects properly flagged in the WP; follow-up at grant level	No: 37/131 (28.2 %) Funding: EUR 372 732 793.62/ EUR 632 885 427.4 (58.89 %)
9.2	Within the IAs, share of EU financial contribution focused on demonstration and first-of-a-kind activities	Topics properly flagged in the WP; follow-up at grant level	40.2 %
N/A	Scale of impact of projects (high technology readiness level - TRL)	Number of projects addressing TRL between (2-3, 4-6, 5-7)	**Based on TRL specified in the topic (project start)** TRL / # projects 2 / 14 3 / 30 4 / 27 5 / 15 6 / 11 7 / 10 8 / 1 unspecified / 24
11.1	Percentage of H2020 beneficiaries from the private-for-profit sector	Number of and % of the total H2020 beneficiaries classified by type of activity and legal status	Participations: 915 / 1537 (59.5 %) Participants: 523/ 790 (66.2 %)
11.2	Share of EU financial contribution going to private-for-profit entities (Enabling and industrial tech and Part III of Horizon 2020)	H2020 beneficiaries classified by type of activity; corresponding EU contribution	EUR 442.3 mil / EUR 632.9 mil (69.9 %)

NUMBER	DEFINITION/ RESPONDING TO QUESTION	TYPE OF DATA REQUIRED	AAR 2021 (CALLS 2014-2020) ([128])
12.1	EU financial contribution for public-private partnerships (PPP) (Art. 187)	EU contribution to PPP (Art. 187)	Cumulative EU contribution to administrative and operational budget for the period 2014-2021: CA: 657,362,659 PA: 550,402,484
12.2	PPPs leverage: total amount of funds leveraged through Art. 187 initiatives, including additional activities, divided by the EU contribution	Total funding made by private actors involved in PPPs • in-kind contribution already committed by private members in projects selected for funding • additional activities (i.e. research expenditure/ investment of industry in the sector, compared to previous year)	2.56 (see section 1.1, Formula B)
13.3	Dissemination and outreach activities other than peer-reviewed publications [conferences, workshops, press releases, publications, flyers, exhibitions, training, social media, websites, communication campaigns (e.g. radio, TV)]	A drop-down list allows for selection of the type of dissemination activity. Number of events, funding amount and number of persons reached thanks to the dissemination activities	Activities as reported by the projects during FCH 2 JU data collection exercise for 2020: **Dissemination activities (excl. Scientific Publications) (64 projects): 179** Conferences/Events (Presentations): 76 Meetings (with policy stakeholders/working groups, etc): 42 Education & Training Activities: 19 Collaboration with EU projects: 12 Press Releases, Newsletters, Videos, Interviews: 10 Clustering Activities: 7 Workshops, webinars: 4 Publications, brochures, leaflets etc: 4 **PRD 2020 (85 projects)** Websites: 85 Twitter accounts: 52 LinkedIn accounts: 68
14.2	Proposal evaluators by country	Nationality of proposal evaluators (at pool level)	N/A (no evaluations in 2021)
14.3	Proposal evaluators by organisations' type of activity	Type of activity of evaluators' organisations	N/A (no evaluations in 2021)

NUMBER	DEFINITION/ RESPONDING TO QUESTION	TYPE OF DATA REQUIRED	AAR 2021 (CALLS 2014-2020) ([128])
N/A	Participation of RTO[3]s and universities in PPPs (Art. 187 initiatives)	Number of RTOs participations in funded projects and % of the total	305 / 1537 (19.8 %)
		Number of universities participations in funded projects and % of the total	207 / 1537 (13.5 %)
		% of budget allocated to RTOs and to universities	RTO: EUR 99.4 million (15.7 %) HES: EUR 49.2 million (7.8 %)
N/A	The aim is to ensure that research projects funded are efficiently compliant with provisions on ethics	% of proposals not granted because of non-compliance with ethical rules/proposals invited to grant (target 0 %); time to ethics clearance (target 45 days)	N/A
N/A	Error rate	% of common representative error; % residual error	H2020: Representative: 3.84 % Residual: 1.73 %
N/A	Implementation of *ex-post* audit results	Number of cases implemented; in total EUR million; of cases implemented/total cases	H2020: # closed participations : 92 Percentage of implementation: 85.31 %

