European Innovation Council

EIC PATHFINDER PORTFOLIO

NOVEL ROUTES TO GREEN HYDROGEN PRODUCTION

Strategic Plan

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Novel Routes to Green Hydrogen Production

European Innovation Council

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1. INTRODUCTION

In 2021, the EIC launched the **EIC Pathfinder** Challenge call "**Novel Routes to Green Hydrogen Production**" , which aims at **developing novel processes and technologies to produce green H2, at different scales and capturing cross sectorial coupling and system integration opportunities**, entirely based on (i) renewable sources and (ii) non-toxic, non-critical raw materials. It focuses on the potentials of new biological, chemical and physical routes for green H2 production which could also facilitate the implementation of the circular economy principles, possibly including the co-production of decarbonised chemicals. The specific target is to support the development of innovative technologies and platforms for green H2 production, including both centralised and/or on-demand generation (i.e. at the premises of the end users and for onsite consumption). Reaching these objectives requires multidisciplinary competencies and cross sectorial approaches.

The proposals selected in this call committed to target novel processes and technologies – chemical, biological, physical – to produce green hydrogen. The technologies should be based entirely on renewable sources and should:

1. Adopt a circular and life cycle thinking approach possibly including the use of bio-wastes and the co-production of green chemicals, fertilizers and/or decarbonised materials, and avoiding or minimizing the use of toxic and critical raw materials.

2. Capture cross sectorial coupling and system integration opportunities (i.e. energy systems, industrial symbiosis contributing to net-zero industrial districts, bio-wastes supply chains).

According to the call: "The beneficiaries are expected to collaborate to the Portfolio's objectives under the guidance of the EIC Programme Managers (PMs). The PMs will work with the beneficiaries to define the governance of the Portfolio, to establish expectations from the projects collaboration, to define rules for resource and data sharing in accordance to Annex 7 of the EIC 2021 WP, and to identify the exploitation, communication and dissemination strategies for the Portfolio. All these elements will be defined at the Portfolio kick-off meeting and in the Portfolio Strategic Plan, to be updated with the project development.

- Portfolio kick-off and annual meetings;

2. PORTFOLIO COMPOSITION AND COMMON GOALS

Hydrogen is an energy vector that needs to be produced, and any sustainable energy transition scenario should carefully assess what are the broader impacts and the implications from the generation of such vector. Hydrogen can be extracted from water, biomass, or from a broad range of other materials that contain it. This process requires input energy, which may be in the form of heat, electricity, direct solar radiation, mechanical, biochemical or other primary energy sources.

To guarantee the diversification of hydrogen production technologies, to avoid dependency on a single primary energy input for its supply, to understand which process best fits for the different energy scenario, and to capture a variety of market needs and system integration opportunities, the portfolio composition aimed at including a broad range of technologies.

The retained proposals constitute a portfolio that covers several different options to produce green hydrogen from renewable electricity (with different electrolysis processes) and from renewable energy sources (sun, biomass). The proposals were classified in six technological areas, selected to capture the major research trends and the strategic areas where EU innovation capacity should be reinforced. The granularity of these areas has been defined considering the evidence from the most promising and leading edge scientific and technological pathways, from the number and typology of proposals received, and considering the typology of primary energy source for the process.

THE SIX TECHNOLOGICAL AREAS ARE:

- ***Area 1 "Electrolyser PEM / Alkaline (PEM)"***
- ***Area 2 "Electrolyser AEM / SOE (AEM)"***
- ***Area 3 "Photo and/or photoelectrocatalytic processes (P)"***
- ***Area 4 "Thermochemical processes (T)"***
- ***Area 5 "Biological processes (B)"***
- ***Area 6 "Other processes (O)" which may include a combination of the previous***

In each technological area, the following portfolio criteria specified in the Challenge Guide had also been considered:

I. system/process integration of the proposed technology that could facilitate the cross/sectorial interactions and system-level integration,

II. circularity in the use of input materials and valorisation of co-produced output,

III. attempt to minimize or avoid critical raw materials, where relevant for the specific technology.

The portfolio consists of 9 projects which started between 1 September 2022 and 1 January 2023 and will run for up to 60 months and a total granted budget around €29 million. If useful, the PMs might ask projects funded from the EIC Pathfinder Open call to join the portfolio and/or participate in all or some selected activities.