Annex 7 – Scoreboard of KPIs specific to JU [129]

KPIs specific to FCH 2 JU

NUMBER	KPI	RESULTS
1	Share of the funding allocated to the following research activities: 1. renewable energy 2. end-user energy efficiency 3. smart grids 4. storage	Renewable energy: EUR 96.2 million (15 %) [130] End-user energy efficiency: EUR 121.4 million (19 %) Smart grids: EUR 38 million (6 %) Storage: EUR 72 million (11 %)
2	Demonstrator projects hosted in Member States and regions benefiting from EU Structural and Investment Funds	The FCH 2 JU has also collaborated with national programmes for the blending of funds. For instance, the FHC 2 JU project HySHIP on a 3MW FC-powered ferry is benefiting from circa EUR 20 million in funding from ENOVA (Norwegian Innovation Fund) in addition to the EUR 8 million support from the FCH 2 JU.

[129] As in 2021 both FCH 2 JU and Clean Hydrogen JU were operational, it was decided that the KPIs for both JUs should be presented here. Nevertheless, for the Clean Hydrogen JU only the baseline and targets can be reported.
[130] Projects addressing topics related to renewable energy integration [KPI 1.1] and storage (KPI 1.4) are interrelated, in many cases covering both aspects. Complementarily, a common KPI of 26 % can be reported for KPIs 1.1 and 1.4.

KPIs specific to Clean Hydrogen JU (Baseline + Targets)

KPI NAME	UNIT OF MEASUREMENT	BASELINE	TARGET 2023	TARGET 2025	TARGET 2027	AMBITION >2027
Resources (input), processes and activities						
1. Supporting sustainable solutions	% of budget (2 indicators)	2.5 [131]	20	35	50	
2. Early research projects	% of budget	10 [131]	10	10	10	
3. Demonstration projects	# of projects	43 [131]	20	40	60	
4. Education and training	# of projects	4 [131]	2	4	6	
5. Monitoring technology progress	Qualitative indicator	N/A	N/A	N/A	N/A	
6. Supporting EC in H2 market uptake	Qualitative indicator	N/A	N/A	N/A	N/A	
Outcomes						
7. Environmental impact and sustainability	TBD	TBD	TBD	TBD	TBD	
8. Capital cost of hydrogen applications	€/kilowatt (2 indicators)	TBD	TBD	TBD	TBD	
9. Research and Innovation Synergies	# of projects	5 [131]	5	10	20	
10. Public perception of hydrogen	Qualitative indicator	N/A	N/A	N/A	N/A	
11. Total persons trained	# of persons	4 163 [131]	1,000	3,000	6,000	
12. Patents and publications	# of patents / publications	12 [131] / 289	17 / 350	20 / 400	25/ 450	
13. 1Promoting cross-sectoral solutions	# of projects	15 [131]	10	15	25	
Impacts						
14. Expected avoided emissions	Million tonnes of CO2-eq	TBD	N/A	N/A	N/A	TBD (2030/ 2050)
15. Deployment of electrolysers	Gigawatt	1	4	6	10	40 (2030)
16. Market uptake of clean hydrogen	Mt of clean hydrogen consumed	0.155	0.7	1	2	10 (2030)
17. Total cost of hydrogen at end-use	€/kg	8	6.5	5.5	4.5	3 (2030)
18. Size of private hydrogen sector	Qualitative indicator	N/A	N/A	N/A	N/A	

Note: The work on the KPIs is under progress, requiring a robust and transparent methodology to be developed with the help of experts in 2022. This especially applies for all elements of the table labelled TBD (to be determined). More detailed information on the Partnership's KPIs, activities, performance and impacts can be found in the Strategic Research and Innovation Agenda and Activity Reports of the Partnership, available on the Partnership's website.

[131] Baseline refers to the achievement over the lifetime of the predecessor partnership (FCH 2 JU).