The retained proposals and their technological classification are reported in Table 1 and 2.

TABLE 1. PORTFOLIO OVERVIEW

Acronym	Number	EIC PO	Start Date	End Date	Project Website
MacGhyver	**101069981**	Antonios FYSEKIDIS	01-10-22	30-09-26	
GH2	**101070721**	Darina BOTSOVA	01-10-22	30-09-25	
H2STEEL	**101070741**	Antonios FYSEKIDIS	01-10-22	30-09-25	
DualFlow	**101070788**	Darina BOTSOVA	01-10-22	30-09-26	
PhotoSynH2	**101070948**	Darina BOTSOVA	01-10-22	30-09-27	
EPOCH	**101070976**	Antonios FYSEKIDIS	01-10-22	30-09-26	
OHPERA	**101071010**	Antonios FYSEKIDIS	01-10-22	31-03-26	
ELOBIO	**101070856**	Darina BOTSOVA	01-01-23	31-12-26	
ANEMEL	**101071111**	Darina BOTSOVA	01-09-22	31-08-26	

TABLE 2. DETAILS OF PORTFOLIO PROJECTS

Acro-nym	Project full title	Techno-logical area	Input	Conversion method	Output
MacGhyver	Microfluidic wAstewater treat-ment and Creation of Green HYdrogen Via Electrochemical Reactions	1	Wastewater	High-volume micro-fluidics, non-CRM electrodes and electrochemical compression	Hydrogen
GH2	GreenH2 production from water and bioalcohols by full solar spectrum in a flow reactor	2	Bioethanol	Photoelectrolysis	Hydrogen + chemicals
H2STEEL	Green H2 and circular bio-coal from biowaste for cost-com-petitive sustainable Steel	4	Biowaste and bioCH4	Pyrolysis	Hydrogen + Biocoal
DualFlow	Dual circuit flow battery for hydrogen and value added chemical production	6	Cellulose, nanocellu-lose	Electrolysis	Hydrogen + chemicals
PhotoSynH2	Photosynthetic electron focus-ing technology for direct effi-cient biohydrogen production from solar energy and biologi-cal fermentation	5	Photosyn-thetic Cy-anobacteria	Solar assisted fer-mentation	Hydrogen
EPOCH	Electrocatalytic Production of liquid Organic hydrogen carrier and CHemicals from lignin	1	Water and lignin	Electrocatalysis	Hydrogen + chemicals
OHPERA	Optimised Halide Perovskite nanocrystalline based Electro-lyser for clean, robust, efficient and decentralised pRoduction of H2	3	Water and glycerol	Photoelectrolysis	Hydrogen + chemicals
ELOBIO	ELectrOlysis of BIOmass	1	Water, al-dose-based sugars and furanic com-pounds	Electrolysis	Hydrogen + chemicals
ANEMEL	ANion Exchange Membrane Electrolysis from Low-grade water sources	2	Saline and wastewater	Anion exchange membrane electro-lyser	Hydrogen

Commonalities among the projects are identified in the use of biomass and waste or seawater, in combination to electrochemical or thermochemical conversion processes, and in the co-production of renewable chemicals.

The logistic and supply chain aspects of these hydrogen and chemicals conversion routes are particularly important. Also, the perspectives to integrate these processes into existing EU biorefineries, infrastructures and technological platforms should be properly captured, together with the assessment of broader socio-economic-environmental and security benefits of domestic resources valorization.

In this perspective, a common goal of the portfolio, with the contribution of each project, is the assessment of which input bio and waste-product can be used for the different conversion processes, which are the potential markets for the co-produced chemicals, and what are the main techno-economic opportunities to develop green H2 generation routes with local resources in European Countries (biomass and bio-waste based materials assessment).

Moreover, all the retained projects focus on the design-selection of non-critical and non-toxic materials, and further common goals of the portfolio regard the comparative assessment of the circularity, life-cycle and critical resources minimization, identification of digital tools to accelerate materials development, and the potential shared use of specific materials among the projects, in particular for the 7 projects in area 1 and 2, 3 and 6 on electrolysis and photo-electrolysis *(materials assessment)*. This could be pursued also sharing laboratory instruments and adopting common characterization methodologies. The common goal is in this case the minimization of environmental footprint and of the use of critical resources.

As written, the portfolio composition is based on a diversified range of technologies. For this reason, a more generic portfolio goal is the techno-economic and social environmental comparison among the proposed technologies and versus state-of-the-art solutions, using common metrics and KPI and for different end-users, to explore in which market segment and at what extent each different technology could best fit *(techno-economic assessment)*.

The identification of further synergies and complementarities among the projects is also possible and will be actively explored during the execution of the projects and with the specific knowledge sharing and networking tools put in practice. The main synergies will be however explored in the areas of (i) materials for H2 conversion through electrolysis, (ii) input biomass / output biobased materials and related markets, supply chains and biorefineries integration opportunities, (iii) common approaches to the life cycle analysis and to quantify the system-level benefits of the proposed solutions, (iv) exploitation strategies as part of the innovation journey.

The Portfolio has the more generic objective to position Europe strategically at the forefront of the sustainable technologies for *green H2 generation without use of Critical Raw Materials and relying on circular and system-integrated resources and locally sourced by-products*.

The overarching portfolio goal is hence to contribute to identify and accelerate the development of the most promising green hydrogen generation technologies to address the EU energy security, while contributing to other sustainability goals such as the production of decarbonized chemicals or the processing and valorization of biowastes and wastewaters, in agreement with the Repower EU and Green Deal targets.

The portfolio activities will stimulate the collaboration among the projects and the networking with the innovation ecosystem to enhance the development of the EU technological autonomy in this field.

3. PORTFOLIO ACTIONS

Portfolio actions include always at least two of the projects forming the portfolio. They have been identified in the portfolio kick-off meeting on 11 and 12 October 2022 and been substantiated in the March 2023 Programme Manager – project meetings. The following list of portfolio actions will be revised and adapted, in accordance with the interests and needs of the projects.

The aim of the project partners within the portfolio is to address the specific challenge objectives described in the call by carrying out, among others, the following actions:

A.

COMMUNICATION AND MANAGEMENT

- Vertical webinars every 3-4 months (each project to present 2-3 ideas), to be organised by the Communication Managers and H2STEEL in the lead;
- Shared folder for common documents: Each project PO to set up a shared Teams folder, inviting the 4 people from each project (PI, innovation – communication – portfolio manager, see 'Governance');

- Junior scientists (PhD & early-stage post-doc staff) meeting every 3-4 months to understand their point of view on the progress of the project and to connect them within each other, to be organised by the Communication Managers with OHPERA in the lead. This will empower the sense of belongingness to the portfolio community and will help young scientists to increase their network that is pillar within deeptech innovation;

- Each project should prepare a file with the list of the participants to the project highlighting in which work package / task they are involved and their respective main know-how. Template to be prepared by the EIC and to be shared among the projects (MACGHYVER in the lead, first draft by July 2023);

- Each project should prepare a file with the list of the "relevant" equipment that can be shared with the other projects. Template to be prepared by the EIC and to be shared among the projects until October 2023 (ELOBIO in the lead);

- Half-a-year newsletter from the projects on progress, events, invitations, to be organized and circulated by the communication manager (GH2 in the lead).

- Workshop on topics of common interests for green H2 generation such as: (i) Policy on renewable energy (ii) use of AI for new materials selection; (iii) enhancement of public-private partnership and research results transfer to the market; (iv) assessment of the social impacts and implications of the hydrogen economy.

B.

TECHNICAL ACTIVITIES

- biomass and biobased materials assessment (as described in the portfolio goals section): H2Steel prepared the template for biomass and biomaterials analysis; GH2 complement this with cost-benefit analysis from a system level perspective;

- techno-economic comparison and market assessment of the different hydrogen generation technologies, including relevant benchmarks, and with common metrics for efficiency and environmental performance, to be coordinated by the innovation/ portfolio managers (as described in the portfolio goals section);

- Materials assessment: the projects dealing with the development of new catalyst will be involved in an "exercise" aimed at accelerating the development of new catalyst without critical raw materials and addressing the following options: use of horizontal techniques such as AI (computational materials science), screening techniques (e.g. in operando), scale up potential (high or medium throughput) (as described in the portfolio goals section);

C.