Annex 8 – Draft annual accounts

EUR '000

	31.12.2021	31.12.2020
NON-CURRENT ASSETS		
Intangible assets	11	25
Property, plant and equipment	173	112
Pre-financing	86 827	113 854
	87 012	**113 990**
CURRENT ASSETS		
Pre-financing	40 946	48 913
Exchange receivables and non-exchange recoverables	9 645	7,028
	50 591	**55 940**
TOTAL ASSETS	**137 603**	**169 930**
CURRENT LIABILITIES		
Payables and other liabilities	(55 888)	(59 139)
Accrued charges	(50 553)	4)
	(106 440)	**(98 303)**
TOTAL LIABILITIES	**(106 440)**	**(98 303)**
NET ASSETS	**31 163**	**71,628**
Contribution from Members	(1 483 783)	(1 403 608)
Accumulated deficit	1 331 981	1 238 612
Economic result of the year	120 639	93 368
NET ASSETS	**(31 163)**	**(71 628)**

Statement of financial performance

EUR ´000

	31.12.2021	31.12.2020
REVENUE		
Revenue from non-exchange transactions		
Recovery of expenses	(4 994)	(3 444)
	(4 994)	**(3 444)**
Revenue from exchange transactions		
Financial revenue	(0)	(6)
Other exchange revenue	(3)	(44)
	(3)	**(50)**
Total revenue	**(4 997)**	**(3 494)**
EXPENSES		
Operational costs	120 395	91 913
Staff costs	3 188	3 086
Other expenses	2 053	1,863
Total expenses	**125 636**	**96 862**
ECONOMIC RESULT OF THE YEAR	**120 639**	**93 368**

Annex 9 – Materiality criteria

The **'materiality'** concept provides the executive director with a basis for assessing the importance of the weaknesses/risks identified and thus whether those weaknesses should be subject to a formal reservation to his/her declaration. The same materiality criteria are applicable to the FP7 and H2020 programmes.

When deciding whether or not something is material, **qualitative and quantitative** terms have to be considered.

In **qualitative** terms, when assessing the significance of any weakness, the following factors are taken into account:

- The nature and scope of the weakness;
- The duration of the weakness;
- The existence of compensatory measures (mitigating controls which reduce the impact of the weakness);
- The existence of effective corrective actions to correct the weaknesses (action plans and financial corrections) which have had a measurable impact.

In **quantitative** terms, in order to make a judgement on the significance of a weakness, the potential maximum (financial) impact is quantified.

Whereas the JU control strategy is of a multi-annual nature (i.e. the effectiveness of the JU's control strategy can only be assessed at the end of the programme, when the strategy has been fully implemented and the errors detected have been corrected), the executive director is required to sign a declaration of assurance for each financial year. In order to determine whether to qualify his declaration of assurance with a reservation, the effectiveness of the JU's control system has to be assessed, not only for the year of reference, but more importantly, with a multi-annual outlook.

The **control objective** for JU is to ensure that the '**residual error rate**', i.e. the level of errors which remain undetected and uncorrected, does not exceed 2 % by the end of the JU's programme. Progress towards this objective is to be (re) assessed annually, in view of the results of the implementation of the *ex post* audit strategy. As long as the residual error rate is not (yet) below 2 % at the end of a reporting year within the programme's life cycle, a reservation would (still) be made. Nevertheless, apart from the residual error rate, the executive director may also take into account other management information at his/her disposal to identify the overall impact of a weakness and determine whether or not it leads to a reservation.

If an adequate calculation of the residual error rate is not possible, for reasons not involving control deficiencies, the consequences are to be assessed quantitatively by estimating the likely exposure for the reporting year. The relative impact on the declaration of assurance would then be considered by analysing the available information on qualitative grounds and considering evidence from other sources and areas (e.g. information available on error rates in more experienced organisations with similar risk profiles).

Considering the crucial role of *ex post* audits in the JU's control system, its effectiveness needs to check whether the scope and results of these audits are sufficient and adequate to meet the control objectives.

EFFECTIVENESS OF CONTROLS

The **starting point** to determine the effectiveness of the controls in place is the 'representative error rate' expressed as a percentage of errors in favour of the JU detected by *ex post* audits measured with respect to the amounts accepted after *ex ante* controls.