COLLABORATION WITH CLEAN HYDROGEN JOINT UNDERTAKING

- Connecting the portfolio projects with the Clean Hydrogen Joint Undertaking and their beneficiaries/partners to bridge early-stage research to industry and markets;

- Building-up a common knowledge management database and repository on all hydrogen projects funded in the European Union; for this purpose, all EIC hydrogen projects are asked to fill-in a questionnaire which will be integrated in Clean Hydrogen JU's TRUST database;

- Co-organizing events on hydrogen, such as the workshop on Seawater sourcing for renewable fuels and chemicals which took place on 8 and 9 June 2023 in Brussels to focus on system integration, create synergies, connect with stakeholders, and catalyse innovation.

D.

FURTHER ACTIVITIES

- Stakeholder mapping: each project identifies the main stakeholders, and this will be discussed in a dedicated portfolio meeting (GH2 in the lead);

- Innovation training course by the EIC Programme Managers in coordination with external expert Edite Cruz aimed at helping the projects designing an exploitation strategy . The course consists of six online sessions with selected representatives of each project. The first session took place in May 2023, the last one is foreseen in December 2023. The following topics are addressed: (i) How to bring a technology to the market? (ii) identification of market opportunities; (iii) Business models; (iv) Market studies, team identification, v) how to pitch, vi) how to write an exploitation plan.

- Meetings with Transition and Accelerator projects in the field of green H2 economy to exchange experiences (to be organized by the Innovation Managers);

- Cooperation with other relevant Joint Undertakings, such as the Circular Bio-based Joint Undertaking (to be discussed with the PIs after each project will perform the stakeholder mapping exercise);

- Potential cooperation with OITBs and further European research infrastructure and testing facilities (to be organized by the Innovation managers);

- Identification of the proper in-operando characterization of different proof of principle components (to be discussed with PIs).

Annex A Tasks and deliverables

TASK 1: CROSS-CATALYSE INNOVATION AND SYNERGIES AMONG PORTFOLIO PROJECTS

- Use of non critical raw materials and commonalities in materials selection
- Innovation management and common technology exploitation plans

TASK 2: TRAINING TO STIMULATE INNOVATION OPPORTUNITIES

- Training course on how to build an exploitation strategy
- Young scientist meetings

TASK 3: PORTFOLIO DISSEMINATION AND COMMUNICATION ACTIVITIES

- Portfolio Website
- Technical Workshops and annual Portfolio meetings

TASK 4: COMPARATIVE TECHNO-ECONOMIC AND ENVIRONMENTAL ANALYSIS

- Biomass and bio-materials assessment and system level cost-benefit analysis
- Techno-economic and environmental assessment and comparison of the different technologies for different market segments

TASK 5: PARTICIPATION IN DATA COLLECTION FOR MONITORING THE TECHNOLOGY DEVELOPMENT

- Activities with Clean H2 Joint Undertaking

DELIVERABLES:

Annual report on Portfolio activities:
The report will present the collaboration activities that have been carried out in each reporting period and contain relevant material (e.g. PowerPoint presentations, minutes of meetings, etc.). It also explains how the portfolio activities and the EIC proactive project management approach contribute to the achievement of the project objectives and help the transition to market. This annual report is elaborated by the communication managers group.

Joint technical report:
Contribution to a joint technical report with other projects in the portfolio on the key factors affecting the penetration of the proposed technologies in each market segment and the relative competitiveness of each solution in different end user applications. This report includes the following three components:

- Biomass and biobased feedstocks assessment;
- Materials selection and potential interactions for the use of non-critical materials;
- Techno-economic and LCA comparison of proposed technologies with common methodology.

Annex B Governance

Figure 1 reports the governance of the portfolio. As illustrated, the EIC Programme Managers steer the portfolio **in close collaboration** with:

- the **Project Officers**;
- the **9 project representatives**;
- the **Advisory Expert Group**, composed by external experts selected by the EISMEA on their expertise and ability to contribute to steer the portfolio with independent and impartial advice. All the experts have signed a **Non-disclosure Agreement** (NDA) with the EIC and hence are entitled to discuss the detailed characteristics of each project. The experts can propose and conduct activities beneficial to the whole portfolio;
- and the **Stakeholder Group**, composed of global value chain actors such as industry representatives, potential end-users, and investors, as well as policy makers. This group serves to foster portfolio exploitation activities through the exchange and engagement of industrial stakeholders belonging to the H2 value chain. The members of the stakeholder group are called stakeholders. They provide non-binding strategic advice to the portfolio, or to a project. The stakeholders agreed to become part of the Stakeholder Group on a completely voluntary basis. There is no requirement on invested time and commitment, nor any obligation to share any data between the involved parties. Stakeholders are not allowed to ask the EIC or any involved party for financial renumeration, on the other hand the EIC and the portfolio projects understand that the commitment by the stakeholders is purely voluntarily and upon the stakeholders' decision and willingness to engage. Portfolio projects are invited to suggest stakeholders to the PMs. There is neither a minimum nor a maximum on the amount of the stakeholders. The stakeholder group meets virtually for the first time when at least three board members have assumed their role. The PMs will present the portfolio projects to the stakeholder group. During this meeting,