According to the JU *ex post* audit strategy approved by the governing board, the representative error rate will be based on the simple average error rate (AER) for a stratified population, from which a representative sample has been drawn according to the following formula:

$$AER\% = \frac{\Sigma\,(err)}{r} = RepER\%$$

Where:

Σ (err) = sum of all individual error rates of the sample (in %). Only those errors in favour of the JU will be taken into consideration.

n = sample size

Second step: calculation of **residual error rate**:

To take into account the impact of the *ex post* controls, this error level is to be adjusted by subtracting:

- errors detected and corrected as a result of the implementation of audit conclusions;
- errors corrected as a result of the extrapolation of audit results to non-audited contracts with the same beneficiary.

This results in a residual error rate, which is calculated by using the following formula:

$$RepER\% = \frac{(RepER\% * (P-A) - (RepERsys\% * E)}{P}$$

Where:

ResER% = residual error rate, expressed as a percentage.

RepER% = representative error rate, or error rate detected in the representative sample, in the form of the AER, expressed as a percentage and calculated as described above (AER%).

RepERsys% = systematic portion of the RepER% (the RepER% is composed of complementary portions reflecting the proportion of 'systematic' and 'non-systematic' errors detected) expressed as a percentage.

P = total amount in EUR of the auditable population.

A = total of all audited amounts, expressed in EUR.

E = total non-audited amounts of all audited beneficiaries. This will comprise the total amount, expressed in EUR, of all non-audited validated cost statements for all audited beneficiaries, excluding those beneficiaries for which an extrapolation is ongoing.

This calculation will be performed on a point-in-time basis, i.e. all the figures will be provided as of a certain date.

Annex 10 – List of acronyms

AEMEL	anion exchange membrane electrolyser
AEL	alkaline electrolysis
AWP	annual work plan
BEV	battery electric vehicle
CAPEX	capital expenditure
CAS	Common Audit Service
CFS	certificate on financial statements
CHP	combined heat and power
CIC	Common Implementation Centre
CRaS	common representative sample
D&E	dissemination and exploitation
DG	Directorate-General
ECA	European Court of Auditors
EHSP	European Hydrogen Safety Panel
FC	fuel cell
FCEV	fuel cell electric vehicle
FCH	fuel cells and hydrogen
FP7	seventh framework programme
GA	grant agreement
GB	Governing Board
GHG	greenhouse gas
GO	Guarantee of Origin
H2020	Horizon 2020
HRB	Horizon Results Booster
HRP	Horizon Results Platform
HRS	hydrogen refuelling station
IAS	Internal Audit Service
ICF	internal control framework
IKAA	in-kind contributions in additional activities
IKOP	in-kind contributions in operational activities
IMO	International Maritime Organization
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
ISO	International Organization for Standardization
JIVE	Joint initiative for hydrogen vehicles across Europe
JRC	Joint Research Centre
JU	Joint Undertaking
KER	key exploitable result
KPI	key performance indicator

LCA	life cycle assessment
LH_2	liquid hydrogen
LOHC	liquid organic hydrogen carrier
MAWP	multiannual work programme
MEA	membrane electrode assembly
µ-CHP	micro-scale combined heat and power
OLAF	European Anti-Fraud Office
OPEX	operational expenditure
PACE	Pathway to a Competitive European Fuel Cell micro-Cogeneration Market
PCC	Proton Conducting Ceramic
PDA	project development assistance
PEM	proton exchange membrane
PEMEL	proton exchange membrane electrolyser
PGM	platinum group metal
PNR	pre-normative research
PO	programme office
QES	qualified electronic signature
R & D	research and development
R&I	research and innovation
RCS	regulations, codes and standards
RCS SCG	Regulations, Codes and Standards Strategy Coordination Group
rSOC	reversible solid oxide cell
SMEs	small and medium-sized enterprises
SoA	state of the art
SOEC	solid oxide electrolyser cell
SOFC	solid oxide fuel cell
SRG	States Representatives Group
SRIA	strategic research and innovation agenda
SyGMa	System for Grant Management
Sysper	Système de gestion du personnel
TRL	technology readiness level
TRUST	Technology Reporting Using Structured Templates
TTP	time to pay
WG	Working Group

EUROPEAN PARTNERSHIP

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