the stakeholders exchange their contact details, and further interaction is upon their initiative. The stakeholders are encouraged to proactively reach out to the projects in the portfolio, to advise them in their area of expertise and to update fellow stakeholder group members. The are likewise encouraged to exchange regularly with the PMs. Finally, projects can reach out to stakeholder board members as well. These activities will start in 2024.

Governance of the Portfolio

NOVEL ROUTES TO RENEWABLE HYDROGEN

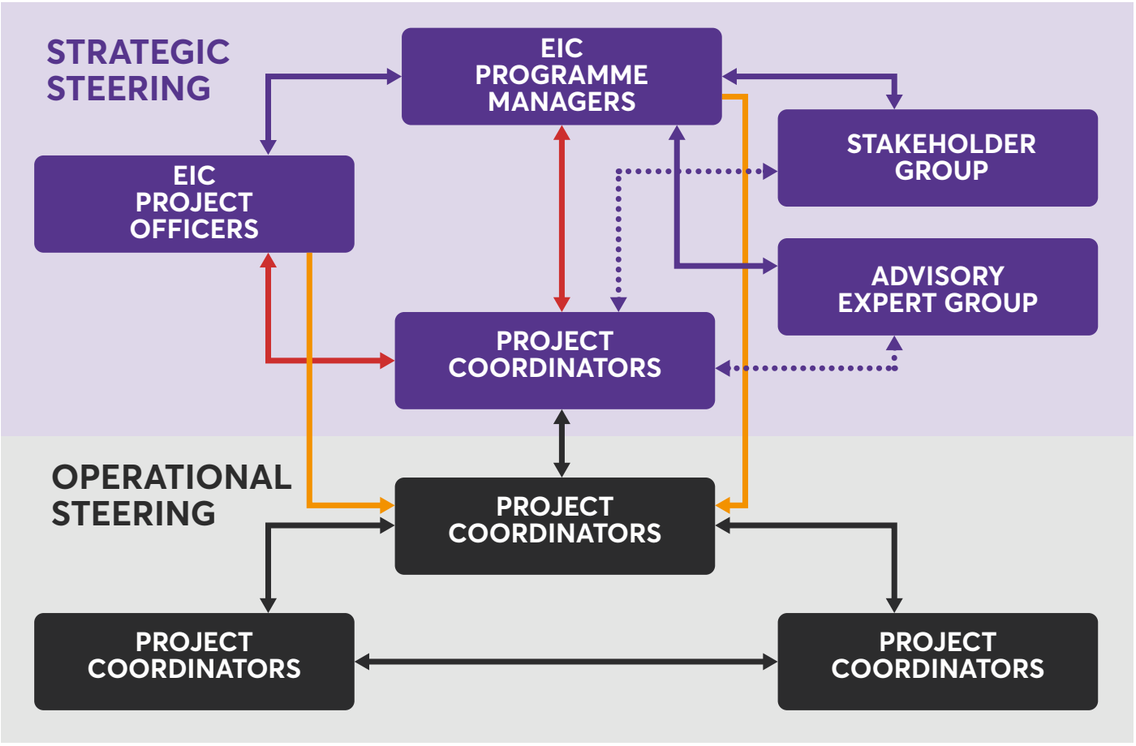

Figure 1. Interactions among the key actors of the portfolio

On the **operational side**, each project was asked to nominate specific managers for each of the **three activity pillars** to ensure targeted workflows within the portfolio and a clear hierarchy within the project consortia. These managers and their specific roles are:

- **Innovation managers**, who are in charge of the exploitation strategies and elaborate the **exploitation plan** (this includes also the IPR strategy); they also identify the market potentials, manage the stakeholders assessment and the tasks 1 and 2:
- **Portfolio managers**, who oversee the portfolio activities and in particular tasks 4 and 5. They are also in charge of the identification of synergies, shared components and collaboration opportunities with one or more projects;
- **Communication managers**, who are in charge of task 3. In particular, they are in charge of the elaboration of a joint communication strategy, including common database for events on an online platform, communication activities and shared database of scientific instruments;

Annex C Communication activities

Each project website should include a **page on the portfolio website to be set-up by September 2023** (ANEMEL in the lead). The Communication working group is responsible to define the content of this page. The page should contain the link of the other projects.

The **Communication Managers** will draft **communication guidelines** to be used when representing the portfolio (texts, images, key messages). The **Communication Managers** will also be responsible for joint communication and dissemination of posts/news from the other projects.

Annex D Annual meetings

The Portfolio kick-off meeting took place in Brussels in hybrid model in October 2022 with the participation in person of all team leaders of the portfolio.

The first Annual meeting of the Portfolio is be scheduled for **October 2023 with the expected participation in person of at least 4 members for each project (the Principle Investigator, the Portfolio Manager, the Innovation Manager and the Communication Manager). Participation of other projects members is also encouraged**. The location and dates of future meetings shall be decided no later than March 2024.

These meetings are also an opportunity to identify new specific collaborations between two or more projects leading to additional portfolio activities (e.g. session with SMEs and corporations, or with investors or etc.) or needs for a revision of the portfolio activities. The PMs can also propose sessions to be added to the annual meeting and invite key stakeholders.

Annual Meeting and Lead	Date and location to be determined by	Date of the Annual Meeting	Finalized Location of the Annual Meeting
1st Annual Meeting (ANEMEL)	June 2023	3&4 October 2023	Tarragona, Spain
2nd Annual Meeting (ELOBIO)	February 2024	12 July 2024	Lyon, France
3rd Annual Meeting (TBD)	February 2025	tbd	

Annex E Non-disclosure obligations and Non-disclosure Agreements (NDAs)

According to the call:

"Where beneficiaries are informed on or given access or disclosure to any preliminary findings, results or other intellectual property generated by other EIC actions, and where this information is earmarked as "confidential" in accordance with section 2.1.b, they must:

- keep it strictly confidential; and not disclose it to any person without the prior written consent of the owner, and then only under conditions of confidentiality equal to those provided under this section; and
- use the same degree of care to protect its confidentiality as the beneficiary uses to protect its own confidential information of a similar nature; and
- act in good faith at all times; and
- not use any of it for any purpose other than assessing opportunities to propose
- other research or innovation activities to the EIC, or any other initiative agreed
- by the owner.

The EIC beneficiary may disclose any such information to its employees and, with the prior authorisation of the owner, to its subcontractors established in a Member State or an Associated Country and:

- who have a need to access it for the performance of their work with respect to the purpose permitted above; and
- who are bound by a written agreement or professional obligation to protect its confidentiality in the way described in this section.

No obligations are imposed upon the EIC beneficiary where such information:

- is already known to the EIC beneficiary before and is not subject to any other obligation of confidentiality; or
- is or becomes publicly known through no act by or default by/of the EIC
- beneficiary; or
- is obtained by the EIC beneficiary from a third party and in circumstances where the EIC beneficiary has no reason to believe that there has been a breach of an obligation of confidentiality.

The restrictions in this section do not apply to the extent that any such information is required to be disclosed by any law or regulation, by any judicial or governmental order or request, or pursuant to disclosure requirements relating to the listing of the stock of the EIC beneficiary on any recognised stock exchange. Upon the end or termination of the grant agreement or of the participation of the EIC beneficiary, it must immediately cease to use the said information, except if otherwise directly agreed with the owner, or if the beneficiary remains a member of the EIC Community referred to under section 2.1.b. The provisions of this section shall continue to be in force for a period of 60 months following the end or the termination of this grant agreement or of the participation of the EIC beneficiary, at the end of which period they will cease to have effect."

Facilitating exchange of information within the Portfolio. Knowledge on the other projects is necessary for the definition of this Strategic Plan. As of May 2023, the only public information on the projects is title, abstract and information on project partners as well as received funding. If considered relevant, projects are encouraged to set-up and sign NDAs.

Facilitating exchange of information with "externals". If activities are organized with the participation of externals, the projects will assess whether an NDA with these external parties is needed and proceed accordingly.

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